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## ESTIMATION OF THE PROBABILITIES OF GIVEN EXTREME MINIMUM TEMPERATURES

By E. N. LAWRENCE, B.Sc.

**Summary.**—A method is described of obtaining the probability of reaching a given extreme (e.g. monthly) minimum temperature at sites where few observations are available. In "flat" country, approximate frequencies may be obtained from suitably prepared charts. The technique may be used for other meteorological extremes.

**Introduction.**—In a previous paper<sup>1</sup>, a method is given for calculating the weekly screen frost frequencies at sites with few observations. This note extends the technique to the determination of the probability of having absolute minimum temperatures greater than a given value during a period of, say, a month. Although the method is general, data for May are used, this being the critical period for frost damage. The data used are those given in another earlier paper<sup>2</sup> and are for 18 sites with observational periods up to 30 yr.

**Method.**—For a particular site with a long period of observations, the series of extreme minimum screen temperatures in May is arranged in descending order of magnitude  $T_1, T_2, T_3 \dots T_n$ . By considering values of temperature a little greater than and a little less than that of the  $r$ th value of the series, we know<sup>3</sup> that the probability of having minimum temperatures greater than  $T_r$  lies between  $(r-1)/n$  and  $r/n$  and may be taken to be  $r/(n+1)$  or some other intermediate value<sup>4</sup> defined by  $r/(n+\frac{1}{2})$  or  $(r-\frac{1}{2})/n$ .

Gumbel curves<sup>5</sup> were plotted of the corresponding values of  $T$  and  $y[-\log_e \log_e (1/P)]$  for values of  $P$  (probability) equal to  $\frac{1}{2}/n, 1\frac{1}{2}/n \dots (n-\frac{1}{2})/n$ . The May curve for Cambridge is shown in Fig. 1. Similar curves, using the other probability estimates mentioned in the previous paragraph, were also examined but are not shown.

Jenkinson<sup>6</sup> has given the general equation of these curves in the form  $T=a(1-e^{-ky})$  where  $ak$  is positive. He has shown that extreme values of  $T$  which may be expected once in  $t$  years ( $P=1-1/t$ ) are determined from a formula of the type  $T=\bar{T}-R\sigma_1$ , where  $\bar{T}$  is the average monthly extreme minimum temperature,  $R$  is given in Table I, and  $\sigma_1$  and  $\sigma_2$  are the standard deviations for 1-yr. and 2-yr. minima.

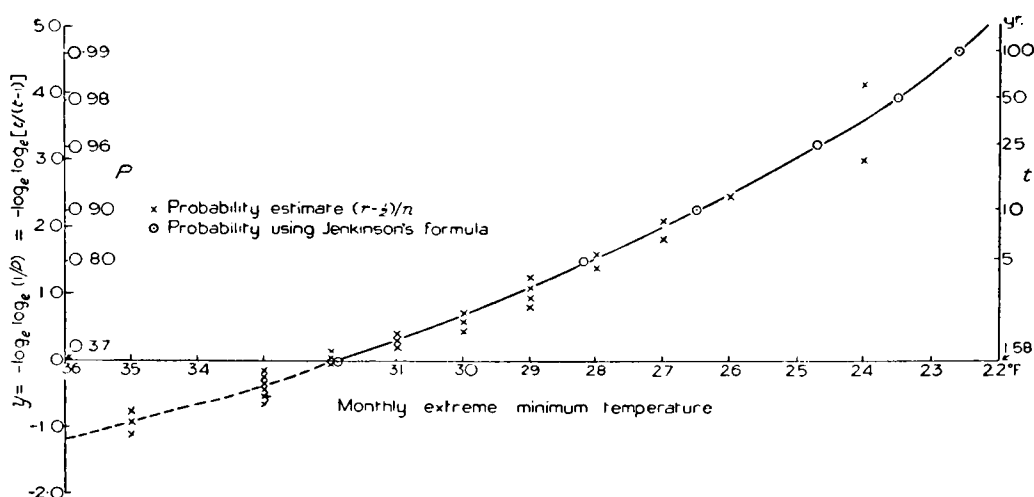


FIG. 1—PROBABILITY CURVE FOR MONTHLY EXTREME MINIMUM TEMPERATURES  
Cambridge, May

In calculating  $\sigma_2$  the two-year periods are not necessarily consecutive. By taking all possible pairs of years, the value of  $T_1$  (the highest minimum temperature in the series) would not enter into the calculation but it can be shown<sup>6</sup> that by considering an infinite number of similar but infinitesimally different samples, each minimum temperature is used  $(2r-1)$  times. Thus each value of  $T_r$  is weighted by this factor when calculating  $\sigma_2$  (see Appendix).

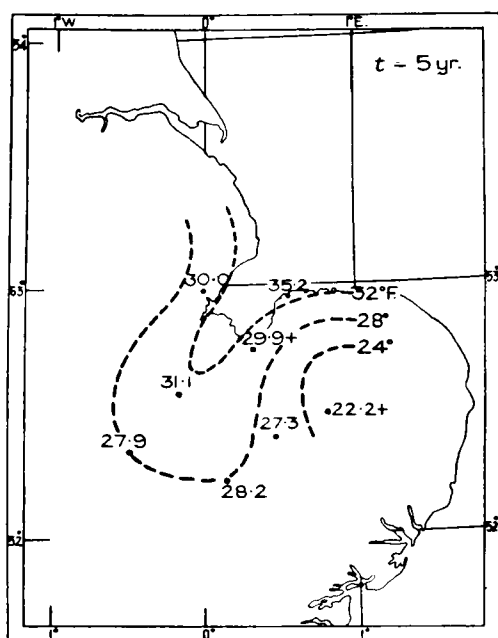
TABLE I—VALUES OF  $R$  FOR COMPUTING EXTREME VALUES OF  $T$  LIKELY TO BE REACHED ONCE IN  $t$  YEARS

$\sigma_1/\sigma_2$	$t$ y	1.58 0	5 1.50	10 2.25	25 3.20	50 3.90	100 4.61
0.95		-0.46	0.66	1.26	2.07	2.71	3.38
1.00		-0.45	0.72	1.31	2.04	2.59	3.14
1.05		-0.44	0.75	1.34	2.00	2.47	2.91
1.10		-0.42	0.77	1.34	1.93	2.32	2.67
1.15		-0.39	0.79	1.34	1.85	2.19	2.47
1.20		-0.36	0.81	1.33	1.79	2.08	2.30
Normal		-0.34	0.84	1.27	1.75	2.06	2.33

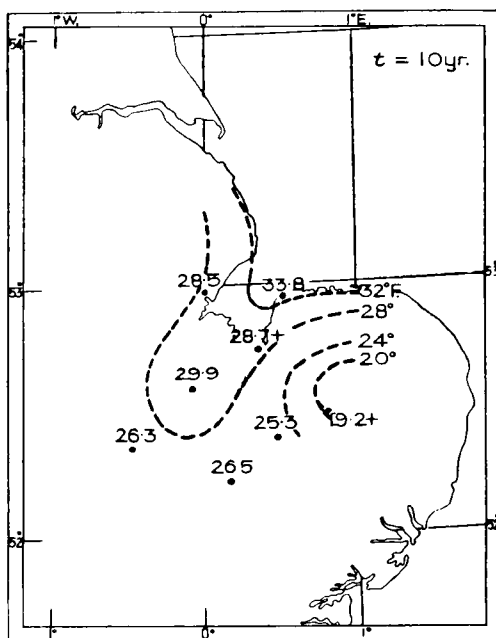
The temperature-probability curves were plotted with  $P$ ,  $t$  or  $y$  [ $= -\log_e \log_e (1/P) = -\log_e \log_e \{t/(t-1)\}$ ] as ordinate and values of  $T$  calculated from Table I as abscissa. An example, that of the calculation for Cambridge, is shown in the Appendix. These curves appeared to follow most closely those using the probability  $(r-\frac{1}{2})/n$ .

Curves of the type shown in Fig. 1 were used to obtain values of  $T$  as plotted in Fig. 2 for  $t=5, 10, 25$  and  $50$ . The plus signs indicate the corrections for standardization of the period (see Table III in the earlier paper<sup>2</sup>). The isopleths of  $T$  appear to follow roughly the pattern shown, as though they were influenced by distance from sea and soil differences. In the lower Severn valley area no such pattern could be seen but here topography is extremely complex. The temperature-probability curves may be used also for the

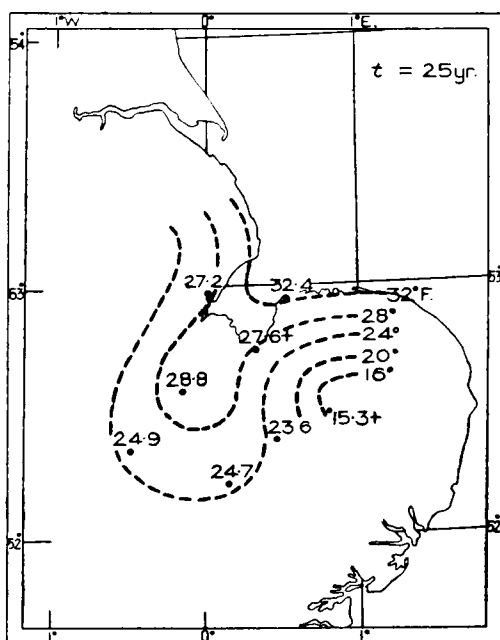




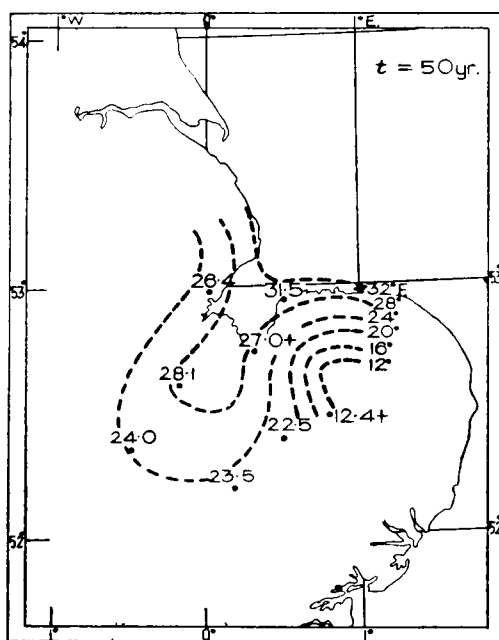
Once in 5 years



Once in 10 years



Once in 25 years



Once in 50 years

FIG. 2—PROBABLE EXTREME MONTHLY MINIMUM TEMPERATURES IN MAY

preparation of charts (see Fig. 3) showing the isopleths of probability that the minimum temperature will not fall to 32°, 30°, 28° or 26°F.

The chart method of obtaining even a very approximate idea of the frequency of frosty Mays cannot be employed in hilly country. In such irregular territory, a technique similar to that of the previous paper<sup>1</sup> may be employed.



TABLE II—VALUES OF  $\sigma_1/\sigma_2$ 

	Period	$\sigma_1/\sigma_2$			Period	$\sigma_1/\sigma_2$	
		April	May			April	May
	yr.				yr.		
Peterborough ...	7	1·41	1·21	Parkend ...	19	1·19	1·27
Tenbury ...	7	1·37	1·09	Bromyard ...	22	1·08	0·95
Boston ...	12	1·04	1·24	Raunds ...	22	1·07	1·26
Terrington				Perdiswell ...	25	1·08	1·31
St. Clement	12	1·06	1·46	Hunstanton ...	27	1·21	1·14
Lynford ...	12	1·14	0·99	Malvern ...	29	1·25	1·30
Droitwich ...	12	1·08	1·45	Cheltenham ...	30	1·46	1·18
Stratford-				Hereford ...	30	1·13	1·26
on-Avon	16	1·10	1·43	Ross-on-Wye ...	30	1·19	1·26
Mildenhall ...	16	1·13	1·28	Cambridge ...	30	1·14	1·12

Means: April 1·17, May 1·23

TABLE III—FREQUENCY DISTRIBUTION OF VALUES OF  $\sigma_1/\sigma_2$ 

$\sigma_1/\sigma_2$	All sites			Sites with period of 25 yr. or more		
	April	May	Total	April	May	Total
0·95-0·99	0	2	2	0	0	0
1·00-1·04	1	0	1	0	0	0
1·05-1·09	5	1	6	1	0	1
1·10-1·14	5	2	7	2	2	4
1·15-1·19	2	1	3	1	1	2
1·20-1·24	1	2	3	1	0	1
1·25-1·29	1	5	6	1	2	3
1·30-1·34	0	2	2	0	2	2
1·35-1·39	1	0	1	0	0	0
1·40-1·44	1	1	2	0	0	0
1·45-1·49	1	2	3	1	0	1

It will be seen in Table III that, considering all sites, on 25 occasions out of 36  $\sigma_1/\sigma_2$  lay between 1·05 and 1·29, whilst, for only those sites with periods of at least 25 yr., on 12 occasions out of 14  $\sigma_1/\sigma_2$  lay between 1·10 and 1·34 which suggests that the range for  $\sigma_1/\sigma_2$  would be considerably decreased if the periods of the samples were longer. For example, of the six sites with the high value of  $\sigma_1/\sigma_2 \geq 1·35$ , four of these have periods of observation not more than 12 yr. and five have periods not more than 16 yr. A value of 1·35 for  $\sigma_1/\sigma_2$  is normally too high, and may generally be considered to contain a sampling error. If it may be assumed that in Table I, the values of  $(\bar{T}-T)/\sigma_1 (=R)$  would not generally be significantly lower than for the normal distribution, that is if it is assumed that the maximum value of  $\sigma_1/\sigma_2$  is 1·20, we obtain the mean value of  $\sigma_1/\sigma_2$  to be 1·13 (April) and 1·16 (May). Taking a mean value of 1·15, the temperature-probability curves were redrawn. For frequencies not less than once in 10 yr., the actual curve and mean curve followed each other closely, and in this range of frequencies, at least, the use of the mean value of 1·15 appears to give results insignificantly different from the sample (see Appendix).

Thus the formula for the temperature corresponding to a probability  $t$  may be written:—

$$T = \bar{T} - R(1·15, t) \sigma_1. \quad \dots \dots (1)$$

If, for example,  $T$  is the minimum temperature which is reached once in five years, then

$$T = \bar{T} - 0·79 \sigma_1.$$

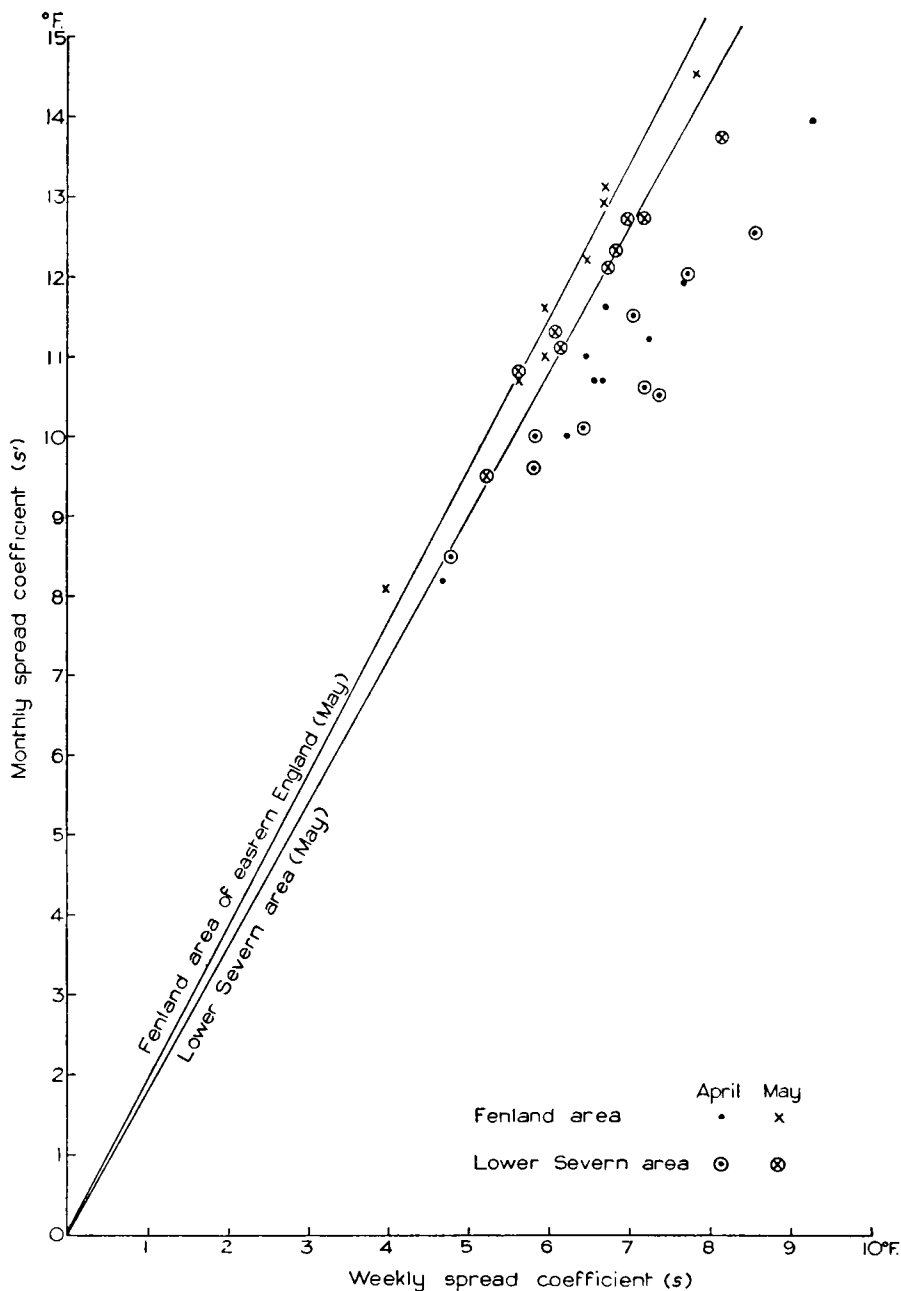


FIG. 4—RELATIONSHIP BETWEEN MONTHLY SPREAD COEFFICIENT  $s'$  AND WEEKLY SPREAD COEFFICIENT  $s$

The weekly spread coefficient  $s$  is based on the four-week periods April 1–28 for April and April 29–May 26 for May.

Using the relationship<sup>1</sup> between standard deviation  $\sigma_1$  and monthly spread coefficient  $s'$  (that is the difference between the mean daily minimum temperature for the month and the mean monthly extreme minimum temperature), we obtain:—

$$T = \bar{T} - R(1.15, t) \cdot s' \cdot \left[ \frac{\sigma_1}{s'} \right]_m \quad \dots \dots \dots (2)$$

where the suffix  $m$  indicates that the elements refer to those of the meteorological station of long standing in the same climatic régime.

Now in the estimation of the May frost risk of a site with, say, only one season of observations, it is desirable to avoid basing the calculation on the one observation of extreme minimum temperature in May. This may be achieved by obtaining an expression for the monthly spread coefficient  $s'$  in terms of the weekly spread coefficient  $s$ , that is the mean daily minimum temperature for the week minus the mean weekly extreme minimum temperature. By means of such a relationship, the calculation may be based on a number of observations of extreme weekly minimum temperature.

To obtain the form of  $s' = f(s)$ , the values of  $s'$  and  $s$  for the 18 sites for April and May were plotted (see Fig. 4). The graph is roughly a straight line through the origin, with the formula:—

$$s' = bs \quad \dots \dots \dots (3)$$

where the parameter  $b$  has the approximate value of 1.79 in the lower Severn area during May and 1.90 in the Fenland area of eastern England during May. That the graph passes through the origin is what might have been expected, for when  $s$  tends to 0 so should  $s'$  tend to 0. Further, it can be shown from theoretical considerations<sup>7</sup> that  $s'$  bears a constant ratio to  $s$ , for the mean spread coefficients of, say, a set of minimum temperatures for a month and for a week each bear a constant ratio to the standard deviation of daily minimum temperatures, the constant depending on the number of independent observations during the month or week. It has been pointed out by A. F. Jenkinson that it is very reasonable to assume that there are about 20 "independent" minima a month or about five a week. Using this assumption and following Tippett<sup>7</sup> the ratio of  $s'$  to  $s$  is 1.87 to 1.16 or 1.6, which confirms the order of magnitude of the value obtained graphically. Fig. 4 indicates that the ratio of  $s'$  to  $s$  depends on the month and area, as might have been expected seeing that  $b$  is a climatic parameter. The value of  $b$  will be lowest in oceanic and continental climates and highest in the day-to-day variable climate of a maritime area along a continental seaboard. The tendency for the value of  $b$  to be lower towards the west of England as compared with the east suggests that during May the oceanic influence of the Atlantic is more dominant than the continental influence of the Eurasian land mass on the climate of this region. During January, when continental influence is much stronger and perhaps the more dominant, it may well be that the lower values of  $b$  occur in the eastern and central parts of England. Ideally, the values of  $b$  should be charted for the whole region for, say, each month and isopleths drawn. These isopleths would show the resultant influence of ocean and continent and also the effects of distance from the sea within our own island, and would enable the value of  $b$  to be fairly accurately interpolated. To estimate the value of  $b$  when data are insufficient, general climatic considerations should be taken into account.

Using the relationship,  $s' = bs$ , we obtain:—

$$T = \bar{T} - R(1.15, t) \cdot s \cdot \left[ \frac{\sigma_1}{s} \right]_m \quad \dots \dots \dots (4)$$

$$\text{or } T = \bar{T}_d - s' - R(1.15, t) \cdot s \cdot \left[ \frac{\sigma_1}{s} \right]_m \quad \dots \dots \dots (5)$$

where  $\bar{T}_d$  is the mean daily minimum temperature for the month,

$$\text{or } T = \bar{T}_d - bs - R(1.15, t) \cdot s \cdot \left[ \frac{\sigma_1}{s} \right]_m \quad \dots \dots \dots (6)$$

The procedure for calculating the frost risk for, say, the month of May for a site for which daily minimum temperatures are available for, say, the late spring season (April and May) in one or two years can now be formulated as follows:—

(1) Calculate the mean daily minimum temperature for each week of the season for at least one season on the site, taking an average where observations for several seasons are available.

(2) Examine the observations for the same period of the nearest meteorological site of long standing in the same climatological régime, and calculate the differences of these from their long-term averages.

(3) Correct the weekly mean temperatures of (1) using the differences calculated in (2); plot the results on a diagram similar to that of Fig. 1(a) of the previous note<sup>1</sup> and draw the curve which best fits these points and lies parallel to the adjacent curves. This curve gives the average minimum temperature of the site during the season.

(4) Similarly, construct the curve of mean weekly extreme minimum temperatures of the site during the season, by using the diagram of Fig. 2(b) of the previous note<sup>1</sup>.

(5) From the graphs of (3) and (4) obtain the May values for the average daily minimum temperature  $\bar{T}_d$  and the average weekly extreme minimum temperature  $\bar{T}_w$  respectively, and hence obtain the value of  $(\bar{T}_d - \bar{T}_w) = s$ .

(6) Using the values of  $\bar{T}_d$  and  $s$  calculated in (5), and the constant  $[\sigma_1/s]_m$  computed from the data of the meteorological station of long-standing, the values of  $T$  for different values of  $t$  may be calculated from equation (6), thus giving the May temperature-probability curve for the new site.

**Other meteorological elements.**—A similar technique may be employed for the estimation of the frequencies of other meteorological extremes.

### Appendix

Calculation of the temperature-probability curve for May at Cambridge from monthly minimum temperatures for the period 1921 to 1950

$T$	$r$ [position in ordered series]	$m$ [number of years]	$m'$ [ $\sum 2r-1$ ]	$x$ [ $T - \text{approx. } \bar{T}$ ]	$mx$	$mx^2$	$m'x$	$m'x^2$
°F.								
36	1	1	1	5	5	25	5	25
35	2-4	3	15	4	12	48	60	240
33	5-10	6	84	2	12	24	168	336
32	11-13	3	69	1	3	3	69	69
31	14-16	3	87	0				
30	17-19	3	105	-1	-3	3	-105	105
29	20-23	4	168	-2	-8	16	-336	672
28	24-25	2	96	-3	-6	18	-288	864
27	26-27	2	104	-4	-8	32	-416	1664
26	28	1	55	-5	-5	25	-275	1375
24	29-30	2	116	-7	-41	98	-812	5684
Sums		30	900		-12	292	-1930	11034

$$\frac{\sum mx}{\sum m} = -\frac{12}{30} = -0.40$$

$$\sigma_1^2 = \frac{292}{30} - (0.40)^2 = 9.56$$

$$\sigma_1 = 3.09$$

$$\sigma_2^2 = \frac{11034}{900} - \left(\frac{1930}{900}\right)^2 = 7.66$$

$$\sigma_2 = 2.77.$$

Therefore  $\sigma_1/\sigma_2 = 1.12$

$$\text{and } \bar{T} = 31 - 0.4 = 30.6.$$

Substituting for  $\sigma_1$  and  $\bar{T}$  in the formula  $T = \bar{T} - R\sigma_1$

$$T = 30.6 - 3.09R. \quad \dots\dots\dots (7)$$

From Table I we obtain the following values of  $R$ :—

$\sigma_1/\sigma_2$	$t$ $y$	1.58 0	5 1.50	10 2.25	25 3.20	50 3.90	100 4.61
1.12		-0.41	+0.78	+1.34	+1.90	+2.28	+2.60
1.15		-0.39	+0.79	+1.34	+1.85	+2.19	+2.46

Substituting in equation (7), the values of  $R$  corresponding to different values of  $t$  we obtain the following values of  $T$  corresponding to different values of  $t$  (or  $y$ ):—

$\sigma_1/\sigma_2$	$t$ $y$	1.58 0	5 1.50	10 2.25	25 3.20	50 3.90	100 4.61
				<i>degrees Fahrenheit</i>			
1.12		31.9	28.2	26.5	24.7	23.5	22.6
1.15		31.8	28.2	26.5	24.9	23.8	23.0

The values of  $T$  corresponding to  $\sigma_1/\sigma_2 = 1.12$  give the “actual” temperature-probability curve (see Fig. 1) and the values of  $T$  corresponding to  $\sigma_1/\sigma_2 = 1.15$  give the “mean” curve based on the actual values of  $\bar{T}$  and  $\sigma_1$  and the “mean” value of 1.15 for  $\sigma_1/\sigma_2$ .

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## PRESSURE WAVES AND SYMMETRY POINTS

By J. WADSWORTH, M.A.

In the *Meteorological Magazine* for August 1953 Dr. J. M. Stagg<sup>1</sup> gave a concise and comprehensive account of methods which have been used in long-range forecasting, and he concludes that methods based on pressure waves and symmetry points offer small chance of success. A similar point of view is expressed in reviews<sup>2,3</sup> of the new “Handbook of statistical methods in meteorology”, which devotes several of its chapters to the subject of periodogram analysis.

There seems nevertheless to be a good *a priori* case for the existence of periodic phenomena in the atmosphere, and Defant’s view expressed in his book “Wetter und Wettervorhersage”<sup>4</sup> still seems to be true, namely that pressure waves in

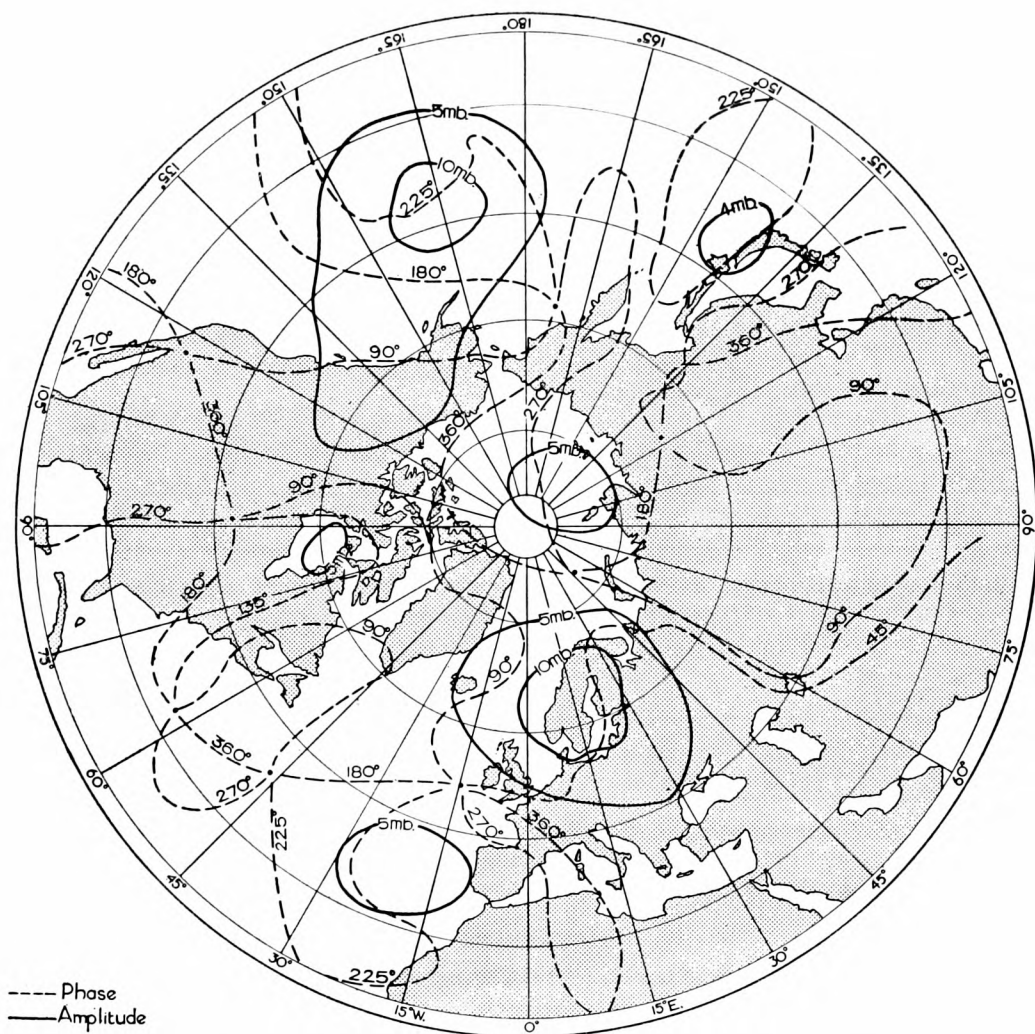


FIG. 1—PHASE AND AMPLITUDE OF THE 36-DAY  
PRESSURE WAVE, OCTOBER 1–DECEMBER 12, 1932

the atmosphere would be analogous to waves in the ocean with a strong presumption for periods which are aliquot parts of the year and free periods of vibration of the atmosphere. The wave problem of the atmosphere, however, is likely to be much more difficult to unravel than that of the sea.

The appearance of symmetry points in pressure graphs can be explained in terms of pressure waves, and the interval between consecutive symmetry points gives a clue to the wave-length of the oscillations causing them. Mildner has deduced from the dates of two symmetry points in the winter of 1923–24 that the fundamental wave-length or period is of the order of 144 days or submultiples of this interval<sup>5</sup>, and the Leipzig school have generally adopted a fundamental interval of 72 days. A more recent investigation by H. Flohn of the harmonics of an 83-yr. record of daily pressure readings at Frankfurt-on-Main<sup>6</sup> shows peaks in the periodogram at 73, 30–33 and  $16\frac{1}{2}$  days. It thus confirms Mildner's earlier choice of a period near 72 days. The Polar-Year winter of 1932–33 was examined for symmetry points using the charts published for the International Meteorological Organization<sup>7</sup> and it was found that an approximate 72-day periodicity in pressure also existed then in Europe, exhibiting itself as a repetition



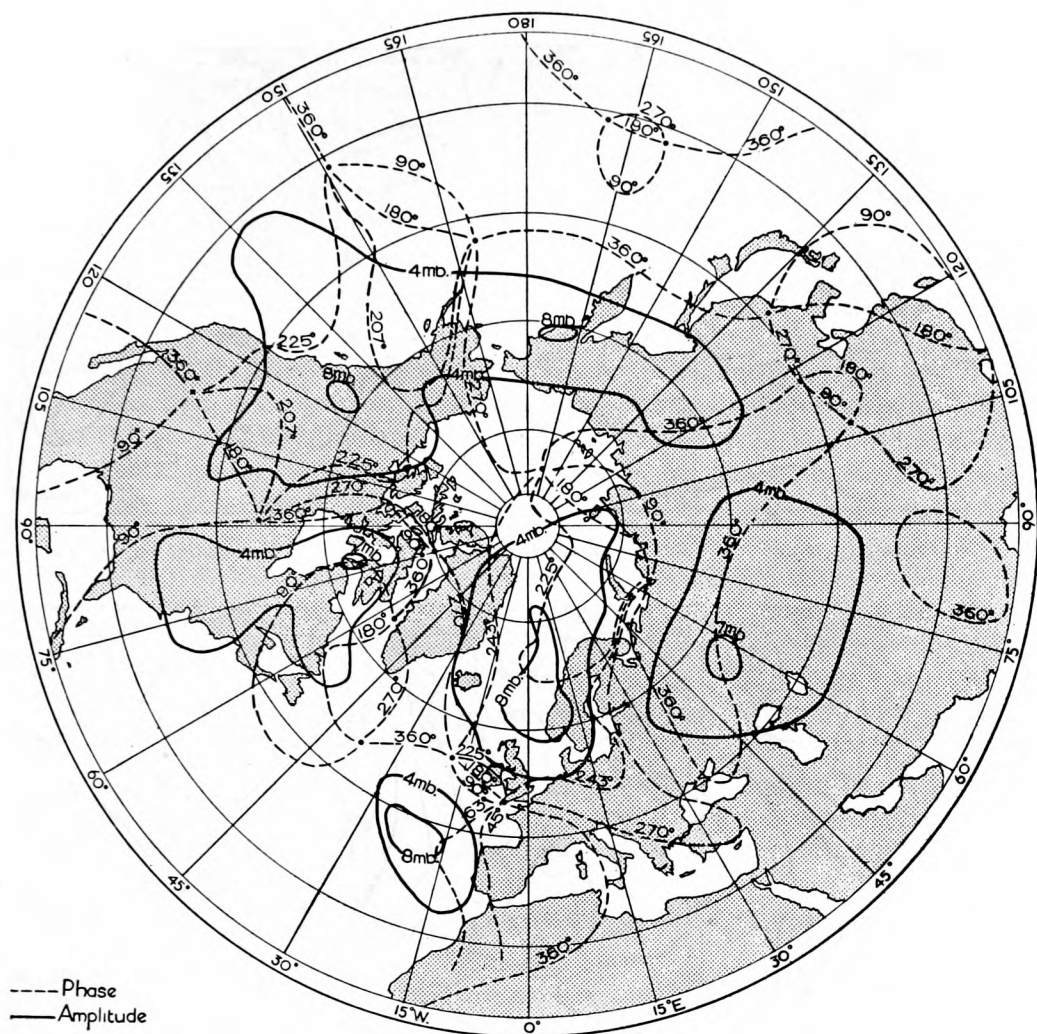
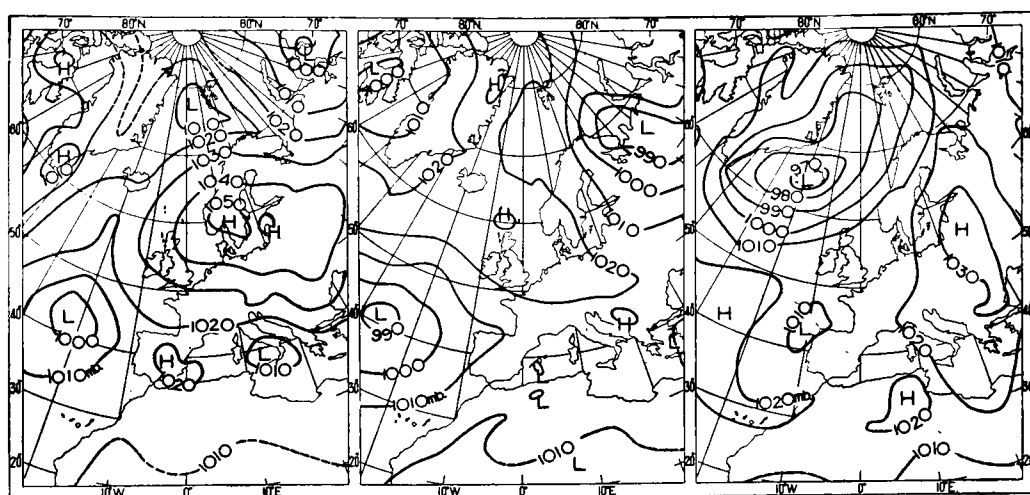


FIG. 2—PHASE AND AMPLITUDE OF THE 24-DAY  
PRESSURE WAVE, OCTOBER 7–DECEMBER 18, 1932

of isobaric features in direct order after intervals of 72 days and in reverse order by reflection about symmetry points.

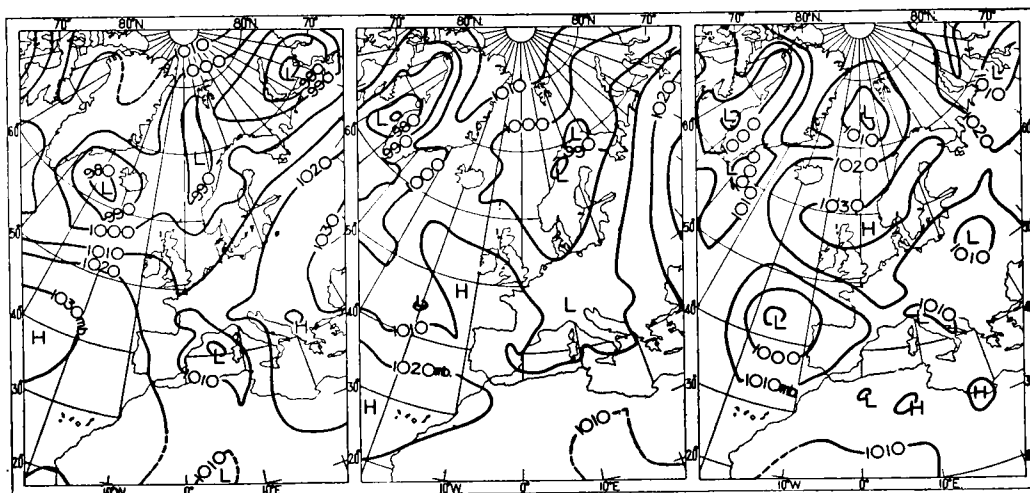
Symmetry points are found with the aid of an index of symmetry which was devised by K. Stumpff<sup>8</sup> to express in numerical form the degree of similarity in size and shape between a pressure graph and its reversed image. Symmetry points are indicated by values of the index near zero and unity. This criterion is not sufficient by itself to define symmetry in the sense in which Weickmann used the term, for it will be satisfied by symmetry points which are entirely fortuitous. A symmetry point must also bear a certain relationship to the crests and troughs of the dominant waves of pressure. In seeking to demonstrate by statistical methods the fortuitous nature of symmetry points it would seem that some critics have ignored the relationship with pressure waves altogether, concentrating their attention on symmetry points defined by the symmetry index alone.<sup>9,10</sup> Indeed Sir Gilbert Walker uses a pressure graph from Kew Observatory to illustrate his paper, although Kew Observatory usually lies in a nodal region or amphidrome of the 24-day and 36-day pressure waves.



November 13, 1932

November 16, 1932

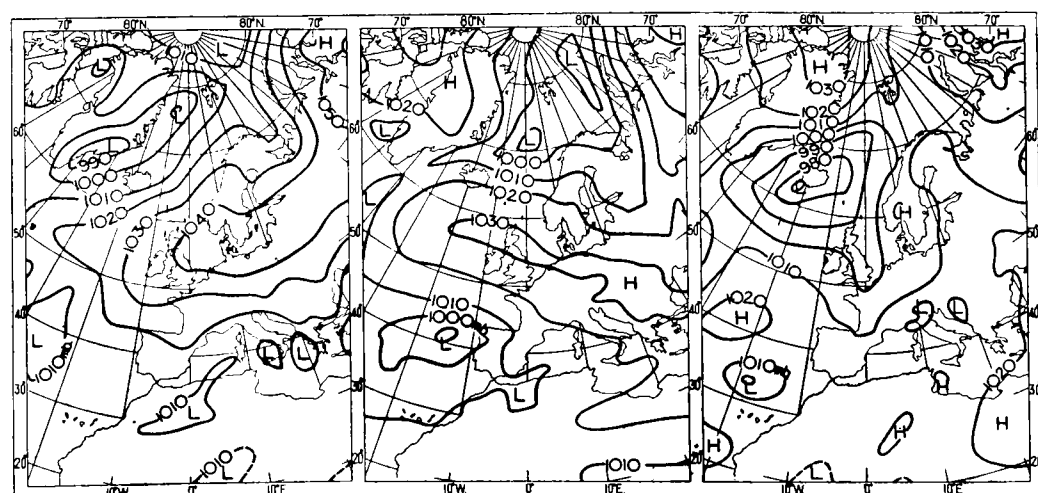
November 19, 1932



December 1, 1932

December 4, 1932

December 7, 1932



January 24, 1933

January 27, 1933

January 30, 1933

FIG. 3—SURFACE ISOBARS, NOVEMBER 1932—JANUARY 1933

The number of symmetry points which may be significant in long-range forecasting is comparatively small. Weickmann quoted those near the solstices and it would seem that there may be others separated from them by intervals of 36 days or 72 days. The winter symmetry point seems to be fairly well established on the continent of Europe, for in the paper referred to above Flohn presents a list of 29 winters between 1914 and 1946 for which the date of a symmetry point between mid December and mid January has been published.

The symmetry points of the Polar-Year winter occurred near the dates October 20, November 25 and December 31. Those of November 25 were associated with troughs of the 36-day and 24-day pressure waves in Scandinavia and the Norwegian Sea respectively. Charts showing maximum amplitude and phase of these two oscillations as determined by harmonic analysis of the isobars of weather maps by the method of Egersdörfer<sup>11</sup> are shown in Figs. 1 and 2. The phase lines correspond to the sine formulae  $y = r \sin(2\theta + \phi)$  and  $y = r \sin(3\theta + \phi)$  respectively, where  $y$  is the displacement,  $\theta$  is the phase angle for any date,  $\phi$  is the initial phase and  $r$  is the maximum amplitude. The charts in Fig. 3 show approximate reflections about the symmetry points of November 25 (top and middle charts) and of December 31 (middle and bottom charts), and also approximate repetitions of the isobars after an interval of 72 days (top and bottom charts). A second repetition may be traced in the charts for April 6, 9 and 12, 1933, after a further interval of 72 days.

An experiment on current long-range forecasting was carried out during the winter of 1942-43, which was mainly directed towards identification of the winter symmetry point of Weickmann and its employment as a basis for forecasts. This experiment did not succeed, for the symmetry point does not seem to have been found at all. The charts available in 1942-43 were far less complete, however, than those of the Polar Year.

The two experiments described above are not sufficient by themselves for a verdict on the efficacy of the symmetry-point method. It must be noted, however, that the symmetrical properties of a pressure graph only refer to the general aspect of the curve and do not extend down to the smallest details. The method cannot therefore furnish a complete forecast in detail, but it might eventually constitute a useful auxiliary method showing the general trend of pressure changes some time ahead. Further experimental work is very desirable, and this could be carried out on a much smaller scale than that of the two investigations of the winters of 1932-33 and 1942-43.

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## RADIO-SONDE CALIBRATION PLANT

By H. E. PAINTER, B.Sc.

**Introduction.**—The Meteorological Office issues about 17,000 radio-sondes every year; before this can be done each radio-sonde has to be calibrated for each of its three meteorological units. When dealing with such large numbers economy assumes great importance, and a radio-sonde cannot receive the same individual attention as an instrument calibrated in a laboratory. For calibration the meteorological units are detached from their radio-sondes, and these units only are placed in a calibration chamber, but during the process each unit has to be connected by leads to its own radio-sonde. All calibration is done in air; even for the bimetallic temperature element a liquid cannot be used, since it would damage the inductance. The requirement for calibration is for a chamber in which as many units as possible can be placed, but when readings are being taken conditions in the chamber must be as constant and uniform as possible. The ranges to be covered must be: pressure from surface to 50 mb., temperature from  $+48^{\circ}\text{C}.$  to  $-85^{\circ}\text{C}.$ , and relative humidity from below 15 per cent. to near saturation. Recently the Instrument Testing and Calibration Section at Harrow has developed and built a new temperature and pressure calibration plant which, particularly as regards temperature, is a considerable improvement on previous methods. This calibration plant was protected by a provisional patent.

**Temperature calibration.**—In previous methods a full range of temperature was covered in one chamber, so that to repeat the process the chamber had to be brought from one extreme of temperature to the other. The new apparatus consists of a number of vessels which contain the thermometer units and which can be totally immersed successively in liquid baths maintained at different temperatures. These baths are cylindrical copper vessels 43 cm. in diameter and 89 cm. high containing about 45 l. of liquid. There is no convenient liquid that can cover the full range of temperature, so water is used for the higher temperatures and trichlorethylene ( $\text{C}_2\text{HCl}_3$ ; freezing point  $-86.4^{\circ}\text{C}.$ ) for the lower temperatures. Two water baths are thermostatically maintained by 4-KW. heaters at approximately  $+48^{\circ}\text{C}.$  and  $+27^{\circ}\text{C}.$  Five trichlorethylene baths are maintained at approximately  $+4^{\circ}\text{C}.$ ,  $-18^{\circ}\text{C}.$ ,  $-40^{\circ}\text{C}.$ ,  $-62^{\circ}\text{C}.$  and  $-85^{\circ}\text{C}.$  by adding crushed solid carbon dioxide. All the baths are insulated with either glass wool or onazote and only the surfaces of the liquids are exposed to the air temperature. The photograph facing p. 17 shows the vessels enclosed by a cabinet. Behind the cabinet is an exhaust duct to remove the trichlorethylene fumes. To maintain an even temperature the liquids are agitated by bubbling air through them.

The vessels which are immersed in the baths consist of the two parts shown in the photograph facing p. 16. To the left is a copper vessel 33 cm. in diameter and 61 cm. high with a flange around the top. This vessel fits around the lower part of the apparatus, known as the head, on the right of the photograph, and

can be clamped to the flat plate A. A rubber gasket fits between the two parts and when these are clamped together they form the sealed chamber in which the temperature units are calibrated. To the framework B can be plugged 18 thermometer units, three only being shown in the photograph. A fan C just below the plate circulates the enclosed air. The air circulation is directed as far as possible on to the temperature-sensitive parts of the thermometers by means of two baffle plates D and a central celluloid chimney E. Within this chimney are two copper-constantan thermo-couples F (32 S.W.G. wire) for measuring the temperature. Above the plate A is a central column on which is an electric motor G which drives the fan C. In former plants the fan motors were within the calibrating chamber, to which they could communicate heat, but here the motor is completely isolated from the calibration chamber. As the same design of head is used for pressure calibration a double pressure seal is placed in the central column H. These seals are spring loaded and therefore apply friction to the fan drive. To overcome this extra load a  $\frac{1}{4}$  h.p. motor is used to rotate the fan. The heat generated by the friction is dissipated by filling the central column with oil which is kept in constant circulation by a small impeller on the spindle. The small tube J is the return circuit for the oil, and to ensure that the seals are kept wholly immersed in oil a reservoir K is fitted on the outside. The two big tufnol discs L that surround the motor carry the transmitters of the radio-sondes. The leads from the thermometer units inside the chamber are connected to their corresponding radio-sonde transmitters through the four tubes M, through which also pass the thermo-couple wires. Seventy leads pass through the tubes all of which are pressure sealed at the bushes N. The metal part of the head is stainless steel.

For a temperature calibration a head is loaded up and after the copper vessel is clamped in place the whole is immersed in the  $+48^{\circ}\text{C}$ . bath. There is at least 2 cm. of liquid above the top plate A, so that the thermometer units are completely surrounded by a liquid at the temperature at which a calibration is required. It is only a matter of waiting until temperature equilibrium has been reached inside the chamber before taking readings, after which the whole vessel and head are removed and placed in the bath at  $+27^{\circ}\text{C}$ . and so on. A second vessel and head can now be placed in the  $+48^{\circ}\text{C}$ . bath, and finally all baths are occupied by vessels, readings being taken from each chamber in turn and the vessel and head being moved to the next bath when it becomes vacant. Small amounts of solid carbon dioxide are added to the baths from time to time to maintain the right temperature. It is possible to have over 120 thermometer units in various stages of calibration at one time.

A thermometer head fully loaded and clamped to the copper vessel weighs about 80 Kg. The moving of these heads from bath to bath is done by an electric travelling hoist which runs on a gantry suspended from the ceiling. In spite of the 80-Kg. weight it is necessary to add a further 9 Kg. of lead to sink the heads in the trichlorethylene (specific gravity 1.48). On the inside walls of the baths are three guides which keep the inner vessels upright and central. A battery supply of 85 V. high tension and 2.4 V. low tension is connected to the head in use. The low-tension supply passes through a uniselector switch O so that only one radio-sonde has low-tension supply at one time.

One of the photographs in the centre of the Magazine shows the temperature calibration plant in use. The baths are enclosed within the cabinet and the heads can be seen. One head is being lowered into a bath by the hoist. The

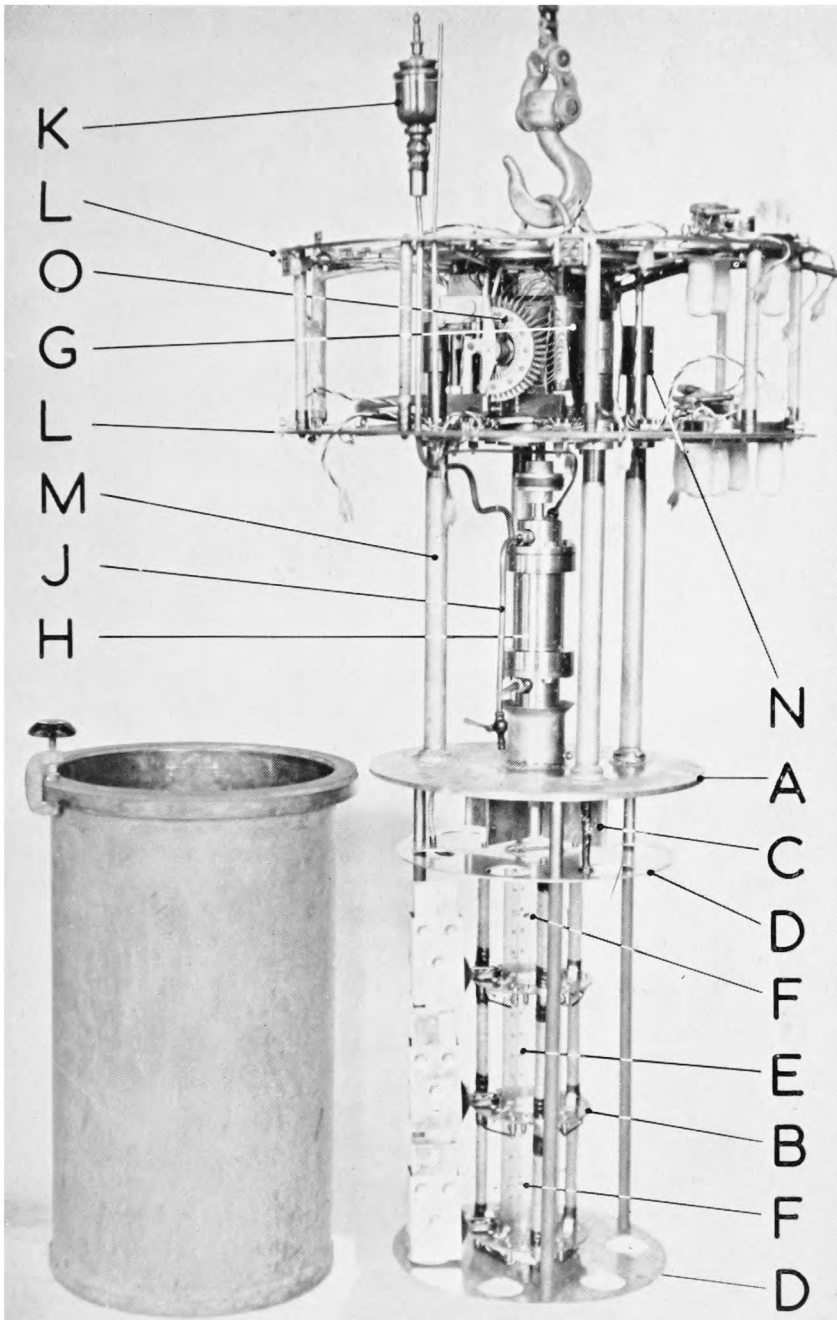
operator on the right is taking readings from one of the heads. The operator has a morse key which works the uniselector switch, and hence switches from one radio-sonde to another.

The sublimation point of carbon dioxide is  $-78.5^{\circ}\text{C}.$ , and it is necessary to be able to calibrate to  $-85^{\circ}\text{C}.$  A special low-temperature bath was constructed using petrol for the liquid and liquid nitrogen as the cooling agent. A 2-cm. spiral tube in the bath surrounds the chamber with the temperature units; the liquid nitrogen is passed through this tube. Initially the petrol is cooled down by carbon dioxide, liquid nitrogen only being used for the final stages. By this means temperature calibrations at  $-100^{\circ}\text{C}.$  can be obtained. However, it has been found in practice that if the solid carbon dioxide is broken very small before being placed in the trichlorethylene and plenty of air is bubbled through the trichlorethylene a temperature of  $-85^{\circ}\text{C}.$  can be obtained, so that at present liquid nitrogen is not used. The other photograph in the centre of the Magazine gives a general view of the temperature calibration plant.

**Pressure calibration.**—The vessels and heads used for pressure calibration are similar to those used for temperature calibration, but because of the smaller radiation shield 30 pressure units can be fitted into each copper vessel. Two outlets on the heads allow for suction lines to be fitted. As the pressure units are also sensitive to temperature changes two calibrations are made, one at  $+15^{\circ}\text{C}.$  and a shorter calibration at  $-60^{\circ}\text{C}.$  A smaller plant similar to the temperature calibration plant has been built for pressure work. The pressure is measured down to 50 mb., but if required 10 mb. can be reached. Measurements are made on a mercury manometer.

**Auxiliary equipment.**—For the working of the plant there are several subsidiary pieces of equipment. A rotary pump produces the low pressure in the pressure plant and a compressor supplies air for bubbling through the liquid baths. Distant-reading temperature indicators are placed in the baths so that the temperature of the liquids is known approximately without reference to the thermo-couples in the calibration chambers. Exhaust fans remove fumes from both pressure and temperature plants as well as from the room in general. A refrigeration plant supplies ice for the thermo-couple reference points. In addition to the battery supplies for the radio-sondes, a mains supply is needed for the motors on the heads, and a 50 V. d.c. supply for the uniselector switches. Storage arrangements are made for 250 Kg. of solid carbon dioxide which is delivered daily. Trolleys have been made to carry the heads when not in use. Ample racking is supplied for the radio-sondes and their units since up to 500 instruments may be in process of calibration at any one time.

**Performance.**—The maximum time taken for temperature equilibrium to be reached in the calibration chamber after transferring from one bath to the next is 25 min. The position of the thermo-couples in the head is not the best to give the mean temperature, but because of the delicate nature of the thermo-couples they have been placed within the celluloid chimney for protection. When temperature equilibrium has been reached the maximum temperature difference as determined by differential thermo-couples is  $0.2^{\circ}\text{C}.$  Temperatures during calibration are recorded to  $0.1^{\circ}\text{C}.$  Starting from the  $+48^{\circ}\text{C}.$  bath the first batch of 18 thermometer units is completely calibrated to  $-85^{\circ}\text{C}.$  in 3 hr., after which 18 are completed every half hour. Two operators are required for calibration, one to record readings and the other to move the heads and maintain the baths at their correct temperatures.

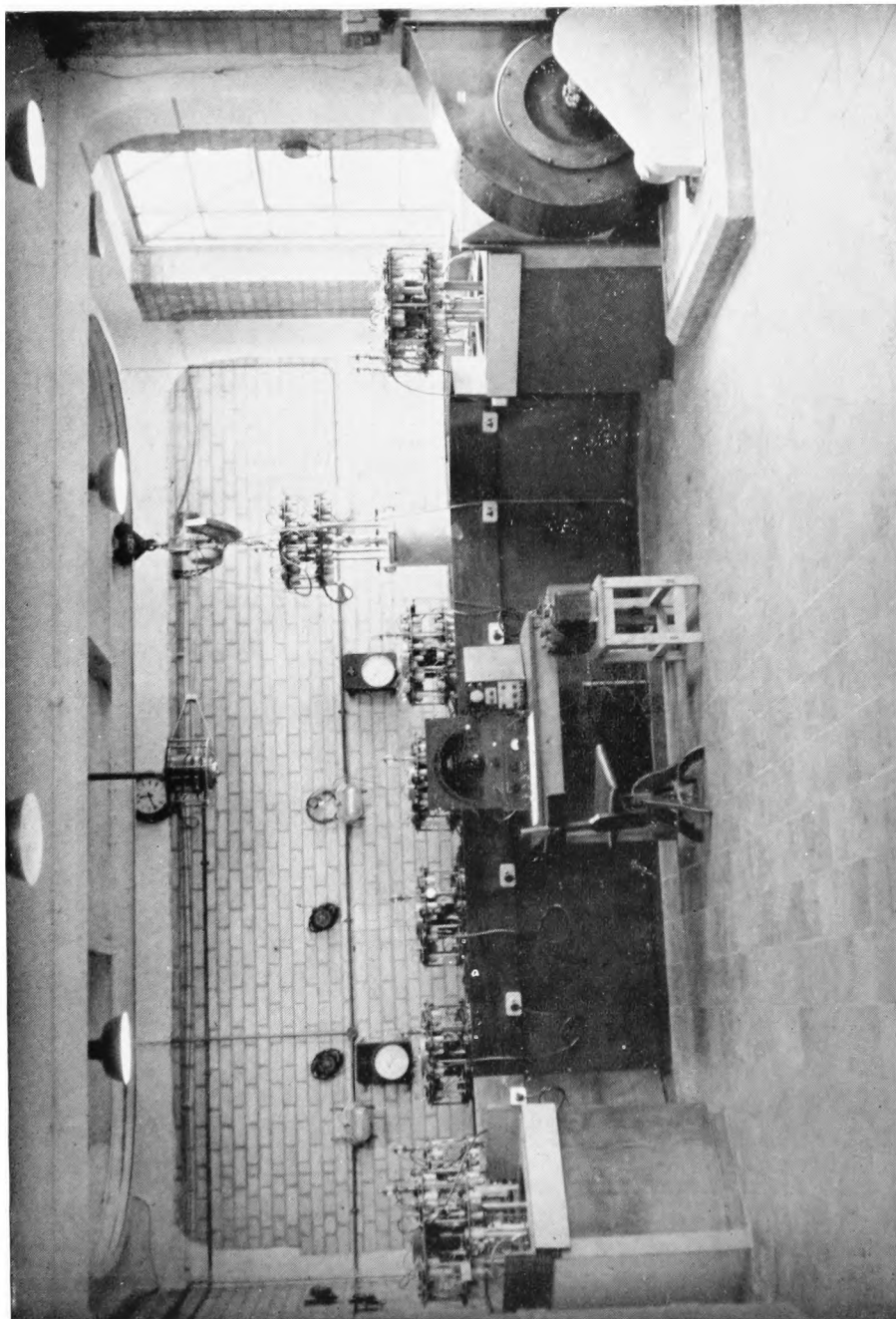


#### RADIO-SONDE TEMPERATURE CALIBRATION HEAD

The apparatus on the right of the photograph is known as the head and is fitted into the copper vessel on the left which is then inserted in a calibration bath (see p. 14).

- |   |  |   |  |
|---|--|---|--|
| A | Flat plate to form part of air-tight seal            | J | Return circuit for the oil in the double pressure seals                          |
| B | Framework holding 18 thermometer units (3 seen here) | K | Oil reservoir  |
| C | Fan to circulate the air                             | L | Tufnol discs to carry the radio-sonde transmitters, three of which are seen here |
| D | Baffle plates to direct the air flow on to the units | M | Connecting tubes carrying electric wires   |
| E | Celluloid chimney                                    | N | Pressure seals for tubes M   |
| F | Copper-constantan thermo-couples                     | O | Uniselector switch   |
| G | Electric motor to drive the fan                      |   |  |
| H | Column housing the double pressure seals             |   |  |





GENERAL VIEW OF THE RADIO-SONDE TEMPERATURE CALIBRATION PLANT

The large object on the right of the picture is an exhaust fan which removes fumes from the plant.





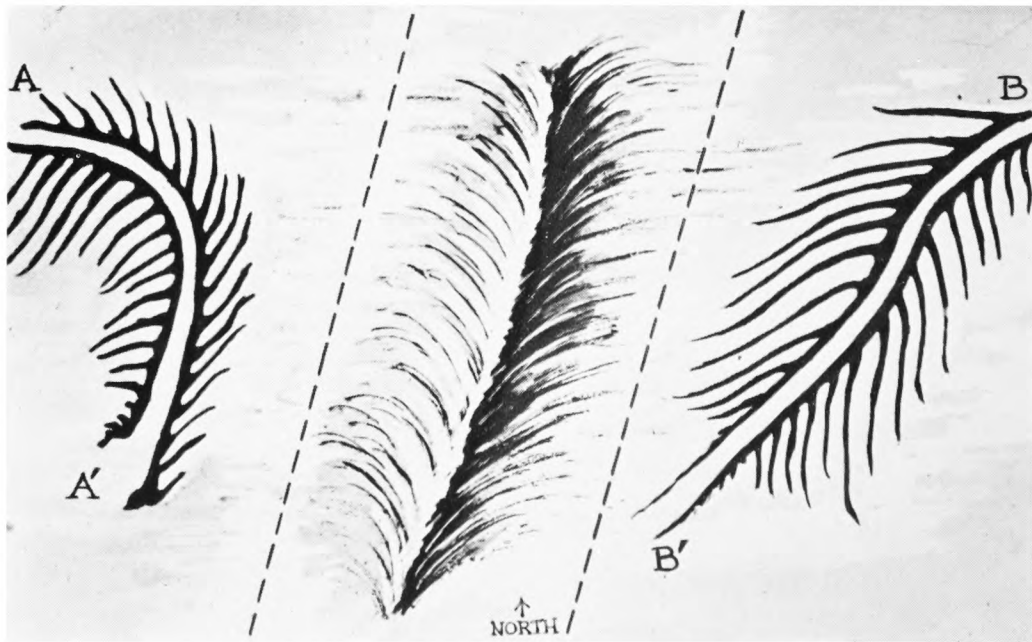
RADIO-SONDE TEMPERATURE CALIBRATION PLANT IN USE

One head is being lowered into a bath by means of a hoist; the man on the right is taking readings from another head; his right hand rests on the Morse key which operates the unselector switch (see p. 14).



RADIO-SONDE TEMPERATURE CALIBRATION BATHS

The grills that can be seen behind three of the baths on the right cover the entrance to the duct of the exhaust fan which extracts fumes from the liquids in the baths (see p. 14).



SKETCH OF THE THREE CLOUD PATTERNS SEEN OVER  
PYRFORD, WEST BYFLEET

(See p. 25).

Pressure on the manometer is read to 0.2 mb., but it is only possible to discriminate on the oscillator to 0.1c./sec. which corresponds to 0.8 mb. at the surface and 0.3 mb. at 100-mb. pressure. When the pressure line is in full production two operators can calibrate 30 pressure units in an hour.

As the meteorological units are separated from their radio-sonde during calibration the conditions are not the same as during an ascent. The effect of the connecting leads between the units and their radio-sondes is to increase the inductance, but the proximity of the copper vessel decreases the inductance. The average frequency difference between a radio-sonde assembled in the calibration equipment and the same radio-sonde assembled for an ascent is +0.4c./sec.; this corresponds to about 0.2°C. and 3 mb. at surface conditions. This difference is of course taken into account by the control readings recorded before an ascent.

**Humidity calibration.**—For the sake of completeness an account is given of the calibration of the humidity units, although the same method has been in use for a number of years. As with the other two units the humidity units are plugged into a frame which can be placed in a processing chamber. The radio-sondes are connected to their units by leads. The air in the chamber is circulated by a small compressor. The air circuit however is closed so that no outside air is drawn in. Before entering the chamber the air can be diverted through one of several canisters. One of these canisters contains silica gel which will dry the air to a relative humidity of about 15 per cent. A second canister contains water heated by a small immersion heater. Heating the water to about 3°C. above room temperature will give the air a relative humidity of about 97 per cent. A third canister contains unheated water, and it is arranged that part of the air passes through this canister and part through the one with silica gel; on mixing, humidities ranging from 15 to 80 per cent. according to the quantity of air going through each canister can be obtained. Calibrations are generally made at about 97, 70, 40, and 15 per cent. relative humidity. A fan in the chamber circulates the air throughout the chamber and readings are taken on a dry-bulb and a wet-bulb thermometer, the bulbs of which are within the chamber.

**Conclusions.**—The new pressure and temperature plant is capable of dealing with far greater numbers than any previous apparatus used, and requires fewer operators for a given number. Previously the radio-sondes were connected to their units by multi-pin plugs and sockets which from time to time gave contact troubles. Now the connexions are by direct leads. There is no improvement over previous methods as regards the accuracy of pressure recording, but temperature calibration is certainly more accurate, since the temperature distribution inside the chamber is considerably more uniform than in any previously used apparatus. The range of calibration, +48°C. to -85°C., necessary because of the great range of climates in which British radio-sondes are used, is also wider than in earlier apparatus.

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## METEOROLOGICAL OFFICE DISCUSSION

### Thirty-day forecasting

The discussion on Monday, October 18, 1954, held at the Royal Society of Arts, was opened by Mr. J. H. Brazell, who based his statement on the following paper:—

NAMIAS, J.; Thirty-day forecasting: A review of a ten-year experiment. *Met. Monogr., Boston, Mass.*, **2**, No. 6, 1953.

Mr. Brazell stated that the main tool used in this synoptic and statistical attack on long-range forecasting is the 30-day mean 700-mb. contour chart. Namias contends that the averaging process submerges the rapidly moving small-scale features and that the 30-day mean charts portray the basic large-scale and slowly developing pattern of circulation. It is claimed that these mean circulation patterns represent a class of planetary waves whose development and movement may be forecast, and that the mean circulations are closely related to the average weather characteristics of the month. In the American experiment temperature and precipitation are the two elements deduced from forecast circulation patterns.

Temperatures are estimated from mean circulation patterns by superimposing the field of 700-mb. height anomaly on the appropriate normal monthly 1000–700-mb. thickness chart. The 700-mb. height anomalies indicate the anomalous components of mean flow. From the direction, speed and fetch of the anomalous components of mean flow and assuming that they are instrumental in effecting a displacement of the thickness lines, it is possible to make a rough estimate of the mean surface temperature anomaly in any area. A more objective method of estimating temperature is to use the strong positive correlation between surface-temperature anomaly and the local 700-mb. height anomaly and the equally strong (if not stronger) negative correlation with the 700-mb. height anomaly about one half wave-length up stream. By means of nomograms, the height anomalies at the two centres of maximum correlation are converted to a surface-temperature anomaly. In the methods used for estimating temperature, it is assumed that conditions at the source of flow are normal. The deviations from normal of long-period average temperatures are smaller than those for short-period averages. Therefore this question of abnormality at source is of more importance to short-range than to long-range forecasts. Nevertheless, even for 30-day periods, the initial stage cannot be ignored and modifications of temperature estimates are introduced when the flow is anticipated to come from areas where conditions have been very abnormal during the preceding month.

The distribution of precipitation is more difficult to relate to mean circulation patterns than temperature. This is not surprising since precipitation is not a continuous element like temperature, and the physical processes which produce precipitation are more involved than those which determine temperature. The main cause of precipitation is vertical motion, and while it is related to the pressure pattern, it cannot obviously be determined from the isobars at only one level. One of the tools used in estimating precipitation is the model due to Klein<sup>1</sup>. This model, which applies to winter, indicates heavy precipitation just ahead of the trough and in the region of confluence, and light precipitation behind the trough and in and to the east of the anticyclones. The model may be adapted for use in summer by shifting the precipitation pattern about one

quarter wave-length westward relative to the contour pattern. This model was designed for the eastern United States, and though it seems to be reasonably applicable to temperate regions where adequate sources of moisture lie to the south, it is definitely not applicable to regions where orographic factors are important or to regions where a moisture source is not readily available. Attempts were made to relate objectively the broad-scale features of monthly mean 700-mb. charts to monthly precipitation during the winter months. The United States was divided into 21 reasonably homogeneous climatological areas, and the object was to find, for each area, parameters which could be used in forecasting precipitation. The application of these objective methods is limited and the results are rather disappointing. Use is therefore made of other reasoning and tools in forecasting precipitation. Most of these lie in the realm of experience and general meteorological knowledge. However as Namias states—at present only thick and coarse brush strokes can be applied in forecasting precipitation.

Attempts to follow development on the 30-day mean charts and to produce such forecast charts are obviously based on the assumption that there is continuity from map to map. It is impossible to advance a proof of the reality of this continuity but, according to Namias, certain facts point to its existence. Work on 30-day mean charts has now been going on for 10 yr., and for 90 per cent. of the time different analysts agree on the continuity. Perhaps it is also significant that Rossby's vorticity and wave-length concepts may be applied, at least qualitatively, with some success to mean maps.

The supposition concerning the development or evolution of long-period circulations advanced by Namias is called "the self-development hypothesis". Briefly this contends that the underlying reason for changes in large-scale patterns of the general circulation lies in seasonal variation of insolation. This variation results in changing the location and strength of important heat sources and sinks near the earth's surface, which in turn impose changes in the pressure pattern. The imposed changes may or may not be in harmony with the flux of vorticity and, if not, the atmosphere attempts to re-arrange itself. The problem is simplified by breaking it down into two steps. First, an attempt to approximate the effect of differential heating incident to seasonal change is made by applying the normal month-to-month 700-mb. height changes to an observed 30-day mean 700-mb. chart. The resulting pattern is called the "first-approximation chart". Secondly, the new artificial pattern must be re-arranged by deciding which ridges and troughs of the large-scale circulation are compatible in terms of wave-length and vorticity flux. In practice the procedure adopted in producing forecast 30-day mean charts is to introduce 10-day height tendencies. These automatically incorporate the normal change of height, and in addition permit displacement computations which make it possible to consider the development of the pattern during the month.

Methods of determining tendencies and trends are based on the fact that statistical estimates of future values of pressure at a point may be made by combining past values with the appropriate normal for the place and time of the year. On this basis a series of regression equations are derived for calculating the following 700-mb. height tendencies and trends:—

"Instantaneous" 10-day tendency

Half-month trend height (this is used to plot the 30-day mean chart centres around forecast day—the half-month trend chart)

Trend tendency (this is the 10-day tendency centred around the half-month trend chart)

Projected tendency.

The instantaneous tendencies are superimposed on the latest 30-day mean chart, and kinematic computations of 30-day displacement of troughs, ridges and centres are made in a manner similar to those made on daily maps when 3-hr. tendencies are used. The trend tendencies are superimposed on the half-month trend chart and 15-day displacement computations are made. In general the projected tendencies are only used qualitatively. Therefore there are available three tendency fields, two sets of displacement computations and the first approximation chart. At times all indications point in the same direction but they often differ and even conflict. When contradictions arise the forecaster must weigh the different indications carefully and give greater weight to the computations which look more promising and which line up with other more physical clues. The forecasts can be improved by introducing physical considerations. The procedure adopted is that if there is no dynamic conflict, then promising kinematic computations are followed. The methods of determining whether dynamic conflict exists are based mainly upon vorticity and wave-length considerations. Constant-absolute-vorticity trajectories or paths are used to estimate the influence of one component of the planetary wave train upon others and to provide a check on the internal consistency of the forecast circulation pattern. Reflection suggests that, if the vorticity concept is to be applied to 30-day mean charts, some account should be first taken of other factors, presumably thermal, which might also bring about important changes. With this in mind, constant-absolute-vorticity paths are applied not to the last observed 30-day mean map, but to the half-month trend and first-approximation charts.

In the American experiment, considerable time was devoted to the problem of verification of 30-day forecasts. The forecasts of temperature and precipitation show some skill but the success achieved is small.

*Mr. Craddock* dealt with some of the work being done in the Long-Range Forecasting Research Branch at Dunstable. Their first aim is to examine the anomalies of the weather elements, temperature, rainfall and sunshine, and see whether they can be forecast. The work commenced with a study of temperature. Mean daily temperature data for several stations are averaged for non-overlapping periods of 5 days and then a harmonic analysis is made with basic period one year. Only two harmonic terms are required to give an extremely close fit to the observed values. The stations cover a wide climatic range so it seems that the annually recurring part of the temperature variation is adequately represented by a harmonic curve with only two terms. On examining the residual deviations between the harmonic curve and the observed 5-day means it appears that some of the deviations may be genuine singularities. However they are certainly small, and the best-fitting two-term harmonic curve gives a good approximation to the normal temperature. When the observed 5-day mean temperatures for any station are superimposed on the two-term harmonic normal, it is observed that the anomalies often persist for quite a time (for example up to 20 days) but they often change sign at intervals of only 5 days. It appears that the average 5-day mean temperature anomaly lasts for about 14 days, and that anomalies are likely to last longer in winter than in summer. *Mr. Craddock* said that this made him very

doubtful about Namias's 30-day means as a tool for long-range temperature forecasts. Averages over a period of 30 days would smooth out most of the significant temperature anomalies.

*Dr. Forsdyke* described work, carried out in the Forecasting Research Division at Dunstable, on the 1000–500-mb. thickness averaged over large areas. Such an average is referred to as an “area-mean thickness”. The areas concerned are of, at least, continental dimensions. The parameter considered is the area-mean thickness anomaly (denoted by  $\bar{H}$ ), which for any day is the algebraic difference between running 5-day and 30-day mean values. Curves were shown of the variation of  $\bar{H}$ , for the 12 months July 1950 to June 1951, in a number of sectors of the northern hemisphere. All the curves exhibit, to a greater or lesser degree, wave-like fluctuations having “periods” varying between about two and five weeks. In the sector from 120°W. to 60°E. and north of 30°N., i.e. a quarter of the northern hemisphere, the range of fluctuations in  $\bar{H}$  is about 200 ft. Assuming a mean thickness of 18,000 ft. over the area, this implies a fluctuation of about 3°C. in the average temperature of the lower and middle troposphere over the whole area. The main interest in these fluctuations lies in their possible causes and their connexions with the general atmospheric circulation. Their introduction into the discussion is justified if they have any bearing on the problem of forecasting. It is evident that they have some connexion with surface patterns. A large negative anomaly in  $\bar{H}$  obviously implies the mean thermal gradient and depression tracks being displaced southward of their normal positions with cold weather in middle latitudes. A large positive anomaly in  $\bar{H}$  implies warm weather in middle latitudes with depression tracks well to the north. The fact that the “period” of these fluctuations is of the order of a few weeks suggests that their possible application is to extended rather than to short-range forecasting.

The most interesting curves of  $\bar{H}$  are those for North America, the Atlantic Ocean and Europe. For the North American sector, the fluctuations are large in amplitude, the maximum overall range being nearly 500 ft., and they are also notably regular. Therefore these fluctuations may constitute a useful aid in forecasting for periods up to a few weeks over North America. For the Atlantic and European sectors, the fluctuations are less marked and less regular and appear to have little forecasting value. There is some suggestion that large anomalies of  $\bar{H}$  over North America tend to be reproduced in the Atlantic after a lag of about 5–7 days. A smaller and less marked west-to-east propagation is apparent between the Atlantic and European sectors. It is considered that this may have some significance in forecasting for periods up to about a week.

*Mr. Lawrence* said that Namias uses mainly synoptic methods, and there are many instances when the non-synoptic approach would produce greater accuracy than that claimed by Namias. Mr. Lawrence went on to discuss a few examples of non-synoptic methods. Baur's data<sup>2</sup> showed a close relationship between mild early Decembers and above-average temperatures during January–February in central Europe. This persistence of mild weather may be explained by the absence of extensive snow-cover in mid December. A good correlation exists also between March fogs and May frosts in south-east England<sup>3</sup>. A foggy March is associated with an anticyclonic type which may persist until or recur in May. Further, an anticyclonic March is a drying March, and, especially if this anticyclonic tendency persists, there will be an

increase in the May frost liability because of changes in thermal capacity, conductivity, porosity, etc., of the soil. Many medium-range forecasting rules could be derived from Brooks and Belasco's work on "Annual recurrences of weather: singularities"<sup>4</sup>. For example, they give the mean dates of the summer monsoon in Europe as June 1-21, the latter being partly confirmed by Lamb<sup>5</sup> who gives June 17-18 as a date of seasonal discontinuity. The following figures which were produced by Jenkinson show as a practical rule that wet early Junes tend to be followed by dry or fairly dry late Junes. The years quoted are all those with ten or more days of at least 1 mm. rainfall during June 1-18.

	Number of days with rainfall $\geq$ 1 mm. at Kew (1903-1952)						
	1903	1905	1912	1924	1926	1935	1946
June 1-18	10	10	12	11	11	13	12
June 19-30	1	4	4	0	0	1	3

An illustration of the value of the physical-climatological approach is afforded by this year's abnormal summer. The mean pressure chart for May 1954 shows an anomaly of up to + 8 mb. in the region from Greenland to Scandinavia and a small negative anomaly in the south of Europe leading to an abnormal easterly wind component across Europe during May. Mr. Lawrence considered that this easterly wind component, plus other drying factors including the mild winter period with its deficiency of snow, resulted in a vast continental soil moisture deficit by the end of May. The presence of an unusually intense reservoir of cold air to the north of Europe together with abnormally dry conditions in Europe may be critical factors in causing a particularly intense or prolonged summer monsoon in Europe. This is borne out by subsequent pressure, temperature and rainfall anomalies, particularly the wet June of 1954 in Great Britain.

*Mr. Gilchrist* stated that he was not convinced that 30-day mean charts had the prognostic value claimed by Namias, and he considered that the persistence of monthly anomalies coupled with forecasting experience accounted for the success achieved.

*Mr. Gordon* drew attention to the importance of the physical-climatological process in relation to the construction of prognostic 30-day mean pressure patterns. Substantial changes in mean climatological conditions occur during the course of a month. Seasonal variations in the strength and distribution of insolation over the globe cause the seasonal variations in the mean-pressure patterns, and it is from these mean-pressure patterns that we deduce information concerning weather conditions. There is a cause-and-effect relation between thermal and kinetic processes about which we must learn more, even though the mechanism of interaction may be very intricate and complex. Mr. Gordon showed a slide indicating the change in mean pressure distribution over the world from April to May. The fall in mean pressure over Asia appears to be balanced in part by a rise over the North Atlantic and Scandinavia. Should conditions in one part of the globe be substantially different from normal then anomalous effects may be produced elsewhere at a later time. It is only by a fuller understanding of the mechanism of interaction of this kind that we may be able to predict mean 30-day patterns.

*Mr. Jenkinson* stated that short or medium spells of weather up to, say, 5-8 days show persistence but that long spells of 15-30 days nearly always show



“anti-persistence”. The physical meaning of this is that there are two different régimes which bring about short and long spells of weather. Hence it is not to be expected that the method of forecasting short spells, i.e. the synoptic method, would have any success at all with long spells. Mr. Jenkinson did not agree with Mr. Craddock that, since meaning over 30 days smooths out so many differences within the period it is preferable to use a short period such as 5 days. The weather of the past summer showed that long periods of anomalous weather, although they might not occur very often, were of great importance and periods of 30 days are worthy of study.

*Mr. Sawyer* said that from reading Namias’s paper it is not at all clear which of the forecasting tools described really contributed to the small degree of success apparently achieved. Perhaps the most important factor is the persistence of anomalies of 700-mb. height, although the use of constant-vorticity trajectories probably plays a part by ensuring that the flow on the forecast mean chart is self-consistent. The difficulty in interpreting Namias’s work indicates that in any further experiments of this nature strict control and testing of methods should be employed. It may be that greater success would be achieved by studying the anomaly patterns of rainfall and temperature and trying to forecast them direct, rather than introducing the flow pattern as an intermediate stage in the forecasting procedure.

*Mr. Gold* said that the application of synoptic methods to long-range forecasting is not likely to lead to success. It is impossible to produce a 30-day forecast from a knowledge of the situation on the first day. A better method of attack is to use long-term climatological variables such as snow-cover over Siberia or icebergs off Greenland.

*The Director*, in summing up, pointed to the great variation that existed in the forecasting accuracy achieved by Namias. He said that it would appear that, at present, there is no sound basis for long-period forecasting, but this does not mean that efforts to find such a basis should be discouraged.

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#### OFFICIAL PUBLICATION

The following publication has recently been issued:—

*Annual Report of the Director of the Meteorological Office*, presented by the Meteorological Committee to the Secretary of State for Air, for the year April 1, 1953, to March 31, 1954.

This Annual Report for April 1953 to March 1954 covers the year during which Dr. O. G. Sutton F.R.S. succeeded the late Sir Nelson Johnson K.C.B. as Director. It describes the organization required to provide meteorological services for aviation, the Services, various Government Departments and public utilities and for the general public.

An account of the research carried out during the year indicates the widespread nature of the investigations and the increasing importance attached to this side of the work of the Office. Use was made of the aircraft of the Meteorological Research Flight in work on cloud physics, for instance, and the development of a radar theodolite for upper air measurements reached an advanced stage. Encouraging results are reported from experiments using electronic machinery to compute future weather situations.

The introduction in January of television forecasts presented by a forecaster aroused considerable public interest. Plans to improve the sound-radio service are also in hand.

One of the four teleprinter channels used by the Meteorological Service now gives a continuous broadcast of weather observations to nearly 200 of its stations. In this connexion it is noted that trials are being extended in the use of facsimile transmission by which weather charts and diagrams are broadcast by radio.

### ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on October 20, 1954, the President, Dr. O. G. Sutton, in the Chair, the following papers were read:—

*McCormick, R. A.—The partition and intensity of eddy energy at the 91-metre level during unstable conditions as observed at Brookhaven National Laboratory\**

Mr. McCormick's paper was presented by Mr. H. Charnock. Investigators working at heights up to a few metres have shown that there is more energy in the horizontal turbulent movements than in the vertical ones with a tendency for more equal sharing at greater heights. McCormick's primary aim was to investigate the sharing at a greater height (91 m.) than previously used. The subject is of practical importance in the diffusion of pollution from chimneys. He took measurements of wind over 10-sec. intervals and subtracted them from the mean wind in the usual way to obtain the three components of turbulent motion. The squares of the turbulent components were summed to obtain a measure of the energy of turbulence, and a method of moving averages, due to Panofsky, used to find the energy associated with eddies of short period (20 sec. to 2.5 min.) medium period (2.5 min. to 17 min.) and long period (17 min. to 57 or 114 min.). It was found that the fraction of the total energy associated with turbulence in the vertical direction did decrease with period, which might be expected if it is supposed that the longer-period eddies are physically larger ones and more affected by the proximity of the ground. Values of Richardson's expression for the rate of change of turbulent energy as a function of the rate of change of wind speed with height and the lapse rate of temperature were computed and compared with the total turbulent energy; the two were found to be proportional with complications depending on whether the previous air trajectory had been over land or sea. Little correlation was found between the intensity of turbulence and the lapse rate of temperature. The Reynolds stress associated with the turbulent motions and also the eddy viscosity were computed, and it was found that the eddy viscosity increased with lapse rate in unstable air.

Among the points raised in the course of the discussion were the validity of supposing the energy summed over longer periods was associated with physically larger eddies, the logical connexion between the supply of turbulent energy supposed given by Richardson's formulae and the amount of energy at any one time, and the validity of the assumptions on the rate of change of wind with height.

*Scrase, F. J.—Turbulence in the upper air, as shown by radar-wind and radiosonde measurements†*

Dr. Scrase took the radio-sonde and radar wind ascent made at Downham Market on the evening of June 29, 1949, to a height of 31 Km. He plotted mean curves of the displacements of the balloon in the west-to-east, south-to-north and vertical directions and of temperature and calculated the deviations at one-minute intervals of the corresponding components of velocity and values of temperature. The random errors as estimated by Harrison were allowed for. The calculations showed that the standard deviation of horizontal wind in the troposphere was about 10 per cent. of the mean wind, but in the stratosphere it appeared to increase to about twice as much. The standard deviations were about twice the random error. The mean vertical wind fluctuation was about 1 kt. in the troposphere and increased to 2 kt. towards the top of the ascent. The maximum minute-to-minute velocities were about 15 kt. in the horizontal and

\* *Quart. J. R. met. Soc., London*, **80**, 1954, p. 359.

† *Quart. J. R. met. Soc., London*, **80**, 1954, p. 369.

8 kt. in the vertical and occurred between 30,000 and 60,000 ft. The periodicity of the fluctuations of all wind components and of temperature was 3–4 min. The fluctuations were of the same order of magnitude as those found by Durst and other workers with different methods. In the troposphere the corrected standard deviation of the temperature fluctuations was  $0.85^{\circ}\text{F.}$ , in the lower stratosphere  $0.64^{\circ}\text{F.}$  and in the upper stratosphere  $0.29^{\circ}\text{F.}$  With the latest radar-sonde theodolite system more accurate measurements should be possible.

The discussion on Dr. Scrase's paper was concerned mainly with the increase with height of the fluctuations of wind which was unexpected by some speakers.

*Jones, R. F.—Five flights through a thunderstorm belt\**

Mr. R. F. Jones described the observations of the vertical accelerations of a Meteor aircraft flying through a belt of thunderstorms on June 13, 1952. The data available covered vertical accelerations of the aircraft, altimeter readings, and indicated airspeeds and air temperatures at 10-sec. intervals, a record of the comments of an observer and radar-echo cross-sections of the cloud. The principal features of the results were

(i) a large increase in frequency and intensity of gusts in the cloud

(ii) the existence of up-currents and down-currents of the order of 20–30 ft./sec. within a horizontal distance of 750 yd.

Down-currents approaching 20 ft./sec. were observed outside the cloud but up-currents of that speed were found only inside. Mean temperatures in the clouds were a little higher than outside. The lapse-rate in the clouds was very close to the saturated-adiabatic value, but outside the lapse-rate was less than that value.

The discussion dealt with the principles of interpretation of the records of aircraft accelerometers and the deduction from them of vertical wind speeds.

## LETTER TO THE EDITOR

### Patterns in very thin stratus

The lower photograph facing p. 17 is of a pen-and-wash sketch of patterns observed in very thin stratus over Pyrford (West Byfleet), Surrey at about 0830 G.M.T. on April 21, 1954. The patterns, as a whole, subtended an angle of about  $120^{\circ}$  azimuth; the horizontal centre line was at an angle of elevation of about  $35^{\circ}$ . The sketch was made as the patterns moved across the sky to the north of the observer, and has been somewhat condensed, the space between the patterns having been reduced at the pecked lines without distortion of the patterns themselves.

The centre pattern indicated that the stratus sheet, estimated to be at about 5,000 ft., had been "whipped down" some hundreds of feet to produce a well defined inverted ridge, orientated roughly north-south. This phenomenon was most striking since it was the only disturbance in a cloud base of remarkable evenness. The pattern was perhaps about a mile long, and moved without any major change in its structure from east to west until out of sight beyond trees.

The other two patterns, AA' and BB' represent two clear lanes in the cloud sheet, except that down the centre of each was a band of stratus. From each side of these lanes there extended the clearances resembling ribs (in the sketch the clear lanes are shown black). The cloud between the ribs showed signs of turbulence, most marked nearest to the parent lane, and it resembled very flattened stratocumulus rolls. The angle between these ribs and the parent lane remained reasonably constant, so that when the parent lane curved, the ribs followed it.

The pattern BB' was seen to be caused by a twin-jet aircraft (thought to be a Canberra) which was flying beneath the thin cloud sheet, banking slightly to port. The aircraft did not apparently enter the cloud at any time, and

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\* *Quart. J. R. met. Soc., London, 80, 1954, p. 377.*

certainly did not climb through it to disappear. The ribs from that lane are therefore in a swept-back design relative to the aircraft movement. The parent lane was formed first, but the rib patterns followed only a few seconds later taking a couple of minutes or so to reach their maximum. The pattern became rather disturbed with the passage of time, generally filling up with stratus by the time it disappeared from view. It is reasonable to assume that the pattern AA' was similarly formed some few minutes (or even seconds) before.

The main airflow at the time at about 5,000 ft. over Pyrford was from  $70^{\circ}$ - $90^{\circ}$  (0800 G.M.T. ascent from Crawley). The upper wind is shown on the hodograph in Fig. 1. No temperature measurement was made at 0800 at Crawley, but the 0200 ascent (Fig. 2, with its wind observations also in Fig. 1) indicates an inversion at the 5,000-ft. level.

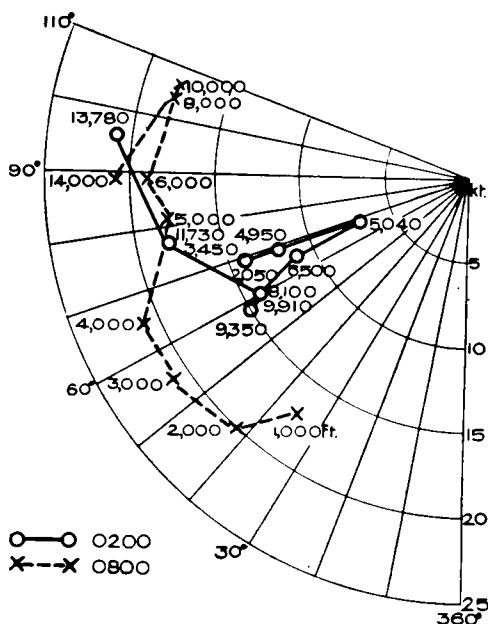


FIG. 1—HODOGRAPH OF UPPER WIND AT CRAWLEY, 0800 G.M.T.

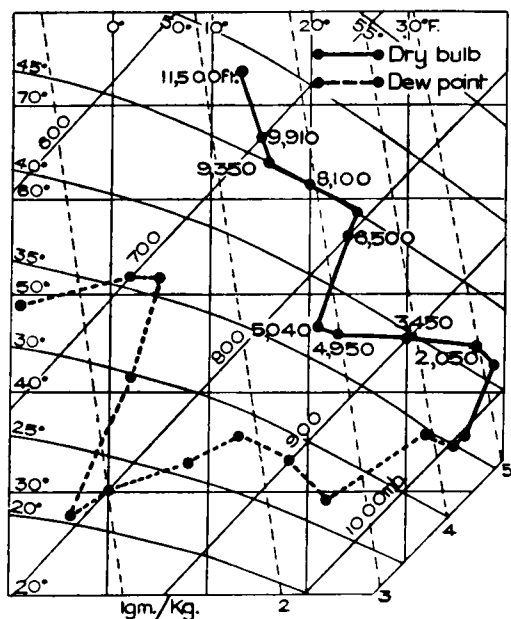


FIG. 2—TEPHIGRAM OF RADIO-SONDE ASCENT AT CRAWLEY, 0800 G.M.T.

It will be seen from Fig. 1 that the wind direction at that height had remained more or less unchanged although it had increased slightly in speed since 0200. The general shear (in the vertical plane) had, however, changed considerably, from the reversal ( $250^{\circ}$  to  $60^{\circ}$ ) at 0200 to the steady southerly up to 10,000 ft. at 0800. The inverted ridge pattern was therefore at right angles to the wind direction, and, assuming the 0800 upper wind to be the more representative, along the shear in the vertical plane. The phenomenon was so local, however, that it is probable that the wind structure as indicated by either ascent from Crawley is not really representative.

The lane patterns with a centre band of cloud bear some resemblance to those seen by the writer at Farnborough in 1948 (independently reported by R. M. Poulter\*), when a clear lane was seen cut in a sheet of altocumulus translucidus, with a cirriform band down the middle. The present author,

\* POULTER, R. M.; Man-made cirrus? *Weather, London*, 3, 1948, p. 232.

whilst agreeing that the 1948 centre band appeared to be cirriform, does not think that the band was cirriform on this recent occasion, it being of the same texture and apparent thickness as the main stratus sheet. No ribbing effect was seen in 1948, although the altocumulus sheet did become "eaten away" with time.

*Harrow, September 28, 1954.*

K. E. WOODLEY

## REVIEWS

*Theoretische Hydromechanik. Band I.* By N. J. Kotschin, I. A. Kibel and N. W. Rose. Translated from the Russian by J. Sauer and technically edited by K. Krienes.  $9\frac{1}{4}$  in.  $\times$   $6\frac{3}{4}$  in., pp. xii + 508, *Illus.*, Akademie-Verlag, Berlin, 1954. Price: DM 45.

This is the first part of what is evidently a standard Russian text on fluid mechanics (the translation is from the 4th Russian edition). In general, because of the language difficulty, Russian technical works are not well known among western scientists and for this reason alone the present volume arouses interest. But it has more claims on our attention than that.

During the early years of the present century the study of fluid motion was dominated by one outstanding work, Lamb's "Hydrodynamics". In some ways this was unfortunate, because Lamb's massive treatise is essentially a work for mathematicians, and many must have turned away from the subject in despair because of the severity of the style and the abstract nature of the results. The "Hydrodynamics", in fact, is almost as much pure mathematics as applied, and it was only when the aircraft designer began to make his needs felt that the emphasis changed. There is a radical difference of outlook between Lamb's monumental work and later treatises, such as Goldstein's "Modern developments in fluid dynamics" or Prandtl's "Strömungslehre".

The present volume invites comparison with that of Lamb in that it deals exclusively with the motion of an inviscid fluid, but the influence of later developments is very evident in the Russian work. The list of chapter headings indicates familiar ground: irrotational motion, hydrostatics, vortices, the motion of bodies through ideal fluids, and waves. It would be asking for the impossible to demand real novelty of treatment in such well explored fields, and the book must be judged mainly on the clarity of the presentation and the way in which the material has been selected.

The book succeeds on both counts. It is a reliable succinct account of the development of the ideal fluid theory. The book can be read by anyone possessing reasonable mathematical skill, and in all respects it represents an admirable synthesis of classical rigour and modern realism. It contains all that is essential and much of what is lacking in Lamb (e.g. two-dimensional aerofoil theory). Meteorologists will feel at home in encountering the words "barotropic" and "baroclinic" at an early stage, and at least one section—that dealing with waves in a zonal west-east current on a rotating earth—is of direct interest, since this study forms the basis of numerical forecasting as it is practised today.

In short, this book (which might be described as "Lamb in modern dress") is to be recommended whole-heartedly as an excellent account of the essentials of the dynamics of an ideal fluid. If the second volume, dealing with real fluids, is as good as this, the whole text will form a first-rate reference work for all who come in contact with this difficult branch of mathematical physics.

O. G. SUTTON

*Tropical meteorology.* By H. Riehl. 9½ in. × 6¼ in., pp. x + 392, *Illus.*, McGraw-Hill Book Company, Inc., New York, Toronto and London, 1954. Price: 61s. or \$7.00.

The Second World War 1939–45 led to a greatly increased demand for meteorological information in the tropical regions. Tropical meteorological services, which had mostly been concerned with the recording and study of climatic data for limited and detached areas, were suddenly faced with demands for forecasts and climatological information for areas extending far outside their own territories—areas which often were meteorologically unexplored. The main interest shifted from climatological tables for individual stations to synoptic charts for large areas. The belligerent nations reinforced the tropical meteorological services with personnel steeped in the methods of temperate-latitude forecasting and eager to apply them in the tropics. The early enthusiasm was shown by the spate of writings on tropical forecasting in the latter part of the war and the early years of peace. Most of these writings did not get beyond the typescript stage, and are now forgotten. The synoptic models of temperate latitudes became strained and emaciated in these attempts made to adapt them to the tropics. The appearance of Professor Riehl's textbook is therefore especially welcome. It is refreshingly definite on a hitherto woolly subject; within the limits of present knowledge it succeeds in fitting the tropical atmosphere into the general picture of the global circulation; and it is convincing because, in the main, it deals with fact and not conjecture.

General pictures of the distribution of pressure and wind, temperature, and rainfall, are presented in the first three chapters. They are treated mainly on the basis of monthly, seasonal or yearly means, and are illustrated by many charts and cross-sectional diagrams. With their wealth of facts, coherently assembled, they give the reader insight into the underlying pattern of the tropical circulation. For emphasis of certain features detailed climatological tables and diagrams are given for a few individual stations, and these fit smoothly into the text, reinforcing the main arguments.

Chapter 4 is concerned with diurnal and local effects. While giving due weight to the undoubted rhythm of day-to-day weather in the tropics, this chapter, as well as its predecessors, does bring out the irregular variations due to atmospheric disturbances, which give rise to the more difficult problems of tropical forecasting.

Convection, the principal rain and cloud-forming process in the tropics, is given a general treatment for the most part. But where reference is made to low latitudes the importance of the lower moist layer and the overlying dry air is fully brought out. The depths of these layers now, quite rightly, have the status of synoptic parameters. The chapter on convection leads naturally to one on the physics of rainfall. This is a valuable contribution by R. Wexler, but it deals with general aspects of rainfall and its title, suggesting a special discussion of tropical rainfall, seems a little misleading.

For synoptic meteorologists the most interesting part of the book is contained in the next five chapters. Chapter 7 deals with the techniques of observation and analysis in the tropics and brings out the point, familiar to all with tropical experience, that there is little or no coherence in the synoptic surface and upper air charts of very low latitudes. Other synoptic aids are discussed,

such as stream-line charts and, for short-period forecasting, station-circle analysis, i.e. the detailed pictorial representation at short time intervals of the distribution of cloud and weather within about 50 miles of the station.

Chapter 8 deals with the approximate dynamics of the air flow, based on the vorticity-divergence equation and its results are freely used in the following three chapters on synoptic models. In dealing with the frontal models—easterly waves, the equatorial trough and minor types of low-latitude disturbances—the author avoids being carried away by the uncritical enthusiasm for fronts not unknown among synopticians. Careful consideration of the facts and their dynamical implications lead to convincing pictures of the structure of fronts, but no attempt is made to classify them rigidly. One suspects, however, that the examples were chosen because they fit the models well. The practising forecaster will often be confronted with situations in which the frontal characteristics are too vague to be recognized. In this part of the book one would like to have seen one or two typical chart sequences with specimen forecasts prepared from them.

Chapter 11 is a long, interesting and thorough discussion of tropical storms. It concentrates on their probable internal mechanism rather than their easily observable characteristics so often described already. The results obtained from aircraft sorties into storms and radar detection of their cloud and rainfall structure make this chapter a most vivid one.

The book ends with a brief discussion of the general circulation of the atmosphere, a useful and readable survey of a problem on which much work has still to be done.

In the reviewer's opinion this is the best work on tropical meteorology yet published. It is written in an easy style but is full of information without padding. To read it properly requires concentration and effort which however are well worth while. The book is lavishly illustrated with neat, well produced diagrams. One does however wish that some of the charts could be made a little clearer by stippling the land areas and adding a few more lines of latitude and longitude; but these omissions are only minor shortcomings in a volume whose excellent content is matched by its high standard of production.

A. G. FORSDYKE

## OBITUARIES

*Mr. Albert Edwin Cowlard.*—It is with deep regret that we learn of the death of Mr. A. E. Cowlard, Experimental Officer, on November 11, 1954, after a long and painful illness, at the age of 57. Mr. Cowlard served through the whole of the 1914–18 war and was severely wounded in the chest. He joined the Meteorological Office in 1925, in the British Rainfall Organization and British Climatological Branch. In the period 1925–39 he dealt with the monthly climatological and rainfall returns, displaying a cheerful and sympathetic understanding of difficulties experienced by the observers. He was transferred to the Instruments Branch in December 1939, was assimilated as Experimental Officer in 1946 and for the last twelve years was Stores Officer in the Instruments Provisioning Branch. In this capacity he was in charge of the storage and issue of equipment, packing and despatch, a position which calls for exceptional qualities of integrity, tact and skill in handling a large

industrial staff, and loyalty and helpfulness to his colleagues in other sections of the Instruments Division. Cowlard possessed these qualities in full measure.

In his younger days Mr. Cowlard was a keen player of tennis, football and cricket and played for the Meteorological Office at the last two. He retained interest in sport until the last. As already stated, the keynotes of Cowlard's character were integrity, loyalty and helpfulness to others, and these expressed themselves in many activities outside his normal duties. For many years he was Treasurer to the Harrow Office Canteen, combining this with a great deal of wise counsels. He was one of the A.R.P. wardens at Stonehouse, Gloucestershire, where the Instruments Branch was stationed during the war, and was a keen member of the British Legion at Worcester Park, on whose behalf he organized the Poppy-Day Collections.

He is survived by a widow and two sons to whom the sympathy of all who knew him in the Office is extended.

*Mr. Anthony Charles Easterling.*—It is with deep regret that we learn of the death, on November 27, of Mr. A. C. Easterling, Scientific Assistant, at the early age of 23 years, after a short illness.

Mr. Easterling joined the Office as a Meteorological Assistant in August 1949, and after training was posted to Exeter where he remained till 1951 except for a short temporary posting to the Central Forecasting Office. In January 1953 he was posted to the Instruments Division, Harrow, and worked on radio-sonde calibration and in the Test Room. He was established as Scientific Assistant in July 1953, and confirmed in this appointment a year later. Mr. Easterling had a lovable character; he was gentle in his ways but firm in what he knew to be right, and he won the affection and respect of all his colleagues at Harrow. Our sympathy is extended to his parents and sister in their great loss.

### METEOROLOGICAL OFFICE NEWS

**Retirement.**—Mr. P. R. Zealley, Senior Assistant (Scientific) retired on October 4, 1954. He joined the Office in 1919 after service in the Royal Fusiliers during the First World War. The greater part of his 35 years in the Office was spent at aviation outstations and included a tour of duty in the Middle East. From 1946 until his retirement he served at Headquarters in the British Climatology Branch at Harrow. Mr. Zealley has accepted a temporary appointment in the Meteorological Office.

**Academic success.**—In June 1954, whilst serving at Mauripur, Senior Aircraftman D. S. Reed passed the Intermediate Examination for B.Sc. in pure and applied mathematics.

**Courses of training for climatological observers.**—Two courses, each lasting four and a half days, were held in October 1954 at the Meteorological Office Training School, Stanmore, and were attended by 31 climatological observers. Talks covered the making and recording of observations, and the lay-out, care and maintenance of instruments; special attention was given to the work at crop-weather and health-resort stations. Visits were made to the Public Services Branch at Victory House, Kingsway, and to the British Climatology and Instruments Branches at Harrow. An incidental advantage of these courses is that they afford an opportunity for observers to get to know one another and the staff of the Meteorological Office. It is hoped to arrange a similar course in October 1955.



## WEATHER OF NOVEMBER 1954

The mean pressure distribution showed a depression of depth 988 mb. centred south-west of Iceland with a pressure gradient associated with south-westerly winds over western Europe. The mean pressure was as much as 12 mb. below normal over the Iceland region and it was above normal over central Europe and Scandinavia; over the northern part of the latter region the excess was 10 mb. in places. The mean pressure over the United States was fairly uniform between 1016 and 1020 mb.

Mean temperature over western Europe was generally 3–4°F. above normal, consistent with the pressure gradient. Mean temperature over most of the United States was also above normal, as much as 10°F. in places in the north-western States.

In the British Isles the weather was wet generally and somewhat milder than is usual in November. The most noteworthy features of the month were the frequent rains of the last ten days, which caused serious flooding in many parts of the country, and the widespread severe gales from the 26th onward when many ships were wrecked around our coasts.

On the 1st an almost stationary front lay over south-east England maintaining cloudy weather, with slight rain in the south. Meanwhile a ridge off our north-west coasts moved south-east; there were long sunny periods at some places in the north-west on the 1st and locally in the south also on the 2nd in those areas which were free from mist or fog. On the 3rd a trough associated with an Icelandic depression moved south-east over Scotland and later became slow-moving over Wales and central districts of England. On the 4th and 5th wave depressions moved north-east along the front giving considerable rain at times in England and Wales; in Scotland and Northern Ireland rainfall was mainly slight. The trough cleared England and Wales on the 7th. From the 8th to the 12th a pronounced westerly type of weather brought a succession of rain belts; the rain was heavy locally on some days, for example 2·35 in. at Borrowdale, Cumberland on the 8th and 2·02 in. at Dunsop Houses, Yorkshire, on the 11th. On the 11th, a small intense depression, moving quickly east-north-east from the Hebrides to south Norway, brought strong gales to the north of Scotland, with a gust up to 90 kt. in the Orkney Islands, and the resulting high tides in the North Sea caused serious flooding at Hull. On the 14th an anticyclone off our south-west coasts moved in over the British Isles and mainly anticyclonic conditions prevailed over much of the country until the 20th, though frontal troughs continued to affect the west and north to some extent. During this period there was widespread fog, particularly in England and the Glasgow area; fog persisted all day in parts of the Severn Valley, near Liverpool and at Renfrew on the 17th, in English industrial areas and parts of south-east England on the 18th, and locally in east and south-east England and the Midlands on the 19th and 20th. There was frost in many places at night, particularly on the 15th, 17th and 18th. The temperature fell to 21°F. at Shawbury on the 17th and at Elmdon on the 18th. On the 21st the anticyclone was displaced towards the continent and fronts moved slowly eastward across the British Isles. There was heavy rainfall at times, for example, 2·45 in. at Tice airport, 2·22 in. at Treherbert, Glamorgan and 2·05 in. at Princetown, Devon on the 22nd, 2·16 in. at Borrowdale and at Lowery, Dartmoor on the 23rd and 2·00 in. at Cricket St. Thomas, Somerset, on the 25th. From the 25th onwards, a succession of intense depressions moved across or near the British Isles and the whole country was in the path of gales that extended over most of the North Atlantic. Strong gales swept our coasts and many ships were wrecked in their vicinity; on the 27th the tanker *World Concord* broke in two in the Irish Sea, another tanker sank without trace off the Cornish coast and the South Goodwin lightship broke adrift and overturned with the loss of all but one of her crew. In the early hours of the 30th a gust of 93 kt. was registered at Pembroke Dock. There were serious floods in many parts of the country including Cornwall, Devonshire, Wales, north-west England and the Midlands. In the last ten days totals of more than 6 in. of rain were registered at a number of places, among the largest totals being 11·21 in. at Tredegar, Monmouthshire, 11·06 in. at Princetown, 8·70 in. at Ambleside, 8·51 in. at Keswick and 8·10 in. at Moor House, Westmorland.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	64	21	+0·9	190	+5	102
Scotland ...	60	18	—0·1	149	+4	94
Northern Ireland ...	59	24	—0·6	149	+2	89

# RAINFALL OF NOVEMBER 1954

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	3·21	136	<i>Glam.</i>	Cardiff, Penylan ...	8·80	217
<i>Kent</i>	Dover ...	4·91	155	<i>Pemb.</i>	Tenby ...	9·39	216
"	Edenbridge, Falconhurst	5·73	161	<i>Radnor</i>	Tyrmynydd ...	11·87	178
<i>Sussex</i>	Compton, Compton Ho.	6·66	175	<i>Mont.</i>	Lake Vyrnwy ...	11·81	206
"	Worthing, Beach Ho. Pk.	5·18	162	<i>Mer.</i>	Blaenau Festiniog	12·24	115
<i>Hants.</i>	Ventnor Park ...	5·14	169	"	Aberdovey ...	8·16	180
"	Southampton (East Pk.)	5·49	175	<i>Carn.</i>	Llandudno ...	5·55	192
"	South Farnborough ...	4·75	179	<i>Angl.</i>	Llanerchymedd ...	7·35	175
<i>Herts.</i>	Royston, Therfield Rec.	3·74	161	<i>I. Man</i>	Douglas, Borough Cem.	7·47	159
<i>Bucks.</i>	Slough, Upton ...	4·44	200	<i>Wigtown</i>	Newton Stewart ...	8·87	178
<i>Oxford</i>	Oxford, Radcliffe ...	4·41	192	<i>Dumf.</i>	Dumfries, Crichton R.I.	9·49	258
<i>N'hants.</i>	Wellingboro' Swanspool	5·05	235	"	Eskdalemuir Obsy. ...	10·75	185
<i>Essex</i>	Shoeburyness ...	3·18	149	<i>Roxb.</i>	Crailing ...	2·71	114
"	Dovercourt ...	2·50	116	<i>Peebles</i>	Stobo Castle ...	7·25	219
<i>Suffolk</i>	Lowestoft Sec. School ...	4·28	182	<i>Berwick</i>	Marchmont House ...	2·55	85
"	Bury St. Ed., Westley H.	3·91	170	<i>E. Loth.</i>	North Berwick Res. ...	2·01	91
<i>Norfolk</i>	Sandringham Ho. Gdns.	4·60	185	<i>Mid'n.</i>	Edinburgh, Blackf'd. H.	2·84	127
<i>Wilts.</i>	Aldbourne ...	5·99	205	<i>Lanark</i>	Hamilton W. W., T'nhill	6·18	173
<i>Dorset</i>	Creech Grange ...	6·45	157	<i>Ayr</i>	Colmonell, Knockdolian	7·76	156
"	Beaminster, East St. ...	8·25	208	"	Glen Afton, Ayr San. ...	11·35	206
<i>Devon</i>	Teignmouth, Den Gdns.	6·85	214	<i>Renfrew</i>	Greenock, Prospect Hill	9·09	150
"	Ilfracombe ...	8·17	208	<i>Bute</i>	Rothsay, Ardenraig ...	8·77	173
"	Princetown ...	14·76	167	<i>Argyll</i>	Morven, Drimnin ...	9·64	142
<i>Cornwall</i>	Bude, School House ...	6·70	188	"	Poltalloch ...	11·39	203
"	Penzance ...	7·74	169	"	Inveraray Castle ...	12·50	148
"	St. Austell ...	8·20	167	"	Islay, Eallabus ...	10·06	187
"	Scilly, Tresco Abbey ...	6·75	196	"	Tiree ...	8·86	183
<i>Samerset</i>	Taunton ...	6·20	228	<i>Kinross</i>	Loch Leven Sluice ...	5·03	140
<i>Glos.</i>	Cirencester ...	5·96	200	<i>Fife</i>	Leuchars Airfield ...	3·65	159
<i>Salop</i>	Church Stretton ...	6·84	221	<i>Perth</i>	Loch Dhu ...	14·55	167
"	Shrewsbury, Monkmore	4·49	199	"	Crieff, Strathearn Hyd.	7·39	170
<i>Worcs.</i>	Malvern, Free Library...	6·54	250	"	Pitlochry, Fincastle ...	7·43	200
<i>Warwick</i>	Birmingham, Edgbaston	6·30	265	<i>Angus</i>	Montrose, Sunnyside ...	4·79	181
<i>Leics.</i>	Thornton Reservoir ...	5·02	222	<i>Aberd.</i>	Braemar ...	7·12	185
<i>Lincs.</i>	Boston, Skirbeck ...	3·88	194	"	Dyce, Craibstone ...	6·02	185
"	Skegness, Marine Gdns.	3·02	140	"	New Deer School House	5·54	164
<i>Notts.</i>	Mansfield, Carr Bank ...	...	...	<i>Moray</i>	Gordon Castle ...	3·35	116
<i>Derby</i>	Buxton, Terrace Slopes	8·63	184	<i>Nairn</i>	Nairn, Achareidh ...	1·71	76
<i>Ches.</i>	Bidston Observatory ...	5·11	204	<i>Inverness</i>	Loch Ness, Garthbeg ...	4·42	105
"	Manchester, Ringway...	5·04	193	"	Glenquoich ...	13·94	115
<i>Lancs.</i>	Stonyhurst College ...	6·35	141	"	Fort William, Teviot ...	10·61	129
"	Squires Gate ...	6·26	190	"	Skye, Broadford ...	10·55	123
<i>Yorks.</i>	Wakefield, Clarence Pk.	4·11	194	"	Skye, Duntuil ...	8·22	137
"	Hull, Pearson Park ...	4·52	206	<i>R. &amp; C.</i>	Tain, Mayfield ...	3·06	103
"	Felixkirk, Mt. St. John...	4·50	184	"	Inverbroom, Glackour...	5·26	85
"	York Museum ...	4·47	214	"	Achnashellach ...	9·30	108
"	Scarborough ...	4·41	179	<i>Suth.</i>	Lochinver, Bank Ho. ...	5·68	112
"	Middlesbrough ...	3·39	160	<i>Caith.</i>	Wick Airfield ...	4·47	142
"	Baldersdale, Hury Res.	6·90	190	<i>Shetland</i>	Lerwick Observatory ...	6·05	142
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	3·19	136	<i>Ferm.</i>	Crom Castle ...	5·28	152
"	Bellingham, High Green	4·19	122	<i>Armagh</i>	Armagh Observatory ...	4·41	155
"	Lilburn Tower Gdns. ...	4·02	120	<i>Down</i>	Seaforde ...	7·49	198
<i>Cumb.</i>	Geltsdale ...	5·02	153	<i>Antrim</i>	Aldergrove Airfield ...	5·03	155
"	Keswick, High Hill ...	13·22	234	"	Ballymena, Harryville...	5·75	142
"	Ravenglass, The Grove	10·36	232	<i>L'derry</i>	Garvagh, Moneydig ...	5·24	133
<i>Mon.</i>	A'gavenny, Plás Derwen	12·55	300	"	Londonderry, Creggan	4·94	120
<i>Glam.</i>	Ystalyfera, Wern House	13·83	211	<i>Tyrone</i>	Omagh, Edenfel ...	5·19	137

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## RECENT SEASONAL CLIMATIC TRENDS OVER GREAT BRITAIN

By J. GLASSPOOLE, Ph.D.

While the climate of Great Britain has remained substantially the same for a long period, there are definite trends which have persisted with varying intensity and duration. Thus it can be said that our climate does not stand still but is constantly changing. These changes, or trends, become more apparent by considering 10-yr. moving averages which smooth out the variations from year to year. The curves obtained by plotting 10-yr. moving averages show maxima and minima at irregular intervals, and the amplitudes vary as well. The trends are also often different in the various seasons. On the whole the weather of the last 10 yr. was somewhat warmer, wetter and sunnier than usual. Further details of the changes are given below under the elements separately. Details of the preparation of the serial values for England and Wales, and for Scotland, for temperature, sunshine and rainfall are given in the note<sup>1</sup> on new climatological averages for Great Britain and Northern Ireland, published in the *Meteorological Magazine*.

**Temperature at sea level** (Fig. 1).—An outstanding feature of the annual-temperature curves is the increase in the decadal values from 1922–31 to 1929–38, in England and Wales from  $49\cdot5^{\circ}$  to  $50\cdot2^{\circ}\text{F.}$  and in Scotland from  $47\cdot0^{\circ}$  to  $47\cdot7^{\circ}\text{F.}$  This increase of  $0\cdot7^{\circ}\text{F.}$  in annual temperature was due especially to that of the summer, although both the spring and autumn also showed increases; the winters on the other hand became somewhat colder during this period.

It is interesting to note that in Iceland the increase of temperature was earlier and larger<sup>2</sup>. All stations there showed a steady rise of annual temperature of about  $2\cdot2^{\circ}\text{F.}$  from about 1916–25 to 1926–35. The rise of temperature began rather earlier in the north than in the south of Iceland, and was associated with an especially well marked rise of temperature in the winter months.

The two sets of curves for England and Wales and for Scotland show differences but on the whole the trends are very similar. The main features of the general trends over England and Wales are:—

*Spring*.—A steady increase from a minimum in 1923–32 of  $47\cdot0^{\circ}\text{F.}$  to a maximum in 1943–52 of  $49\cdot0^{\circ}\text{F.}$

*Summer*.—A more rapid increase, from a minimum in 1922–31 of  $59\cdot2^{\circ}\text{F.}$  to a maximum in 1932–41 of  $61\cdot0^{\circ}\text{F.}$ , followed by a decrease of temperature.

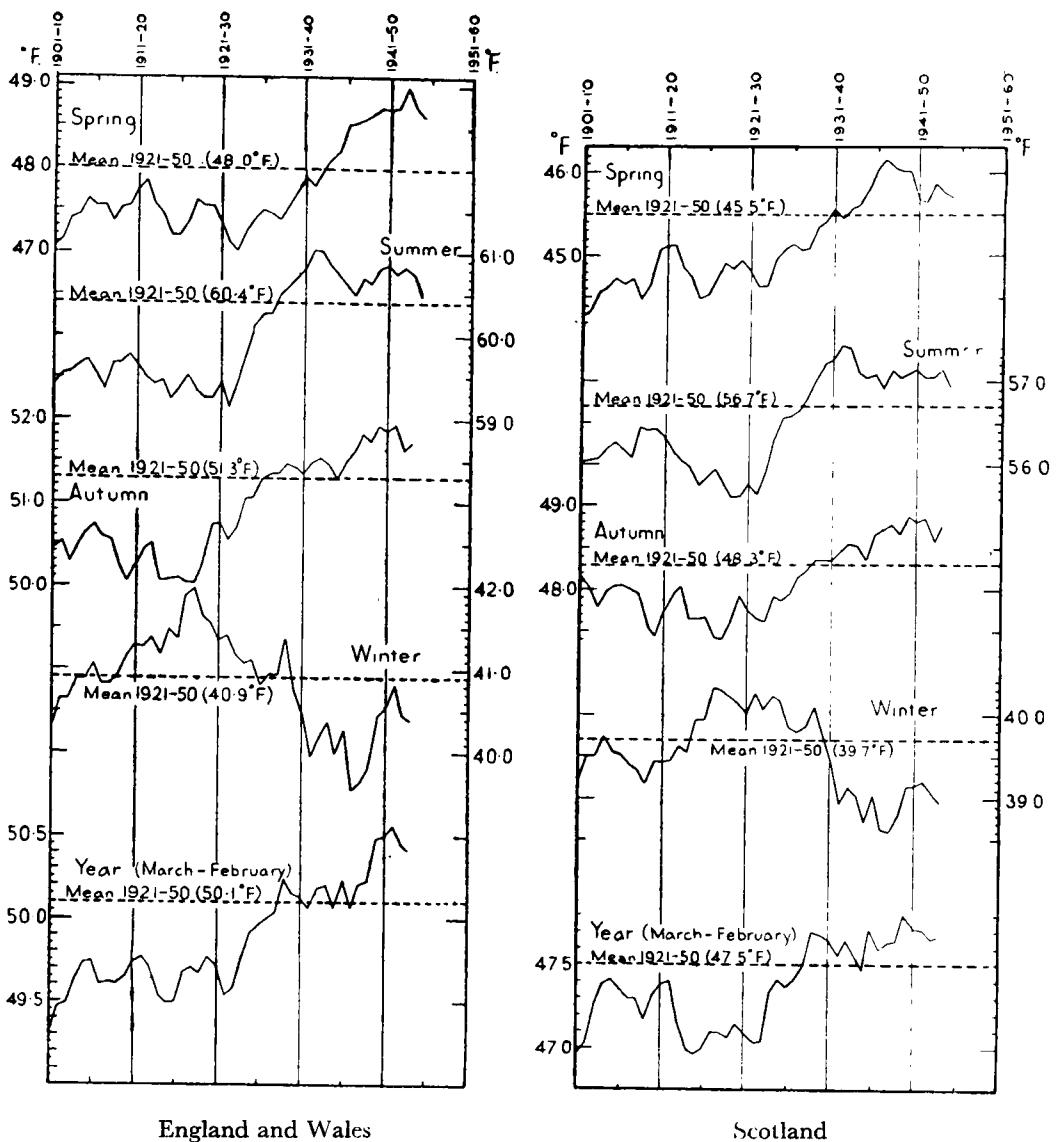


FIG. 1—10-YR. MOVING AVERAGES OF TEMPERATURE

*Autumn.*—A steady increase from a minimum in 1918–27 of 50.0°F. to a maximum in 1942–51 of 51.9°F. The rise in temperature in the autumn started earlier than with the spring or summer and continued for a longer period. The amplitude in all three seasons amounted to about 2°F.

*Winter.*—While the trends shown by the curves for the spring, summer and autumn are similar, the curve for the winter is more nearly a mirror image of the others, especially of that of the autumn. Thus the winter curve shows a general decrease from a maximum in 1918–27 of 42.0°F. to a minimum in 1937–46 of 39.6°F., a range of 2.4°F. This was followed by a rapid increase in the winter temperature until 1942–51 with 40.8°F. The increase in the winter temperature from 1937–46 to 1942–51 was 1.2°F. whereas in the same period the increase in the spring, summer and autumn was much smaller, being 0.2° or 0.3°F.

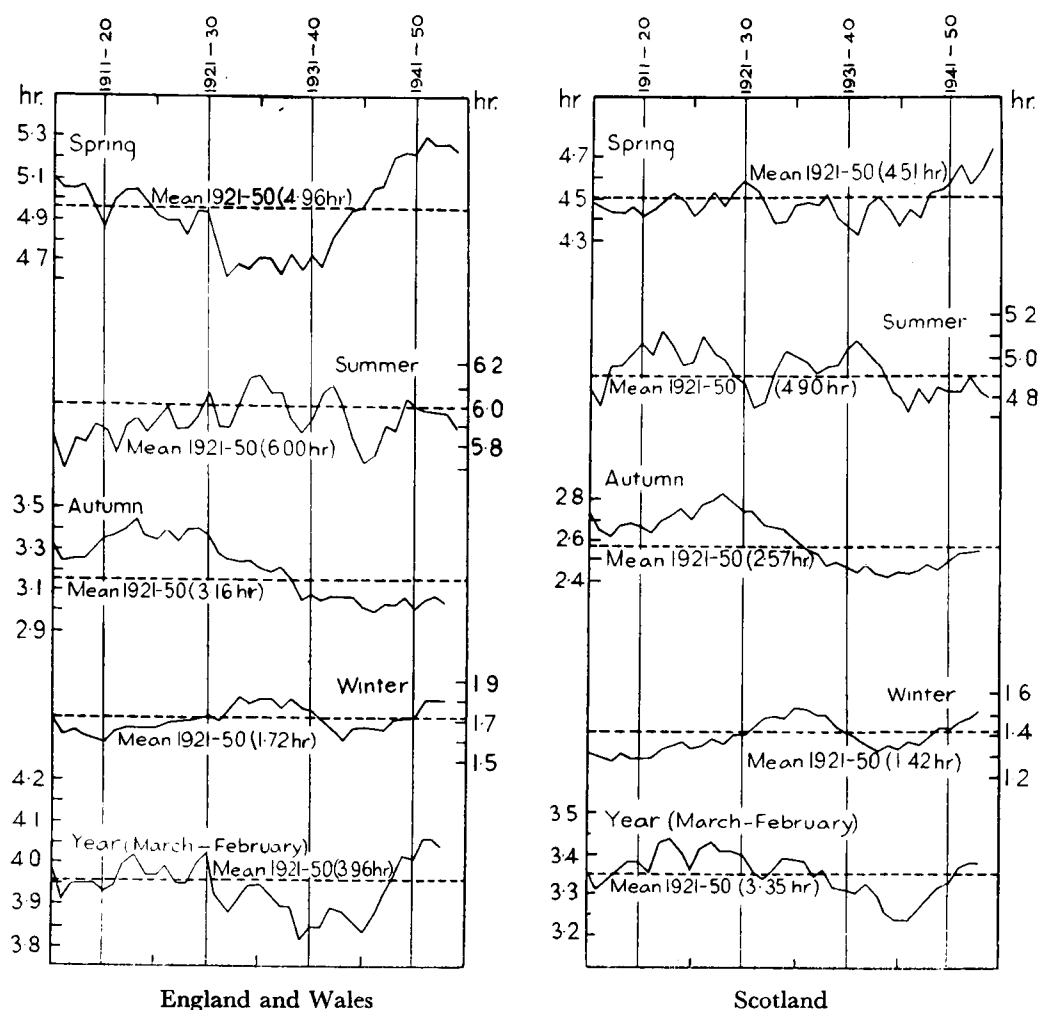


FIG. 2—10-YR. MOVING AVERAGES OF SUNSHINE

**Relationship between temperature and sunshine.**—Comparing the curves for sunshine (Fig. 2) with those for temperature (Fig. 1) it is apparent that the trends for these two elements are dissimilar for each season and for the year. There is therefore no direct relationship between changes of sunshine amount and temperature.

**Sunshine** (Fig. 2).—The two curves for the year show a number of differences, but the general trends are similar. Both show a marked rise from 1936-45 to 1943-52, of from 3.83 to 4.06 hr./day over England and Wales and from 3.24 to 3.38 hr./day over Scotland. The two sets of curves are also similar for the seasons but there are marked differences, e.g. the summer curves from 1908-17 to 1920-29 are below average over England and Wales but above over Scotland.

The main features of the curves for England and Wales are:—

*Spring.*—A well defined increase occurred from 1932-41 to 1942-51 of from 4.67 to 5.31 hr./day. There is a similar but less marked increase over Scotland from 4.32 to 4.66 hr./day.

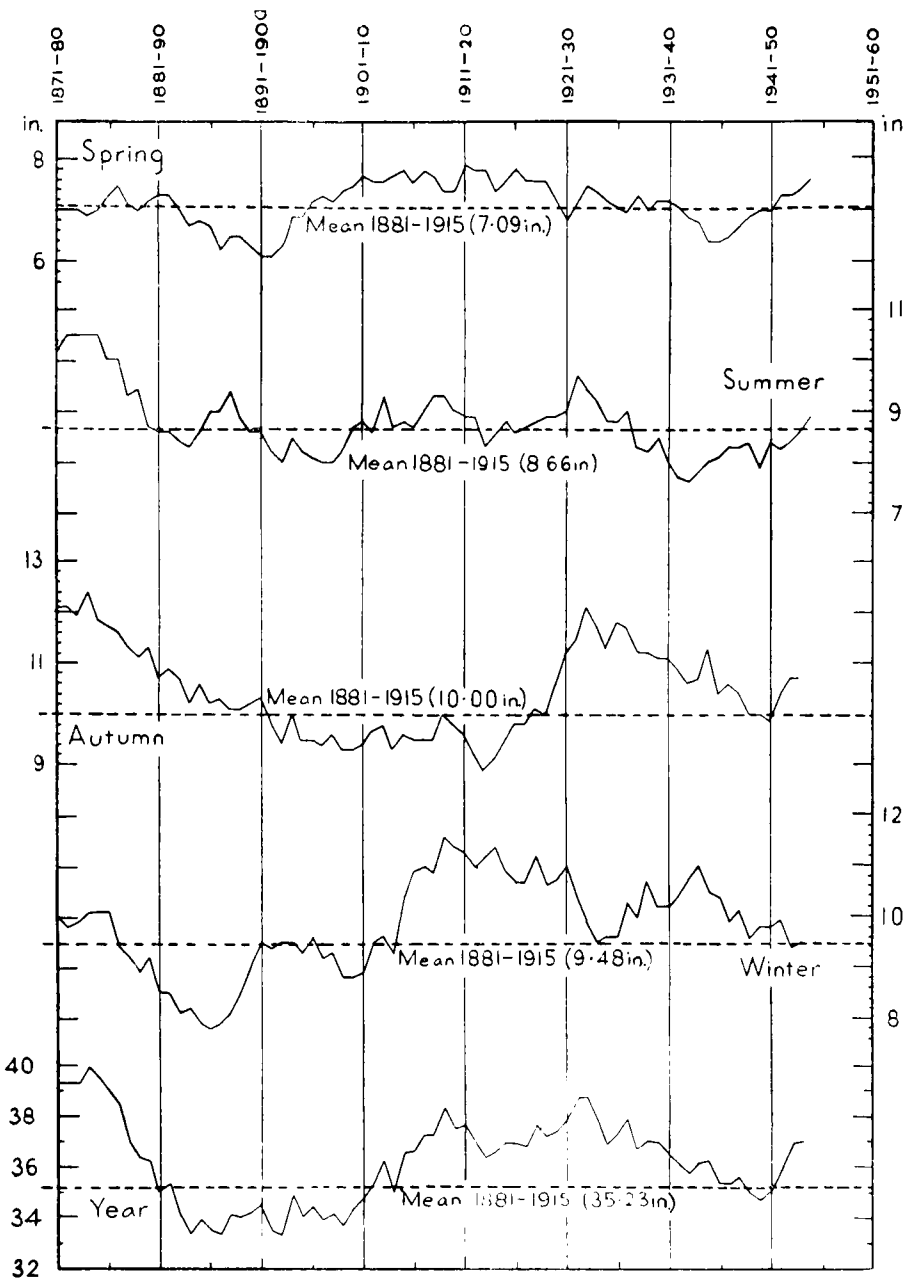


FIG. 3—10-YR. MOVING AVERAGES OF RAINFALL IN ENGLAND AND WALES

*Summer.*—The curve shows a number of maxima and minima. The most recent extremes were 5.72 and 6.04 hr./day in 1936-45 and 1940-49 respectively.

*Autumn.*—The curve shows a steady decrease from a maximum in 1914-23 of 3.44 to a minimum in 1937-46 of 2.99 hr./day. The curve of sunshine is similar to a mirror image of the temperature curve for the autumn.

*Winter.*—The curve shows a smaller amplitude and shorter wave-length than for the autumn, the minima being in 1911-20 and 1934-43 of 1.6 and the maximum in 1924-33 of 1.8 hr./day.

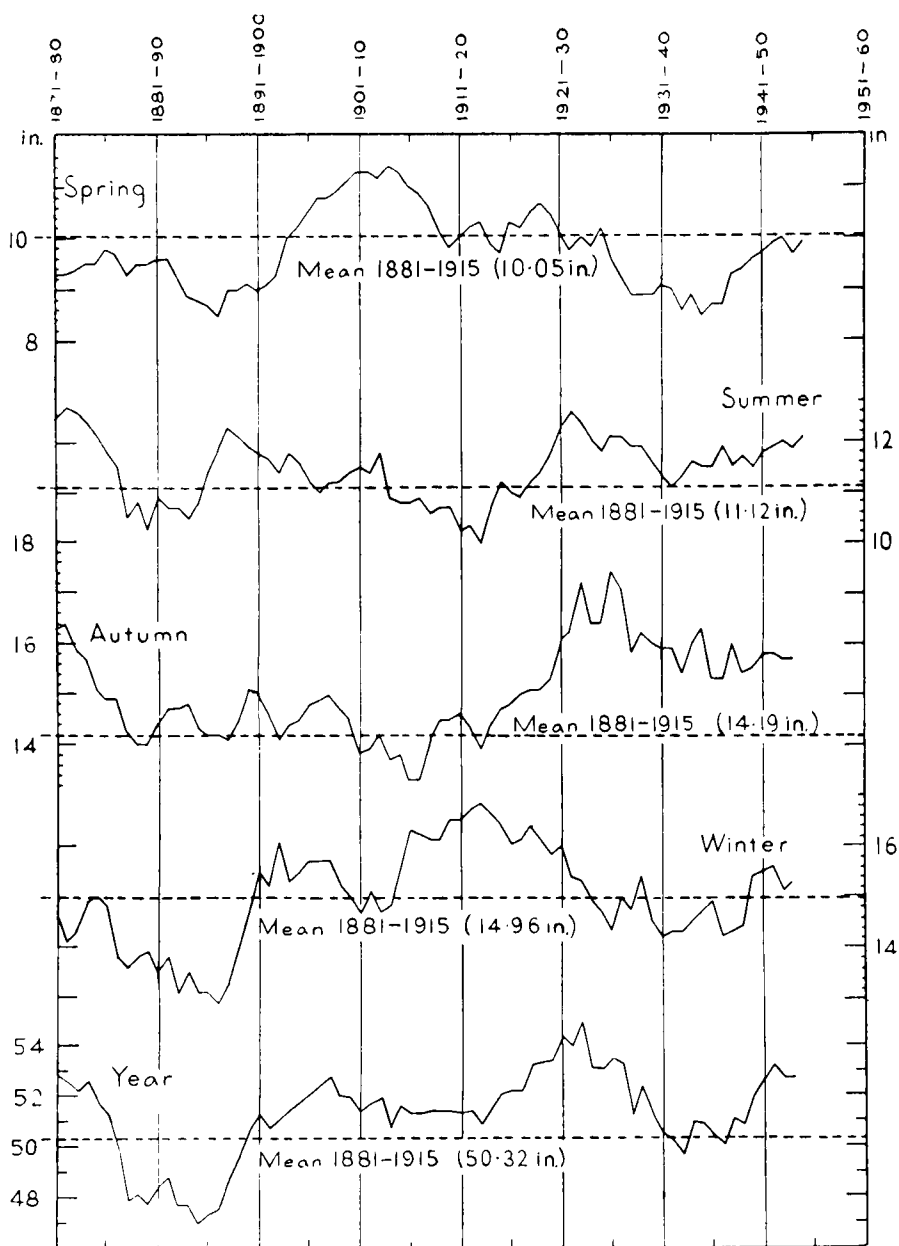


FIG. 4—10-YR. MOVING AVERAGES OF RAINFALL IN SCOTLAND

**Rainfall** (Figs. 3 and 4).—The curves for rainfall cover a longer period than those for both temperature and sunshine. The general seasonal trends of rainfall are quite distinct from those of temperature or sunshine. The annual curves show two maxima and one minimum, the extreme range over England and Wales being given by 1874–83 with 39.9 in., 1893–1902 with 33.2 in. and 1923–32 with 38.8 in., and over Scotland by 1871–80 with 52.8 in., 1885–94 with 47.0 in. and 1923–32 with 54.9 in. The rise in the curves during recent 10-yr. periods is also noteworthy.

These two sets of curves for England and Wales, and for Scotland show differences, but on the whole the trends are similar. Some of the more striking

differences are the relatively dry summers over England and Wales compared with wet summers over Scotland from 1928–37 to 1942–51, and the wet winters over England and Wales compared with mainly dry winters over Scotland from 1924–33 to 1939–48.

The main features of the general trends over England and Wales are:—

*Spring*.—A simple curve with minima in 1892–1901 and 1936–45, and a maximum in 1911–20.

*Summer*.—The general trend of the summer rainfall is similar to that for the spring, but the outstanding feature is the maximum about 1873–82, which has not been reached since.

*Autumn*.—The trends are more similar to those of the summer than those of the spring. Maxima occurred in 1874–83 and 1923–32, with a minimum in 1913–22 and a range of 3·5 in., more than in either spring or summer.

*Winter*.—The trends are quite different from those of the other seasons, with a minimum in 1886–95 and a maximum in 1909–18, a range of 3·8 in.

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### NEW BAROMETER CONVENTIONS

#### with a note on the determination of gravity at the station

By R. FRITH, Ph.D.

Whenever very precise measurements of length have to be made it is necessary to take account of the temperature of the measuring scale. It is traditional that measuring scales graduated in inches shall be correct when the temperature of the scale is 62°F., and scales graduated in metric units when the temperature of the scale is 0°C. (32°F.). For this reason, when mercury barometers were first used for measuring pressure, the scales of inch barometers were engraved so that they were true scales of length when the temperature of the scale was 62°F.\*; the scales of millimetre barometers were engraved so that they were true scales of length when the temperature of the scale was 0°C.\* It follows that when one barometer had both inch and millimetre scales the two scales did not exactly correspond since the inch scale was correct when the temperature was 62°F. and the millimetre scale correct when the temperature was 0°C.

When the true height of the mercury column has been determined, making any necessary correction for the temperature of the scale, it is necessary to make further corrections for the temperature of the mercury and the value of the acceleration due to gravity ( $g$ ) at the station, since, with any given pressure, the height of a barometer column will depend upon the density of the mercury and the value of  $g$ . The conditions which, until recently, were adopted as standard were:—

*Temperature of the mercury*: 0° C. (at which the density of mercury is 13·5951 gm./cm.<sup>3</sup>)

*Gravity*: Value of  $g$  at M.S.L. in latitude 45° (taken to be 980·62 cm./sec.<sup>2</sup>).

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\* This refers to the original, Fortin-type, barometer. The scales of Kew-type barometers are not true scales of length at all but are “contracted” to allow for the variation of the level of mercury in the cistern. However, the scales were still made to be correct, allowing for this contraction, at 62°F. or at 0°C. as the case may be.



The pressure was then expressed in “inches of mercury” or “millimetres of mercury”.

However, both the “inch of mercury” and the “millimetre of mercury” are artificial units of pressure, and in 1914 the Meteorological Office decided to adopt as the unit of measurement of atmospheric pressure the millibar ( $1,000 \text{ dynes/cm.}^2$ ). Before a barometer scale could be engraved in these units it was necessary to specify “standard conditions”, i.e. the temperature and value of  $g$  under which the instrument would read correctly without the application of any corrections. The standard value of  $g$  was again specified as  $980.62 \text{ cm./sec.}^2$ ; but it was decided to select a standard temperature such that the correction to a mercury barometer used in the latitude of London (where  $g$  is about  $981.194 \text{ cm./sec.}^2$ ) and in a room where the temperature was  $61^\circ\text{F}$ . should be small; in other words the temperature correction and the gravity correction should cancel out. This standard temperature turned out to be  $285^\circ\text{A}$ . (i.e.  $12^\circ\text{C}$ . or  $54^\circ\text{F}$ .). There were thus in use three different standard temperatures:—

$0^\circ\text{C}$ . for scale and  $0^\circ\text{C}$ . for mercury for millimetre barometers

$62^\circ\text{F}$ . for scale and  $0^\circ\text{C}$ . for mercury for inch barometers

$285^\circ\text{A}$ . for the whole instrument for millibar barometers.

Moreover, when other countries changed over to the millibar scale they tended to adopt standard temperatures to suit their own requirements. This multiplicity of standard temperatures was a fruitful source of confusion and error; and, early in 1945, the National Physical Laboratory at Teddington suggested that steps be taken to introduce a simple, unified set of barometer conventions to apply throughout the world to all types of mercury barometers. In consultation with the Meteorological Office and, later, with meteorological services and standards institutions in other countries, proposals were drawn up and submitted to the World Meteorological Organization and to the International Organization for Standardization. These proposals fall into two parts:—

(i) Definitions of “an inch of mercury” and “a millimetre of mercury” as pressure units

(ii) Recommendations on standard conditions for mercury barometers.

It was proposed that the definition of “an inch of mercury” should be changed from “an inch of mercury at  $0^\circ\text{C}$ . and  $980.62 \text{ cm./sec.}^2$ ” to “an inch of mercury at  $0^\circ\text{C}$ . and  $980.665 \text{ cm./sec.}^2$ ”;  $980.665 \text{ cm./sec.}^2$  is the value for “standard gravity” which has been used universally by physicists for many years and mercury being regarded as an incompressible fluid with a density at  $0^\circ\text{C}$ . of exactly  $13.5951 \text{ gm./cm.}^3$ . A similar change was proposed in the definition of “a millimetre of mercury”. These definitions have been accepted by the World Meteorological Organization and by the International Organization for Standardization, and were brought into use by the Meteorological Office on January 1, 1955. They differ from the old units by about four parts in 100,000. This difference is too small to be of any practical significance in meteorology.

It was proposed that the standard conditions for mercury barometers should be:—

*Temperature* (of the whole instrument):  $0^\circ\text{C}$ .

*Gravity*:  $980.665 \text{ cm./sec.}^2$ .

These proposals, too, have been adopted by the World Meteorological Organization. New and repaired barometers supplied to the Meteorological Office after January 1, 1955, are adjusted to these new conventions; and the National Physical Laboratory have announced that all mercury barometers tested by them after January 1, 1955, will be tested against the new conventions. The new conventions have also been issued by the British Standards Institution as a new British Standard (B.S. 2520).

Barometers adjusted to the new conventions will, of course, give precisely the same answer as barometers adjusted to the old conventions provided that the appropriate correction tables are used. Uncorrected readings will differ by about 2 mb. New basic tables are available, and these tables should be used in the preparation of correction cards for all barometers made, or repaired, after January 1, 1955. These instruments may readily be distinguished since the standard conditions are engraved on a plate immediately above the attached thermometer; they can also be distinguished by the date on the National Physical Laboratory certificate; all certificates dated January 1, 1955, or later will be based on the new conventions.

Since the standard temperature is now expressed in degrees Centigrade, the attached thermometers on Meteorological Office barometers are gradually being changed to read in degrees Centigrade instead of, as at present, in degrees Absolute.

**Revised formula for the determination of gravity at the station.**—The value of "gravity at the station" is usually computed from an empirical formula. For many years the Meteorological Office has used the formula

$$g_{\phi} = g_{45}(1 - 0.00259 \cos 2\phi),$$

where  $\phi$  is the latitude of the station. It has been known for some time that the values given by this formula are incorrect, especially at high-level stations. It has therefore been decided to use, in future, the revised formula (recommended by the World Meteorological Organization)

$$g_{\phi,h} = 980.616(1 - 0.0026373 \cos 2\phi + 0.0000059 \cos^2 2\phi) - 0.00009406h,$$

where  $\phi$  is the latitude and  $h$  is the height of the station in feet.

This new formula has been used in the preparation of the new tables necessitated by the introduction of the new barometer conventions. In addition, strictly, all existing barometer correction cards should be recomputed. Fortunately this is not really necessary and the following simpler procedure has been adopted by the Meteorological Office with effect from January 1, 1955:

At stations where the error due to the use of the old gravity formula does not exceed 0.05 mb. no change is being made.

At stations where the error lies between 0.06 and 0.15 mb. every entry on the correction card is being changed by 0.1 mb.

And so on for stations with greater errors.

As a result, barometer readings at stations in the British Isles whose height exceeds 675 ft. were all reduced by 0.1 mb. with effect from January 1, 1955. There was no change at stations below 675 ft. At some high-level stations overseas readings were reduced by as much as 0.5 mb.

[To face p. 40]



CIRROCUMULUS CLOUD AT GRANWELL, NOVEMBER 15, 1954  
(see p. 60)

To face p. 41]



CIRROCUMULUS CLOUD AT CRANWELL, NOVEMBER 15, 1954  
(see p. 60)

## A NOTE ON SUMMER WEATHER IN THE EUPHRATES VALLEY

By A. F. JENKINSON, B.A.

It has been shown by Jenkinson<sup>1</sup> that during summer the passage of depressions eastwards over the Ukraine is followed, after an interval of about two days, by the arrival of colder air over Lower Egypt, which clears away low stratus there. The same air mass, much modified, also reaches the Euphrates Valley, with an increase in the north-westerly gradient winds giving strong surface winds and sandstorms. On the average a fall of pressure at Odessa to 1009 mb. will cause the wind at 1,000 ft. at Shaibah to increase to north-westerly 40 kt., and a rise of pressure at Odessa to 1017 mb. will cause the wind at 1,000 ft. at Shaibah to decrease to 10 kt.

A south-easterly thermal wind, associated with the colder air over the eastern Mediterranean, develops over the Euphrates Valley during the sand-storm period. The air in the layers to 800 mb. is somewhat cooler than usual, but above 700 mb. the air is warmer than usual.

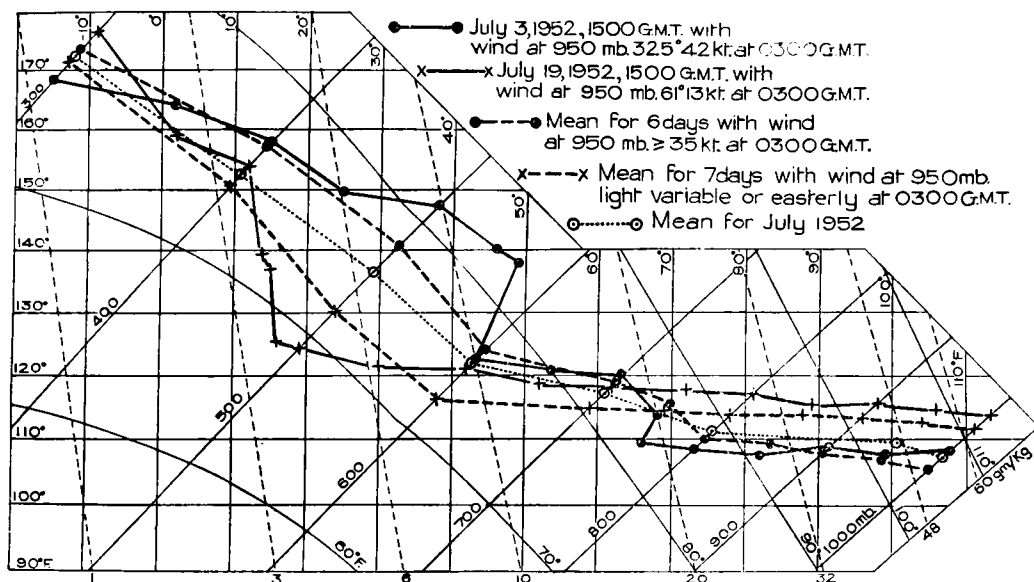


FIG. 1—TEPHIGRAMS OF RADIO-SONDE ASCENTS AT HABBANIYA, JULY 1952

During the periods of light surface wind a moderate westerly thermal wind prevails, and above the lower layers which are warmer than usual there is a layer which is colder than usual.

Typical tephigrams for Habbaniya at 1500 G.M.T. during July 1952 on an occasion of strong north-westerly wind and sandstorms (July 3) and one of light wind from an easterly point (July 19) are shown in Fig. 1. This diagram also shows tephigrams of the mean conditions for the six days of that month when the wind at 950 mb. at Habbaniya at 0300 G.M.T. was greater than or equal to 35 kt. from a north-westerly direction, and for the seven days when it was light variable or easterly. The tephigram of mean conditions for the whole month at 1500 G.M.T. is also shown.

It will be seen that the variability of temperature during the month is much greater in the layer between 550 and 450 mb. than it is in the layers below and above these levels. The standard deviations of temperature at 1500 G.M.T.

for July 1952 and for July 1951-52 combined, shown in Table I, confirm this conclusion.

The mean vector wind at 500 mb., for the six days with the wind at 950 mb. greater than or equal to 35 kt., was  $270^{\circ}$  2 kt., and for the seven days with the wind at 950 mb. light or easterly  $270^{\circ}$  25 kt.

TABLE I—STANDARD DEVIATION OF TEMPERATURE AT HABBANIYA

Time of observation: 1500 G.M.T.

	July 1952	July 1951-52
mb.	<i>degrees Centigrade</i>	
300	1.6	...
400	1.9	1.8
500	3.6	2.9
600	2.4	1.9
700	1.8	...
850	1.7	...
Surface	1.6	...

*Authority.*—London, Meteorological Office. *Daily Weather Report, Overseas Supplement.*

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### SEA-BREEZE AT THORNEY ISLAND

By A. J. WATTS, B.Sc.

The sea-breeze is always important at an airfield near the coast, but especially so when there is a light off-shore gradient. It is in these conditions that its arrival is most clearly marked: there is usually a large change in wind direction, a sharp fall in temperature and a rise of relative humidity. Not infrequently there is also a sudden change in visibility. It is thought therefore that the method of forecasting the sea-breeze in these conditions, which has been developed at Thorney Island, may be of interest at other coastal stations. It must be stressed that it applies only when the gradient wind is off shore.

It was assumed at the outset of the investigation that the main factors controlling the onset of the sea-breeze were the strength and direction of the gradient wind, and the difference of temperature between land and sea. The first requirement was therefore to obtain a satisfactory measure of these quantities.

**Excess land temperature.**—The temperature over land was taken as the value recorded by a distant-reading thermograph mounted on the roof of the meteorological office (47 ft. above ground level and three miles from the open sea). As there is a wide strip of low flat country surrounding the station (see Fig. 1), all of it very similar to the airfield, it is thought that this temperature should be fairly representative of the neighbourhood.

The inshore sea-surface temperature was taken as the weekly mean value, taken at high water by means of a Kent thermograph, the bulb of which is situated just within the entrance to Chichester Harbour (two miles south of the office) and 2 ft. below the sea surface.

In what follows, the excess land temperature is the air temperature minus the sea-surface temperature both as defined above. It is evidently not an ideal parameter for our present purpose, but appeared the best available. It was,

indeed, fortunate that the inshore sea temperatures were available, since otherwise it would have been necessary to rely on published mean sea temperatures<sup>1</sup>. The differences are considerable. In June 1952, for instance, the mean inshore temperature was 5°F. above the published mean value, while in February 1952 it was 10°F. below the published mean. It will be shown presently that 10°F. is more than enough to produce a sea-breeze, so that sea-breezes can occur on many days when, if one relied on the mid-channel mean

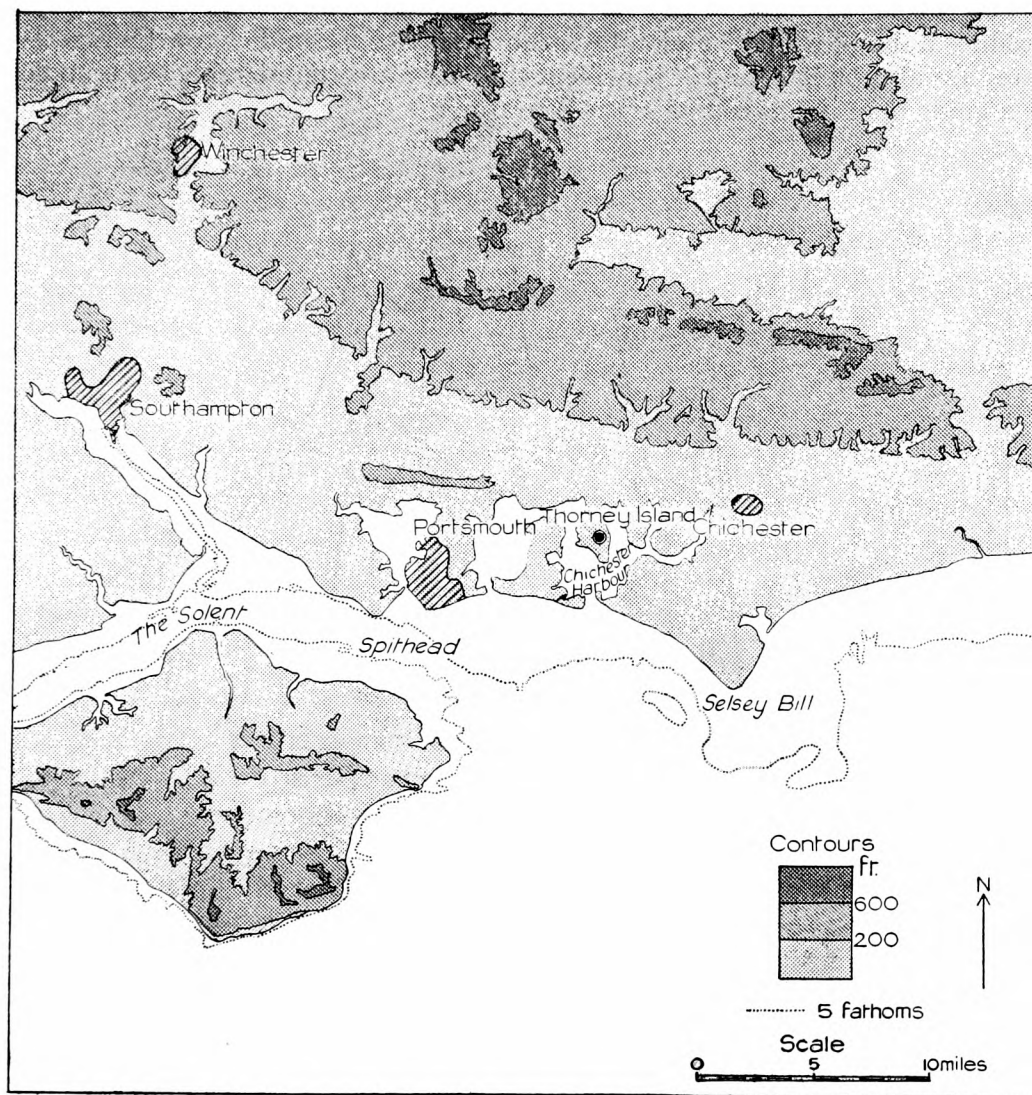


FIG. 1—AREA ROUND THORNEY ISLAND

values of temperature one would rule them out. For example, on January 20, 1953, a sea-breeze occurred, and brought a sharp fall in visibility; yet the maximum air temperature at Thorney Island was only 47°F., which is the mean mid-channel sea temperature for the month. Evidently the sea-breeze was possible only because the inshore water was colder than this.

The difference between inshore and mid-channel temperatures is particularly well marked in this district, where there are wide tidal mud-flats and sand-flats. The water is very quickly warmed during a summer day by flowing over mud



heated by the sun and, conversely, it can be rapidly cooled in winter by flowing over mud previously exposed to nocturnal radiation. For example, in summer, the water temperature at low tide (when the water around the thermometer has recently drained off the flats) is often more than  $10^{\circ}\text{F.}$  warmer than at the preceding high tide.

Fig. 2 shows the weekly mean values of maximum air temperature at Thorney Island and of inshore sea temperature during 1952. It will be seen that, except in autumn, there was always a temperature difference in the right direction to produce a sea-breeze. The monthly mean values of the mid-channel temperatures are also plotted, and it is evident that they are considerably less reliable as a guide than the measured sea temperatures.

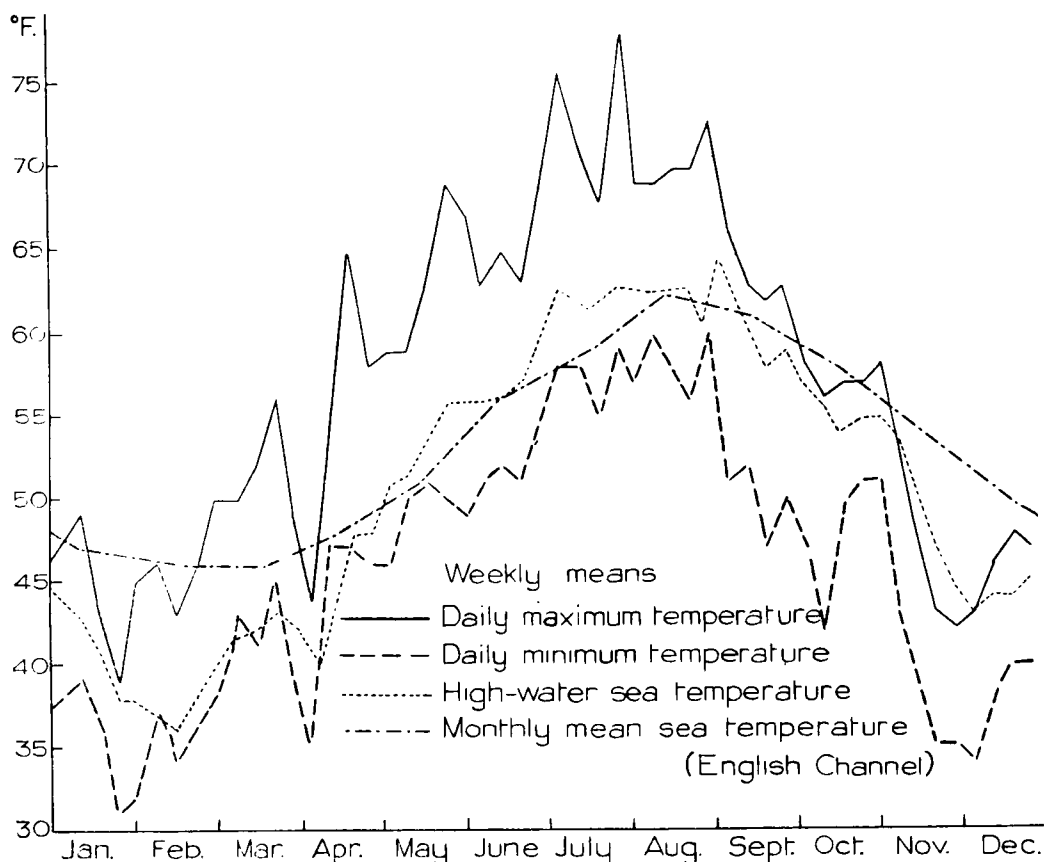


FIG. 2—LAND AND SEA TEMPERATURES AT THORNEY ISLAND, 1952

**Temperature difference required to produce a sea-breeze.**—It seemed probable that a sea-breeze would not occur unless the excess land temperature exceeded a certain critical value, and further, that this value would depend on the strength of the opposing gradient wind. To test this, occasions in the years 1951–54 on which there was an off-shore gradient wind of less than 25 kt. and on which there was a positive excess land temperature were plotted in Fig. 3. The ordinate is the wind at 3,000 ft., estimated from the radar-wind ascents at Larkhill or Crawley, and the abscissa is the excess land temperature. The observations are divided into five groups according to wind direction at 3,000 ft. The mean sea-breeze direction was found to be  $190^{\circ}$  and five arbitrary sectors were fitted about the reciprocal direction to embrace the sector  $280^{\circ}$  to  $89^{\circ}$ . It will be seen at once that a critical line can be drawn separating the



occasions when a sea-breeze did occur from those when it did not. The curves of Fig. 3, therefore, provide a simple and quite reliable method of determining whether or not a sea-breeze will occur.

Certain of the cases shown in Fig. 3 are classed as "marginal". In these, the wind fluctuated between off shore and on shore. The mechanism seems to be as follows: temperature rises over land, and a sea-breeze is induced; this brings in cooler air which, in the marginal case, is sufficiently dense to prevent further convection, so that the sea-breeze ceases, and the gradient wind takes control again. Evidently this sequence can occur several times in succession.

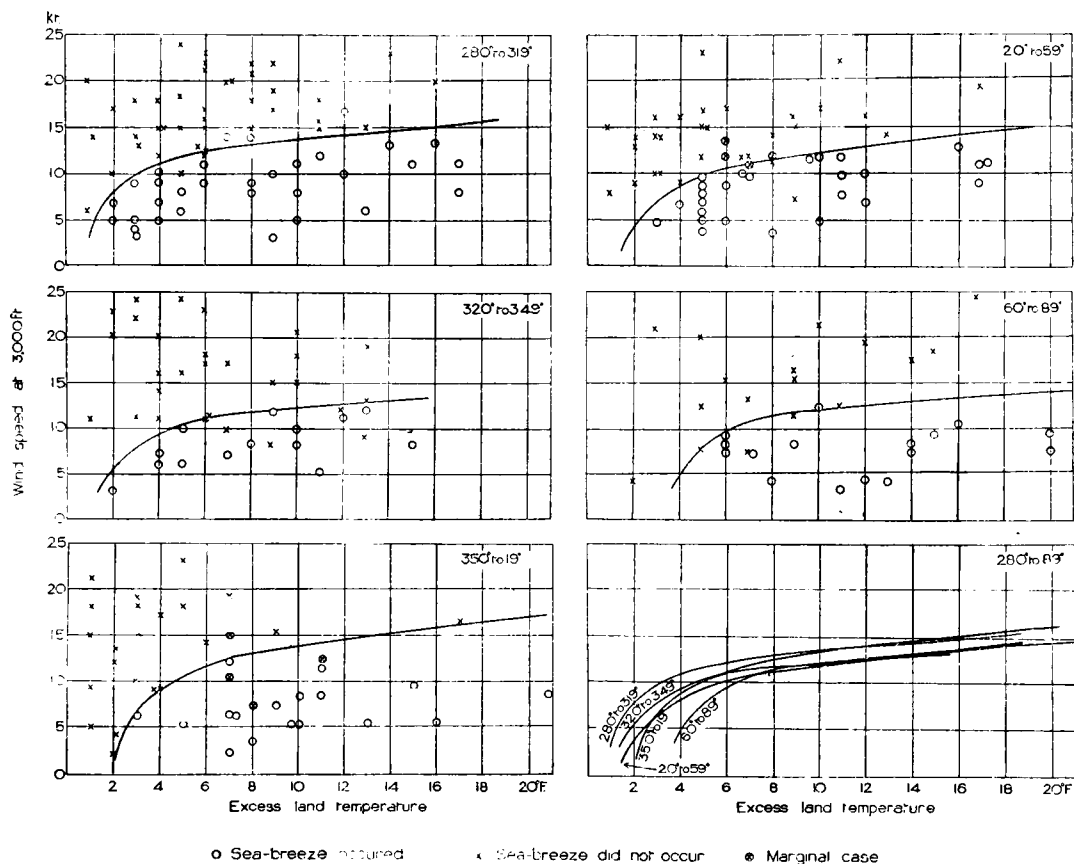


FIG. 3—OCCURRENCE OF SEA-BREEZE AT THORNEY ISLAND

**Time of onset of the sea-breeze.**—In Fig. 4, the time of onset of the sea-breeze is plotted as abscissa against the wind speed at 3,000 ft. as ordinate. It will be seen that there is a reasonably close relationship. In each of the diagrams of Fig. 4, a curve has been fitted to the observations, and in some 69 per cent. of the occasions the actual times of onset are within an hour of the time given by the curve. The observations in Fig. 4, as in Fig. 3, are divided into the same five groups as before.

The winds used were estimated from the radar-wind ascents at Larkhill or Crawley. Considerable inaccuracies are inherent in this process, and it is thought that, if winds could have been measured at Thorney Island and nearer to the time of onset, a considerably better fit would have resulted. Certainly the majority of the points which are very far from the curves represent occasions when the gradient wind was changing rapidly and was therefore difficult to estimate.

Attempts have been made to improve the fit of the points by using some other zero for the time scale than midnight. Trials have been made using as zero sunrise and the time at which air temperature became equal to sea temperature, but no improvement resulted. An equally surprising result was that, so far as could be judged, the magnitude of the excess land temperature had no bearing on the time of onset of the sea-breeze.

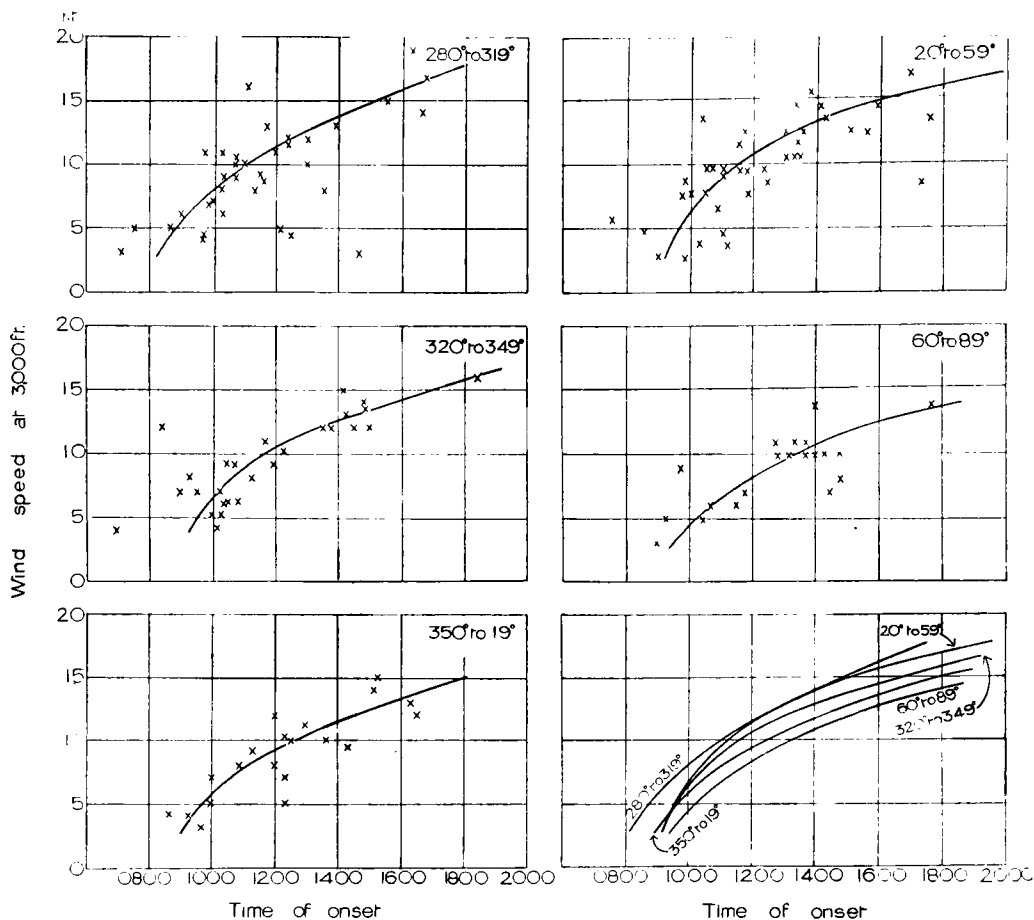
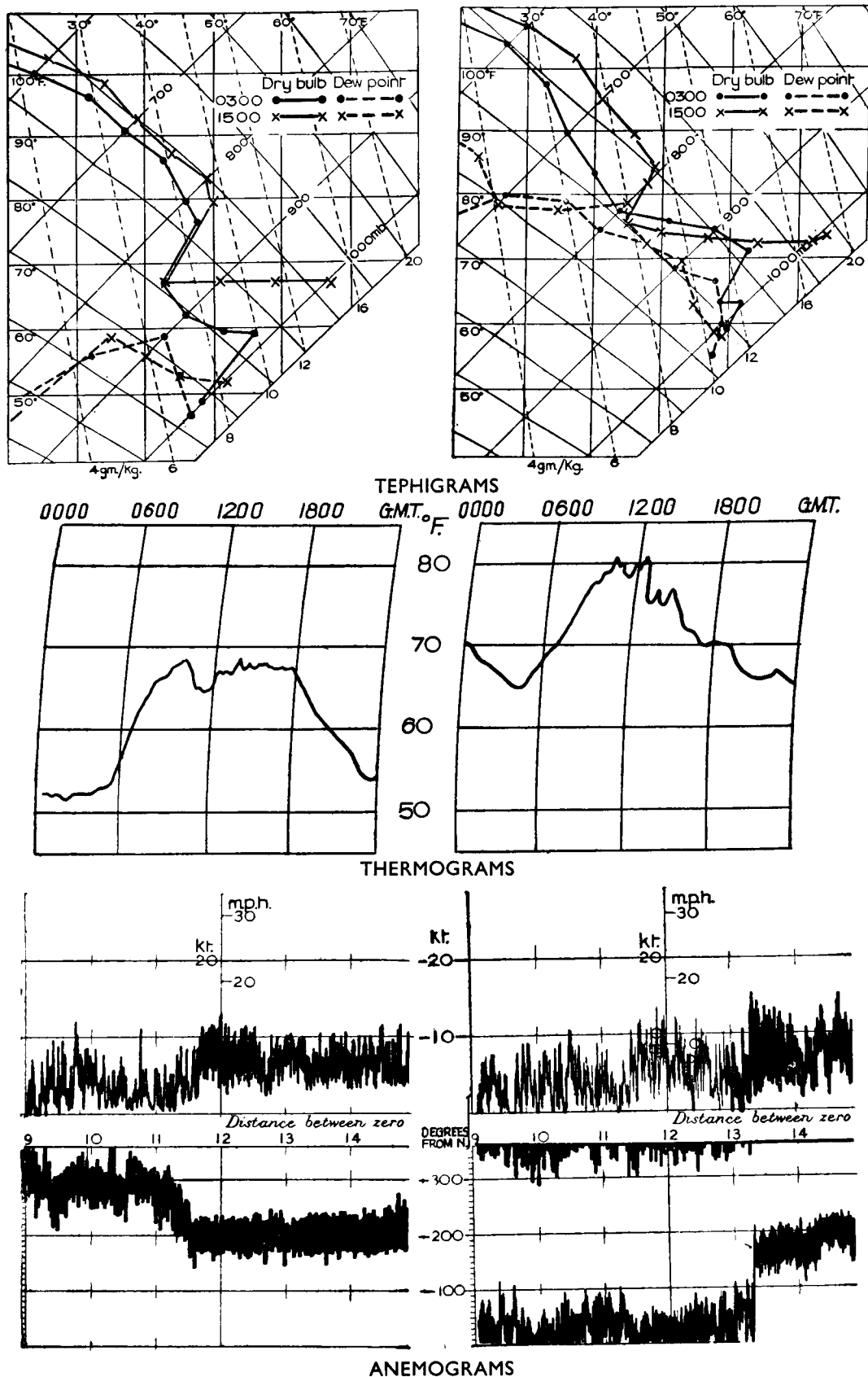


FIG. 4—TIME OF ONSET OF SEA-BREEZE AT THORNEY ISLAND

**Effects of stability.**—When conditions are thermally stable, the sea-breeze arrives with a gradual change of wind; but in unstable conditions it arrives suddenly. Out of 58 occasions of sea-breeze in 1952, 26 occurred when convection was possible to a height of at least 10,000 ft., and the average time taken to establish the sea-breeze was 21 min.; in 16 of these cases the time taken was 10 min. or less. On the remaining 32 days, when convection was not possible, the average time was 117 min.

Typical anemograms are shown in Fig. 5. They are taken from the pressure-tube anemograph at Thorney Island, the head of which is 75 ft. above sea level. The Larkhill upper air temperatures and Thorney Island thermograms are also reproduced.

The anemogram for June 11 shows the normal manner of onset in stable conditions with the gradual change of wind direction to 190–200°, which is the normal sea-breeze direction for this station. The anemogram for July 23



June 11, 1952  
 July 23, 1952  
 FIG. 5—TYPICAL OCCASIONS OF SEA-BREEZE AT THORNEY ISLAND

shows the sudden change of wind direction which often occurs in unstable conditions.

While dealing with the relation between manner of onset and stability there appeared to be evidence that the greater the stability the longer the period of change from gradient-wind to sea-breeze direction. However the difficulty of satisfactorily measuring stability precluded any attempt to define the relationship.

**Forecasting the sea-breeze at Thorney Island.**—Sea-breeze forecasts are made in the following manner:—

- (i) Obtain the maximum expected excess land temperature.
- (ii) Forecast the upper wind speed and direction.
- (iii) Choose the diagram in Fig. 3 corresponding to the forecast upper wind direction and plot the excess land temperature against the forecast upper wind speed and read off whether the sea-breeze is probable, marginal or improbable.
- (iv) If the sea-breeze is probable or marginal, using the forecast wind speed, read off the time of onset from the appropriate diagram in Fig. 4.
- (v) Consider whether the air stream will be stable or unstable at this time. If stable then expect an average period of transition from gradient to sea-breeze direction from about two hours before the forecast time. If unstable expect a sharp change from gradient to sea-breeze direction at about the forecast time.

**Acknowledgement.**—I would like to thank Dr. H. G. Stubbings of the Admiralty Central Metallurgical Laboratory for making the sea-temperature information available.

## NIGHT COOLING UNDER CLEAR SKIES AT MILDENHALL

By E. D. ROBERTS, B.Sc.

**Introduction.**—W. E. Saunders<sup>1</sup> found that a discontinuity occurred in the rate of cooling on radiation nights at Northolt, the cooling being comparatively rapid to this point, and then slower. He found that the temperature  $T_R$  at the point of discontinuity could be related by a simple formula to the afternoon maximum temperature  $T_M$  and the corresponding dew point  $T_D$ , and he devised a method for forecasting the subsequent minimum temperature  $T_{\min}$ . An attempt has been made to apply this method to the observations at Mildenhall.

**Temperature of discontinuity.**— $T_R$  and the time of  $T_R$  were found by scrutiny of the hourly observations and thermograms over the period August 1948 to April 1950. A night was considered suitable if the mean cloud amount was less than 1 okta and if fog was absent for the major part of the night. Some nights which were clear at first but cloudy later were used to determine  $T_R$  but not to determine  $T_{\min}$ .

The discontinuity in the cooling curve was well marked on about 70 per cent. of the 125 nights considered, and on these occasions  $T_R$  could be determined easily from the thermograms. On the remaining occasions the time and temperature discontinuity were not well marked, and hourly observations were used in the estimation; these results are more subjective and may give errors in the time of  $T_R$  of as much as 2 hr. Values of  $T_R$  were plotted against a calculated value of  $\frac{1}{2}(T_M + T_D)$ . This gave a mean deviation of 5°F. about the line

$$T_R = \frac{1}{2}(T_M + T_D) - 4.$$

Treating the occasions of no inversion separately from those with an inversion at or below 850 mb., a better measure of agreement was obtained. For no inversion

$$T_R = \frac{1}{2}(T_M + T_D) - 1$$

with a mean deviation of  $2^{\circ}\text{F}$ . (54 occasions). For an inversion at or below 850 mb.

$$T_R = \frac{1}{2}(T_M + T_D) - 5$$

with a mean deviation of  $1.5^{\circ}\text{F}$ . (71 occasions).

**Time of discontinuity.**—The time of the evening discontinuity throughout the period was plotted together with the daily rainfall. Fig. 1 shows these values together with the Northolt curve for comparison. A change-over period between October and November is apparent for 1948, as Saunders found at Northolt, although it is difficult to link this with rainfall. No marked change-over period occurs in the 1949 values. A mean curve for time of discontinuity for the period considered can be drawn parallel with the sunset curve and about  $1\frac{1}{2}$  hr. later, but the mean deviation from this curve is 1 hr. and the extreme deviation 2 hr.

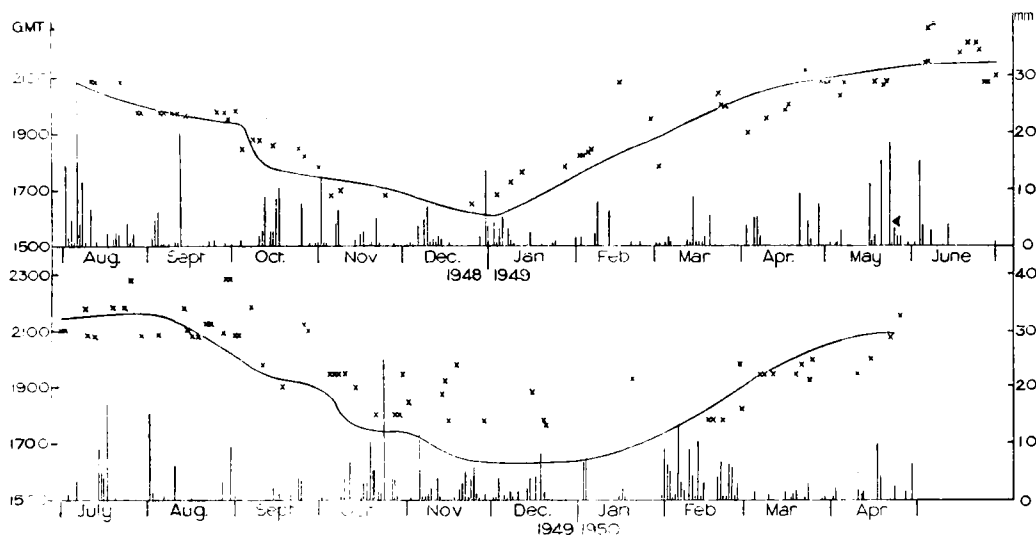


FIG. 1—DAILY RAINFALL AND TIME OF EVENING DISCONTINUITY

**Subsequent cooling.**—Using Saunders's method an attempt was then made to find some relationship between the temperature at the discontinuity and the minimum temperature. Diagrams relating the calculated values of  $T_R$  to  $T_{\min}$  were plotted as for Northolt, distinction being made between inversion and non-inversion cases and between light and moderate winds. Separate diagrams were constructed for the winter and the summer, that for the period October to March lying to the left of that for the period April to September in Fig. 2. The curve AB gives the mean in each case for a gradient wind less than 15 kt. and CD for greater than 15 kt. It was found that the deviations from the mean were greater than those for Northolt.

**Forecasting the cooling curve.**—When a cloudless night is anticipated two points of the cooling curve can be forecast, namely  $T_R$  and  $T_{\min}$ .  $T_R$  is calculated from the appropriate equation, the approximate time being  $1\frac{1}{2}$  hr. after sunset, and  $T_{\min}$  is then determined from the appropriate curve in Fig. 2, its approximate time being sunrise.

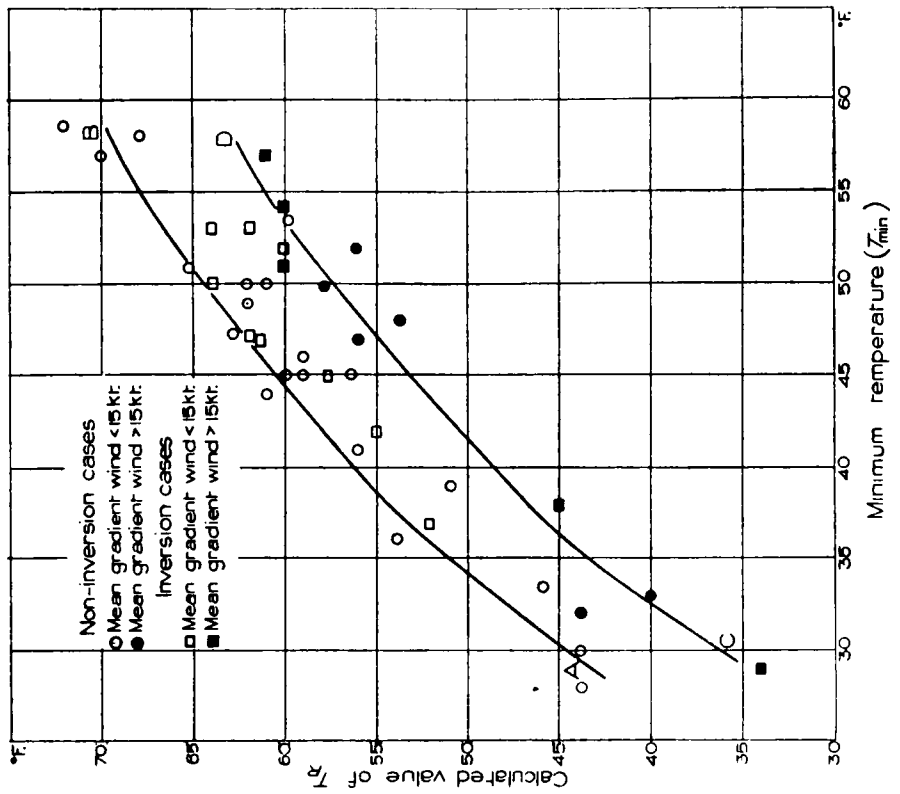
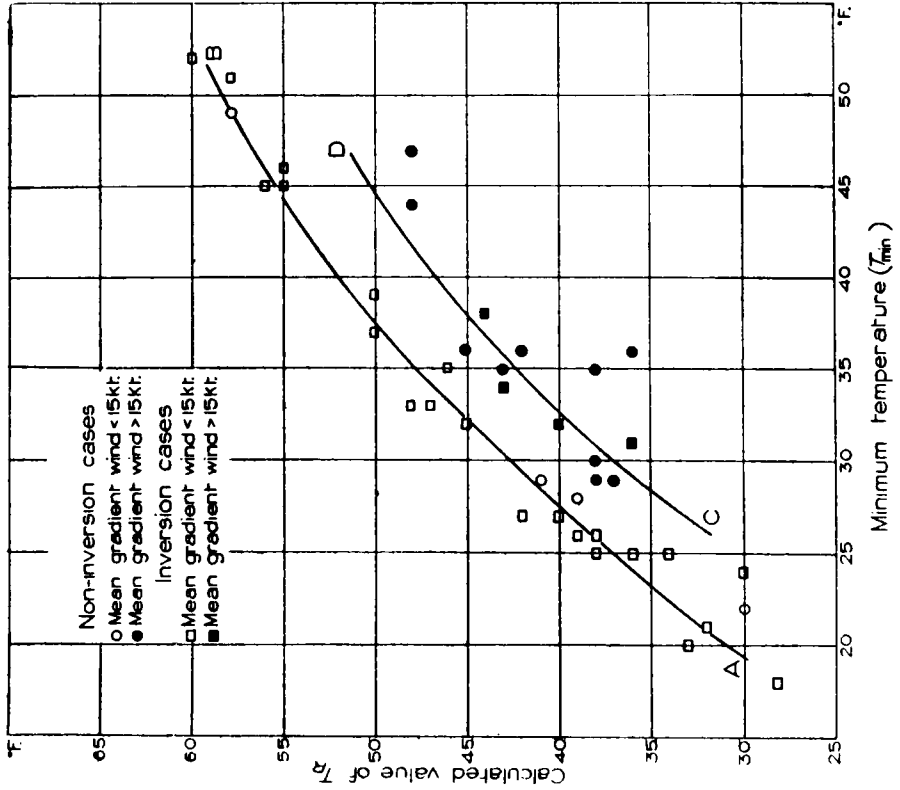


FIG. 2---RELATION BETWEEN CALCULATED TEMPERATURE AT THE TIME OF DISCONTINUITY AND THE MINIMUM TEMPERATURE

**Conclusion.**—The method has not been used for a long period at Mildenhall, but the results so far obtained have been reasonably good. However, the main sources of error in forecasting the minimum temperature remain the difficulty of estimating gradient wind and mean cloud amount during the night.

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## METEOROLOGICAL OFFICE DISCUSSION

### Weather radar in research and operations

The discussion on Monday, November 15, 1954, at the Royal Society of Arts was opened by Mr. W. G. Harper with a short survey of meteorological radar theory and practice, followed by a description of recent developments and of research uses of radar in meteorology.

The importance of Ryde's theoretical investigations of the scattering and attenuation of a radar beam by precipitation, fog and cloud droplets<sup>1</sup> was stressed. Mr. Harper used a form of Ryde's radar equation to show that the range of wave-lengths from 3 to 10 cm. is the most suitable for study of the movement, structure, and development of precipitation by ground-based radar, but that shorter wave-lengths still are needed if measurable signals are to be received from cloud droplets.

Airborne radar equipment must be limited in weight and size, and these considerations preclude the use of 10-cm. radar. Adequate working ranges can be obtained however using wave-lengths in the range 3–6 cm. Its use in the Thunderstorm Project in America<sup>2</sup> showed that airborne radar enables the pilot to fly a course which will usually completely avoid turbulent areas in thunderstorm conditions, and Jones<sup>3</sup> at East Hill has found that the most severe gusts in cumulonimbus are associated with echo discontinuities. He was able to show that practically all turbulence could have been avoided if the aircraft had kept clear of radar response areas by a margin of one mile. This was also the finding in the trials of airborne radar in tropical thunderclouds at Singapore by the Transport Command Development Unit<sup>4</sup>.

Mr. Harper produced slides to show the distinctive appearance on radar of different frontal and shower situations as seen on the 3-cm. and 10-cm. equipment at East Hill, and went on to show that simple extrapolation of the movements of precipitation areas on radar can give accurate short-period forecasts of precipitation. A six-month trial of this technique was completed in the early summer of 1954, forecasts being made independently from radar and by an experienced forecaster at Dunstable, and it was shown that radar could be a valuable aid to the forecaster. Two main reasons can be given for this, the accurate delineation of precipitation areas by radar, which is something new in meteorology, and the fact that radar takes into account the control of precipitation movements by winds aloft related to the particular precipitation mechanism. The main limitations of centimetric radar for this purpose are (i) its inability to detect drizzle and very light rain because of their small drop sizes, and (ii) in the duration of forecasts due to the speed of movement of weather echoes in relation to the range at which they can first be detected. The East Hill 10-cm. radar can detect moderate rain out to about 60 miles, and

heavy rain to about 120 miles, and forecasts from radar could rarely have been made for more than a 3-hr. period. They were frequently cut to 2 hr., occasionally to 1 hr. Radar cannot forecast development or decay of weather, but its instantaneous picture will often show if development or decay has taken place some time before this could be realized from hourly synoptic charts.

Theoretical studies have shown that non-spherical precipitation particles de-polarize the radar beam, and Labrum<sup>5</sup> in Australia, by mounting ice crystals and hemispherical water drops in a 10-cm. wave guide, has now provided the experimental confirmation of this. It is found that the radiation scattered by a partly melted ice sphere approaches that from a spherical raindrop when it has acquired only a thin skin of water. Mr. Harper showed how this effect and Ryde's radar equation successfully explain the bright band which is often observed just below the freezing level on the height-range radar display.

The value of radar in the study of precipitation processes was further illustrated from work in Canada on precipitation streaks<sup>6</sup>. Slides were shown of particularly well developed snow trails falling from what are thought to be generating elements. These elements were found often to be closely linked with frontal surfaces and to be embedded in frontal cloud. The variations in slope of the trails with height give the variations in fall velocity of the particles with height if the upper winds are known. Langleben<sup>7</sup> finds that they have a relatively uniform speed of about 3 ft./sec., and concludes that they must be snowflakes throughout the whole course of their descent. Dennis<sup>8</sup> has suggested that snow from these trails may be a factor in initiating shower activity in cumulus clouds, for the tops of precipitating cumuli are often seen to extend to the level of such trails in Canada. Radar is clearly an invaluable tool in this kind of investigation, but present radar equipment cannot define positively the nature and size of precipitation particles, and there is great advantage in the close co-operation of research aircraft and weather radar.

An accurately calibrated radar gives values of  $\Sigma Nd^6$  if the raindrops are spherical, where  $N$  is the number of drops, of diameter  $d$ , per unit volume. This is called the radar reflectivity. It is evident that large drops make an exceptionally large contribution to the received power, and that radar is extremely sensitive to changes in drop-size distribution. Best<sup>9</sup> and others have shown that there is an empirical relation between the reflectivity and the rainfall rate at the ground, but variability in the drop-size distribution can result in calculated rainfall being out by a factor of 2 even in steady-rain conditions. There are similar difficulties in measuring water content, a quantity of interest in relation to the rate of icing of aircraft.

It has been mentioned that cloud droplets can give measurable radar echoes at very short wave-lengths. As the wave-length decreases to about 1 cm. attenuation by rain increases extremely rapidly, but in addition attenuation by water vapour and atmospheric oxygen becomes pronounced; 8-mm. radar however has been shown in America to have great value as a cloud base and top indicator if used to investigate clouds vertically above the radar. Clouds containing large droplets are invariably recorded and clouds, such as altocumulus, cirrostratus and stratocumulus, containing smaller droplets or large ice crystals on about 40 per cent. of occasions. Droplets in fogs are in general too small to be detected by 8-mm. radar.



To show how wide is the field of research in which radar can be applied, Mr. Harper finally described Hewitt's work in South Africa on the radar study of lightning discharges<sup>10</sup>. Hewitt developed a drum camera which would photograph the radar return from each separate pulse of a 50-cm. radar, the pulse recurrence frequency being 1,000 per second. He was able to identify distinctive echo sequences which he associates with (a) the ionization in the main channel, and (b) the ionization resulting from a junction-streamer process in a cloud-to-ground discharge.

In the discussion which followed some exception was taken to the form of radar equation used by Mr. Harper but he was able to justify this fully in later correspondence.

*Capt. Jackson* (International Federation of Airline Pilots Association) asked about the screening effect of one cumulonimbus cloud by another. Mr. Harper said that this was negligible on 10-cm. radar, but would be noticeable on 3-cm. airborne radar because of the combined effects of range and rain attenuation. Capt. Jackson also asked whether there was any characteristic echo from hail, as had been reported from America.

*Mr. Jones* thought that the evidence of correlation between echo appearance and hail was not convincing, and was not borne out by observations in this country.

*Mr. Robinson* (Radar Research Establishment, Malvern) said that they hoped to develop a variable polarization radar which will, for example, distinguish between ice particles and supercooled water drops.

*Mr. Bigg* was disappointed at not hearing of radar means of detecting fog.

*Wg Cmdr Macintosh* (Ministry of Transport and Civil Aviation) on the other hand was very relieved to learn this. They were installing an 8-mm. radar at London Airport for the control of airport ground traffic, and had been worried lest it become ineffective in fog.

*Mr. Robinson* described investigations with an 8-mm. radar at Malvern and confirmed that radar echoes from fog were never seen. He thought it might prove possible to detect fog droplets at very short ranges on  $3\frac{3}{4}$ -mm. radar if the very difficult problems of design at this wave-length could be overcome.

*Mr. Gold* expressed surprise at the difficulty of measuring cloud base by radar. Mr. Harper confirmed that normal weather radars, operating in the wave-length range 3–10 cm., could not detect cloud bases; 8-mm. and 12-mm. radars could do so much of the time, but the cloud base on these displays would be masked if precipitation was falling beneath it.

*Mr. Sawyer* asked whether it would be possible to remove the effect of range attenuation from the radar display. He thought it would be of special value in the case of widespread warm frontal rain, showing more accurately the intensity variations in the front. Mr. Robinson said there would be no difficulty in designing such an attenuator.

*Dr. Scrase* asked whether "angels" were ever seen at East Hill. Mr. Harper replied that they were occasionally seen on 10-cm. radar. They appeared as echo spots at heights usually from 2,000 to 5,000 ft., out to ranges of about 20 miles, and were received most frequently from clear skies after sunset. "Angels" were quite distinctive and could not be confused with weather echoes.

They are thought to be due to sharp gradients of refractive index in the atmosphere, which have not been detected by existing aircraft instruments.

*Mr. Wallington* spoke of the value of radar methods in short-period forecasting, and said that aircraft radar sets had been set up at some meteorological offices after the war for this purpose.

*Mr. Peters* thought that the results of the forecasting trial were encouraging, and mentioned the special value of radar reports on ceremonial occasions such as Trooping the Colour. He thought that more work was needed on the study of the control of precipitation movements by upper winds, and also commented on the difficulty of coding weather-echo information.

*Cmdr Frankcom* said that the ocean weather ships observed frontal precipitation on their radar equipment, and reported it in plain language with their routine observations.

*Mr. Durward* commented on the high cost of special radar equipment, and thought we should try to make more use of existing radars.

Discussion then centred around the possibility of obtaining weather-echo information from operational stations.

*Mr. Bradbury* described the co-operation already given in this way by Fighter-Command radar stations, who supplied weather-echo reports in NUBEX code three times a day. He had also obtained invaluable information from London Radar (London Airport) on special occasions such as fly-pasts.

*Mr. Robinson* thought that air-traffic-control radars would be modified in the near future to minimize rain echoes, and that it would be better to design a set specially for meteorological purposes.

*Mr. Harper* wondered whether it would be feasible to transmit the radar display from East Hill to the Central Forecasting Office, Dunstable by line-of-sight radio link.

*Gp Capt. Fennessy* (Decca Radar) said that this would cost nearly as much as a complete new radar set.

*Dr. Stagg*, as Chairman, then closed the discussion remarking that, despite the value of radar, forecasters need not expect to have rows of radar tubes for their use in the foreseeable future.

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9. BEST, A. C.; The size distribution of raindrops. *Quart. J. R. met. Soc., London*, **76**, 1950, p. 16.
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## OFFICIAL PUBLICATION

The following publication has recently been issued:—

### METEOROLOGICAL REPORTS

No. 15—*Cumulus and cumulonimbus cloud over Malaya*. By R. Frost, B.A.

During the early summer of 1950 a series of flights through cumulus and cumulonimbus clouds over Malaya and Sumatra was made and the results are discussed in the present paper. It was found that (i) the transition from cumulus to cumulonimbus cloud occurred when the cloud tops were between 30,000 and 33,000 ft. (i.e. where the temperatures were about  $-30^{\circ}$  to  $-35^{\circ}\text{C.}$ ); (ii) cumulonimbus clouds on occasions reached the tropopause at approximately 55,000 ft.; (iii) contrary to experience in middle latitudes, radar echoes were received from cumulus clouds the tops of which were well below the  $0^{\circ}\text{C.}$  level; and (iv) practically all turbulent areas could be avoided if the radar response areas were avoided by about one mile. Observations of hail, snow, sleet, lightning and turbulence made during penetrations into cumulonimbus clouds, and which are the first of their kind in the tropics, are also discussed.

## ROYAL METEOROLOGICAL SOCIETY

### Rainfall in relation to water supply

At the meeting of the Society on November 17, 1954, Prof. P. A. Sheppard, a Vice-President, in the Chair, a symposium was held on rainfall in relation to water supply.

The broad outlines of the subject were set out by a leading water engineer, Mr. D. Halton Thompson, in describing the functions, needs, and problems of his profession, whose duty it is to see the consumer's tap never runs dry. There are two main types of water-supply systems: the overground using rivers, dammed if necessary into reservoirs, and the underground pumped through wells and bore-holes from the deep-water storage. Both types ultimately depend on rainfall, but only a fraction of rainfall is available for water supply because of losses by evaporation and transpiration and the need to maintain a proportion of river flow below a reservoir. Reservoirs must be so designed that water can be drawn off at all times at a constant rate, that they will not run dry in drought, and that excess flood water will run off without causing damage. A major problem is deciding the imposition of restrictions during a drought. In waterworks design knowledge of extremes of rainfall is essential, so that a proper balance can be maintained between cost of construction and risk of water shortage. Meteorological data presented in a practical form and analysed to enable the utmost information to be extracted are vital for the solution of the water engineer's problems.

Dr. J. Glasspoole spoke next for the meteorologists on rainfall. He dwelt first on the attainment of accuracy in rainfall measurement by the placing of rain-gauges in the proper exposures, the location of probably erroneous gauges from successive maps of annual rainfall and the need for inspection of rain-gauges. Next, he turned to the variations of annual rainfall over the British Isles. He thought there was scope for a more exact analysis of the variation of rainfall with height, because in mountainous areas records were too few for use of the planimetric method of determining rainfall by measuring areas between isohyets. He then dealt with the variability of rainfall with time with reference to the frequency of runs of wet or dry years, of droughts, and the seasonal variation of rainfall. Endeavours to unravel long-term trends in past years for forecasting the future had not been successful. Much was known of the frequency of monthly rainfalls which were of great value in estimating the reliability of rainfall; it was known for instance that it was reasonable to expect that in the driest years any group of four consecutive months will give at least 9 per cent. of the average annual rainfall at any station. Finally he referred to the information on intense falls, essential in the design of reservoir and drainage systems, for obtaining which a close network of recording rain-gauges is necessary owing to the rapid variation of rate of fall with distance. In the course of his talk he listed six ways in which the meteorologist could help the water engineer; inspection of rain-gauges, greater accuracy in the recording of snow in mountainous areas, better understanding of the physics of rain, statistical study of water data, prediction of future rainfall, determination of the area covered by heavy rain.

The third speaker was Mr. N. A. F. Rowntree describing the methods used by water engineers for assessing the available supply by means of rainfall and river-flow records. Among his points of especial meteorological interest were the desirability of publishing meteorological data for the

natural hydrological year of October to September rather than for the calendar year, the need for study of the effects of trees on rainfall and on run-off, the need for more statistical study of rainfall extremes, notably the possibility of the occurrence of extremes exceeding those adopted in design, and the value of the daily forecasts of cold spells and dry spells. Forecasts of the end of cold spells were of particular importance in minimizing waste of water from burst pipes.

Dr. H. L. Penman spoke next on components of the water balance of a catchment area illustrated by data for the Thames basin for the period 1932-36. The basic water-balance equation is that the water content of soil and rock at the beginning of a period plus rainfall during the period equals the sum of run-off and rainfall in the period and the water stored in the earth at the end. Of these quantities rainfall is the most accurately determined and run-off the next. The water in the underground storage is very difficult to determine and is probably best found as a difference from the other quantities. Evaporation is also very difficult to estimate and at present the accepted errors exceed the midsummer river-flow values. Finally Dr. Penman dealt with the effect of plants in removing water from the soil, showing that the net loss to the water engineer in this way could be equivalent to the dry-weather flow in the rivers for several months. Further, the magnitude of the soil-water deficit was a measure of the possible need for irrigation, a need which the water engineer might in the future be called on to meet at times, moreover, when other demands are greatest and supplies least.

The fifth speaker was Mr. B. J. Mason on the artificial production of rain. He said that the introduction of dry-ice, silver iodide or large water droplets from aircraft into suitable clouds had definitely shown the possibility of inducing some precipitation to occur, but large-scale work was for economic reasons possible only with silver-iodide-crystal generators on the ground. He thought there was no evidence that rainfall could be increased over large areas for long periods. In this work it was very difficult to separate variations in rainfall produced artificially from natural ones, and, further, nothing is known of the diffusion of silver-iodide particles or as to how long they remain active. He outlined his views on a suitable area for cloud-seeding trials having a line of burners across the wind between an up-wind target area and a down-wind control area. The two areas should have a high correlation of natural rainfall. He described also a method of selecting days at random for seeding using rainfall on days of no seeding as a control.

The last speaker, Dr. S. Buchan, discussed the geological aspects of underground water supply.

Some of the points raised in the discussion which followed were the validity of correlating rainfall anomalies in the target area with those over a wider area as a means of estimating the effectiveness of cloud seeding and the need for intensive observations over specially selected areas for the study of water-supply problems.

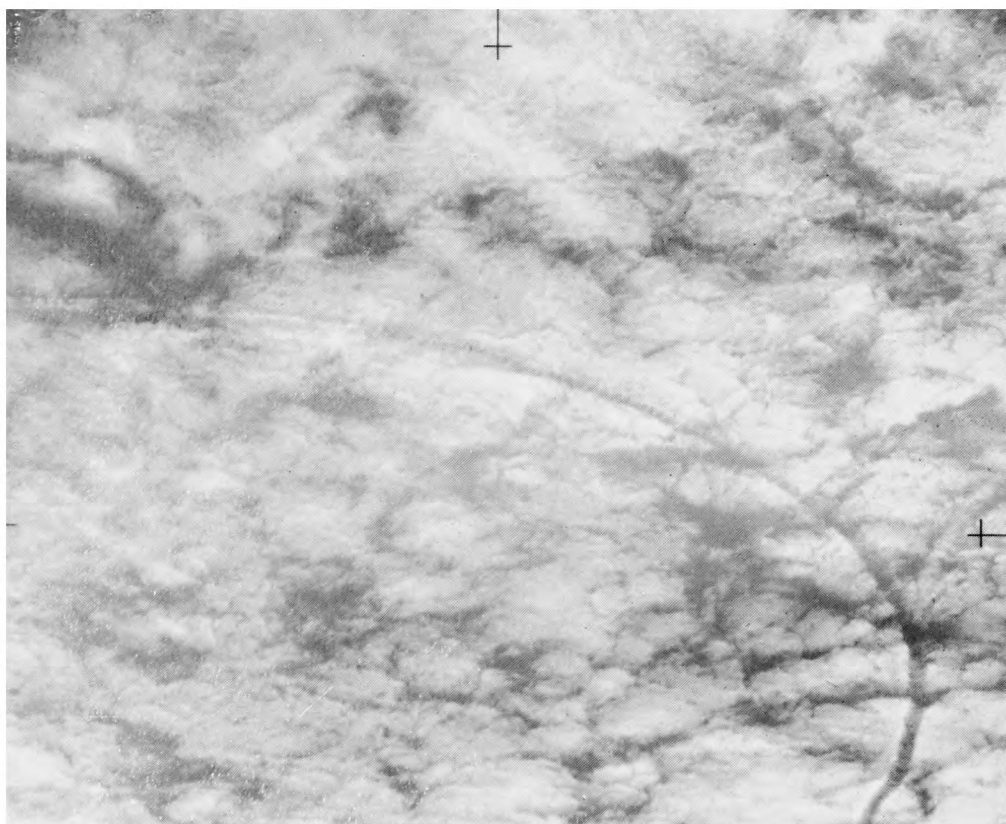
## **LETTERS TO THE EDITOR**

### **Circular condensation trails**

In his letter in your September 1954 issue, Mr. Hornbrey gives quite an accurate description of the very distinctive type of condensation trail commonly left by the B47 Stratojet. It is an important recognition feature of the aircraft, since its presence can be deduced with very little doubt at 15-20 miles distance with the naked eye in favourable conditions. The formation of the condensation trail rings can best be seen when the trail is semi-persistent (3-4 miles long), but can be recognized under conditions of persistence when the trail is not too stale.

It would perhaps be worth while to expand on some aspects of Mr. Hornbrey's description. Immediately after formation there are four separate trails, one from each engine pod, but the outer two quickly curve inwards (possibly under the influence of the wing trailing-vortex motion) and virtually join up with the corresponding inner trails. Even at this stage the cores of the two trails have a peculiarly smooth, hard appearance, with a rather diffuse "ectoplasm" which fairly quickly evaporates.

About one mile behind the aircraft the trails, which have hitherto been quite straight, begin to writhe, becoming kinked irregularly but symmetrically with respect to each other. The amplitude of the kinks increases continuously until each trail breaks up, and corresponding arcs join up to form the more-or-less complete rings described in Mr. Hornbrey's letter.



DISTRAILS SEEN OVER WEST FREUGH, STRANRAER, OCTOBER 14, 1954  
(see p. 58)



ARROW-SHAPED CLOUDS FORMED IN ASSOCIATION WITH  
THE DISTRAILS OVER WEST FREUGH, OCTOBER 14, 1954  
(see p. 58)



*Reproduced by courtesy of B. C. S. Wilson*

STRATOCUMULUS IN WAVES, CYRENAICA, MARCH 15, 1953  
(see p. 60)

I shall not offer a rival theory for this peculiar form of condensation trail, but suggest that the relevant cause is not purely meteorological. Striking regular formations of other kinds have often been observed in trails made by other aircraft types, but these are usually isolated cases which can be ascribed to special meteorological conditions. However, I have seen a Stratojet in company with a Canberra, the Stratojet forming the condensation trail typical of its kind, and the Canberra a quite indistinctive trail.

R. D. M. HARPER

*Grange Hostel, Farnborough, Hampshire, October 13, 1954*

### **Upper winds over Trinidad**

With the restitution of radio-sonde ascents from Chaguaramas, Trinidad ( $10^{\circ}41'N$ .  $61^{\circ}37'W$ .) in the New Year of 1954 after a break of a number of years, interest, previously stimulated by the goodwill flight of R.A.F. Canberras to South America late in 1953, was again focused on high-level winds in this area. Soundings became a regular twice-daily occurrence from January 27, 1954, and records were kept of the information received from that date until March 7, 1954. It is now of interest to inspect these data in view of the article by Bannon\* published in the September issue of the *Meteorological Magazine*.

Out of a possible 80 ascents, 60 were received during the period January 27 to March 7, 1954, all of which reached 40,000 ft. or higher, whilst 18 ascents reached over 70,000 ft. With the exception of one ascent on February 13, which is suspect, and that on March 7, when a wind of  $10^{\circ}29$  kt. was reported, winds at 30,000 ft. during the whole period were westerly, direction varying between  $220^{\circ}$  and  $320^{\circ}$ ; and of the 58 observations at this level 47 were between  $240^{\circ}$  and  $300^{\circ}$ . The average wind speed of these 58 observations regardless of direction was 29.0 kt. while the highest recorded was 73 kt. on January 27 and 28, both at 1500 G.M.T.

At 40,000 ft. a similar flow pattern was evident, although 11 occasions of wind flow between  $180^{\circ}$  and  $210^{\circ}$  and one northerly 61 kt. have been removed from the summary. There were therefore 46 occasions of winds between  $220^{\circ}$  and  $320^{\circ}$  of which 39 were between  $240^{\circ}$  and  $300^{\circ}$ . The average speed of these 46 occasions was 35.8 kt., the maximum being 62 kt. on January 27 at 1500 G.M.T.

At 45,000 ft. a maximum of  $270^{\circ}74$  kt. was attained on January 27 and  $290^{\circ}79$  kt. on February 1.

At 50,000 ft. occasional light easterly winds appeared while the westerlies took on a more west-north-westerly orientation, and of 47 observations, 41 had a westerly component, 36 came from between  $220^{\circ}$  and  $320^{\circ}$  and 34 from between  $270^{\circ}$  and  $320^{\circ}$ . The average speed of these 36 occasions was 30.8 kt.

One occasion, however, has been left out of this average, that of February 25 at 0300 G.M.T. On this occasion, winds were reported as having increased from 27 kt. at 40,000 ft. to  $310^{\circ}98$  kt. at 45,000 ft.,  $300^{\circ}100$  kt. at 50,000 ft. and  $290^{\circ}23$  kt. at 55,000 ft. Wind at 50,000 ft. 24 hr. previously was  $280^{\circ}27$  kt. and 24 hr. later  $310^{\circ}26$  kt. While sudden rather startling wind changes both in speed and direction have been observed elsewhere in these statistics, nothing

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\* BANNON, J. K.; Note on the sub-tropical jet stream in January and April 1951. *Met. Mag.*, London, **80**, 1954, p. 257.



quite of this order of magnitude has been observed, and it is therefore treated with some scepticism. However, it must be stated that it was the appearance of considerable variability between winds of no more than 12 hr. apart in the early flights from Chaguaramas which prompted the compilation of the records.

Above 50,000 ft. the westerlies decreased appreciably in strength, and after a height interval of varying thickness an easterly current returned. This was not usually the case below 65,000 ft., but at 75,000 ft. 16 of the 18 observations available were between  $80^{\circ}$  and  $100^{\circ}$  while the other two were  $60^{\circ}$  and  $110^{\circ}$  respectively; wind speed had increased rapidly. The average speed of these 18 easterly winds was 27.5 kt. Still further increase in the speed of the easterly current was evident between 75,000 and 85,000 ft. At 80,000 ft.  $110^{\circ}$  45 kt. was attained on February 6,  $100^{\circ}$  40 kt. on February 17,  $90^{\circ}$  38 kt. on February 18,  $90^{\circ}$  50 kt. on February 27 and  $100^{\circ}$  47 kt. on March 4, while on March 5 a wind of  $90^{\circ}$  70 kt. was attained at the limit of the ascent, 86,000 ft. One interesting feature of the ascent of February 25, the occasion of 100-kt. westerlies, was that the easterlies freshened at a much lower level than on any other occasion, reaching  $90^{\circ}$  33 kt. at 65,000 ft. and  $80^{\circ}$  55 kt. at the limit of the ascent, 67,000 ft.

It will be noted that the stations selected in Bannion's article are all in the vicinity of the northern tropic with the exception of Albrook Field in the Panama Canal Zone and Dakar. Albrook Field is on the approximate latitude of Trinidad, while Dakar is some  $4^{\circ}$  further north, but the point stressed here is that strong westerly winds are still well in evidence as close as  $10^{\circ}$  from the geographic equator and on occasion may increase to jet-stream proportions.

The flow during the period under consideration is marked by three maxima in the westerly current, between January 27 and February 1, on February 19, and between February 28 and March 4; on each occasion westerlies at some level attained a speed in excess of 50 kt. On the first two occasions the synoptic charts prepared at Trinidad indicated the polar front near or a little south of Bermuda, but on both occasions a trough existed ahead of it over the area of the Lesser Antilles, and on the first occasion this trough moved north-north-east or north-east and developed into a small low near the Azores. On the third occasion, a series of deep depressions occurred over the eastern United States and, although outbreaks of cold air occurred in the Gulf of Mexico and possibly also in the western Caribbean, there was little evidence of cold air further east or south-eastwards.

P. S. GRIFFITHS

*Meteorological Office, Piarco Airport, Trinidad, November 9, 1954*

### **Distrails**

On the morning of October 14 a Lincoln aircraft was carrying out bombing trials over Luce Bay between 1100 and 1200 G.M.T. at an altitude of 18,000 ft. From the ground it appeared that the aircraft was at times flying into a thin cloud layer, which was being reported at West Freugh as high altocumulus. Whilst flying in this cloud layer the aircraft was leaving a very distinct distrail. The photographs facing pp. 56 and 57 were taken at approximately 1155 G.M.T., and the weather conditions were as follows: visibility 40 miles, trace of cumulus base 2,000 ft., 3 oktas of altocumulus base 18,000 ft., thin cirrus above, total cloud amount 4 oktas.



After the aircraft had completed about five runs over the target area the arrow-shaped white cloud near the centre of the photograph began to form near the first distrail. It seems possible this cloud was produced in some way by the distrails, as it was completely isolated from the main cloud layer and appeared to be thicker. Its structure resembled an X-ray plate of the human chest. About fifteen minutes later the altocumulus cloud inside the distrails in the top right-hand corner of the photograph appeared to have *virga* below them. A second arrow-shaped cloud, shown towards the top right corner began to form but did not develop to so large a cloud as the first one.

J. M. STUART

*West Freugh, November 20, 1954*

[It seems likely the cloud in which the distrails were found was composed of supercooled water drops, and that the passage of the aircraft produced a form of ice-crystal seeding either by causing the drops near its path to freeze by turbulence or by shedding rime from its wings. The rapid growth of the crystals would cause them to fall out of the cloud layer leaving a clear lane through the cloud which would only slowly fill up by lateral diffusion. On this basis the denser arrow-shaped cloud would be composed of falling ice crystals and the reference to *virga* would appear to confirm this.

A similar effect has been produced in stratocumulus cloud by dry-ice seeding from a Meteorological Research Flight aircraft. Vertical wind shear would help to give the falling crystals an apparent lateral spread when viewed from the ground.

This explanation would not be satisfactory if the distrail formed immediately behind the aircraft, in which case the explanation of distrail formation given by Dr. Scorer\* of evaporation of the water drops by exhaust heating would be the more likely. Dr. Scorer's theory would not account for the formation of the arrow-shaped clouds.—R. F. JONES.]

## NOTES AND NEWS

### **Kew, Makerstoun and Eskdalemuir Observatories**

The account of the unveiling of the memorial tablets at Kew in the November issue recalls the Makerstoun Magnetic Observatory on the banks of the Tweed, for John Welsh received his training there under John Allan Broun, F.R.S.

The Makerstoun Observatory was erected by General Sir Thomas Makdougall Brisbane in 1841 and its observations were published in detail in the *Transactions of the Royal Society of Edinburgh* until 1855. A Mr. Russell was the first director, but J. A. Broun succeeded him within a year and shortly obtained the appointment of John Welsh as his assistant. After the departure of Welsh to Kew in 1850 and of Broun to Travancore in 1851, the editing of the Makerstoun results was carried out by Balfour Stewart at Kew. A successor of Broun at Travancore was Dr. A. Crichton Mitchell who later was in charge of Eskdalemuir Observatory some 30 miles south-west of Makerstoun.

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\* SCORER, R. S.; Contrails and distrails. *Met. Mag., London*, **82**, 1953, p. 27.

### **Cirrocumulus cloud at Cranwell**

The photographs of cirrocumulus cloud facing pp. 40 and 41 were taken at Cranwell at 1600 G.M.T. on November 15, 1954. The development of the cloud was watched by Messrs. Blackham, Clarke and Mason of the meteorological office at Cranwell during the afternoon as it increased from 1 okta at 1300 to 3 oktas in the south-west at 1600 G.M.T.; the weather was fine throughout.

The 1200 G.M.T. chart on that day showed a warm front along the east Irish coast, with an anticyclone centred over the Midlands. Rain associated with the warm front began at Cranwell at 2340 G.M.T.

### **Working exhibit of smoke-pollution sampling equipment at the Science Museum, South Kensington**

An observing station for measuring the smoke and sulphur-dioxide pollution in the London atmosphere has been established in the Science Museum by co-operation with the Fuel Research Station of the Department of Scientific and Industrial Research. The station is one of a number that are being established to permit a more detailed examination of atmospheric pollution in London and elsewhere.

The sampling equipment is displayed as a working exhibit in the Meteorology gallery. The smoke particles are captured on filter paper through which air is drawn, from just above the museum roof level, by means of a small electric pump. As a result, a grey stain appears on the filter paper, the intensity of which is a measure of the degree of smoke pollution. The same air is bubbled through a weak solution of hydrogen peroxide where the atmospheric sulphur dioxide is dissolved to form an acid solution, the strength of which is measured by standard chemical methods.

### **Stratocumulus in waves**

The lower photograph facing p. 57 was taken by Mr. B. C. S. Wilson from the cemetery of Sidi Ubeida on the main road from Benghazi to Benina in Cyrenaica on March 15, 1953, about midday. The cloud was associated with a weakening cold front extending from Greece to the Gulf of Sidra and thence westwards as the warm front of a depression moving eastwards across Algeria.

During March 15 the surface wind was gusty and increasing from the east, reaching gale force during the afternoon; there was intermittent slight rain at 1520. At 6,000 ft. (800 mb.) the wind was little more than 20 kt. but from the south-west; and the radar-wind ascents from Benina showed a wind shear at about the level of the cloud increasing from 305° 18 kt. at 0200 to 290° 32 kt. at 1515 G.M.T. Since the photograph was taken looking approximately northwards the waves can be seen to be roughly at right angles to the direction of the wind shear.

### **Council for the Promotion of Field Studies**

The Council have recently published details of their courses for 1955. The courses include one on the physical basis of meteorology with special reference to current weather to be held at the Malham Tarn Field Centre (near Settle,

Yorkshire) during August 24–31. The meteorological offices at Preston and Squires Gate assist in the instruction at Malham Tarn by providing data for plotting synoptic charts and by discussing current weather and forecasts.

Further particulars may be obtained from the Council at Balfour House, Finsbury Pavement, London, E.C.2.

## REVIEW

*Klima und Wetter in Arosa.* By Prof. Dr. F. W. Paul Götz, 9 $\frac{3}{4}$  in.  $\times$  7 $\frac{1}{4}$  in., pp. 148, *Illus.*, Verlag Huber & Co., Ag., Frauenfeld, 1954. *Leinen Fr.* 18.70; *DM* 18.

In this beautifully produced volume Dr. Götz gives a very detailed and vivid description of the climate and weather of Arosa in eastern Switzerland based on observations made since 1890. Separate chapters cover temperature, dryness of the air, atmospheric purity and ozone content, wind, cloudiness, precipitation and snow-cover, sunshine and radiation. Finally, there is a chapter on the variations in weather through the year, and on secular changes in climate. Each chapter contains a large number of tables and curves of mean values and variations of the element concerned. There are a number of good photographs of the observing station, instruments, clouds and optical phenomena.

The variations of the elements are treated in relation to the synoptic situation. For example, interdiurnal variability of temperature is connected with air-mass changes. The book is an excellent example of a treatise on synoptic climatology as well as on climatology.

The radiation climate of Arosa merits special mention. The mean annual duration of bright sunshine is 1,900 hr., 51 per cent. of the possible, and the mean annual global radiation is 127 Kg. cal./cm.<sup>2</sup>, values which are of the order of 1.4 times those for Kew.

The secular variation of each element is described with 10-yr. overlapping means. It is particularly interesting to compare the curves for the separate elements. The secular variation of temperature over the last century has been much discussed, but the reviewer believes this book affords one of the first opportunities of comparing the secular variations of several elements. Curves of 10-yr. overlapping means of temperature are given for the year, and the winter and summer half-years. All are roughly parallel. The 10-yr. overlapping means for the year show a fall from about 2.8°C. for periods terminating about 1900 to 2.4°C. for those terminating about 1910 followed by a rise to a peak of 3.2°C. for 1920–29, after which period there has been an irregular mainly falling tendency down to 2.8°C. for the 10 yr. ending in 1945.

The secular variations of the frequency of occasions of interdiurnal changes of temperature exceeding 5°C. for winter and spring provide curves which are roughly the inverse of those for temperature. The summer and autumn curves have less marked changes and show on the whole a rise throughout.

Cloudiness had a secular variation roughly the inverse of the variation of temperature. The 10-yr. mean was 5.4 tenths in 1891–1900. The value rose to 5.6 tenths in 1903–12 and fell to 5.4 tenths in 1912–21. The means have since risen and the value for 1936–45 was 6.3 tenths. The variation has been

very similar in all seasons and is shown to have been the same over the whole of Switzerland. The 10-yr. overlapping means of annual precipitation rose from about 1,200 mm. for the period 1891–1900 to 1,400 mm. for 1909–19 since when there has been a very irregular fall.

Summarizing the secular variation of climate Dr. Götz shows that about the turn of the century the climate became more maritime in nature followed by a return to a more continental type in the last ten years.

G. A. BULL

## HONOURS

The following awards were announced in the New Year Honours List, 1955:—

### KNIGHT BACHELOR

Dr. O. G. Sutton, C.B.E., F.R.S., Director of the Meteorological Office.

### O.B.E.

Mr. H. W. L. Absalom, Assistant Director, Meteorological Office.

### M.B.E.

Miss L. F. Lewis, Experimental Officer, Meteorological Office.

Mr. H. L. Pace, Senior Experimental Officer, Meteorological Office.

### B.E.M.

Mr. H. A. Curtis, Senior Scientific Assistant, Meteorological Office.

## OBITUARY

*Mr. Terence Brady.*—We regret to announce the death of Mr. Brady, Senior Scientific Assistant, as a result of the accident to the British Overseas Airways Corporation aircraft at Prestwick on December 25, 1954. Mr. Brady joined the Office in 1941 and the whole of his service was spent at outstations. After a tour of duty in the West Indies, he served alternately at Prestwick and London airports. It was from London Airport that Mr. Brady was travelling home to Scotland on Christmas leave when the accident occurred.

## METEOROLOGICAL OFFICE NEWS

**Award.**—It was announced in the *London Gazette* of November 26, 1954 that Mr. R. A. Hamilton, Principal Scientific Officer, had been awarded a Clasp to his Polar Medal for good services with the British North Greenland Expedition 1952–54 as Chief Scientist and Second-in-Command, 1952–53. Mr. Hamilton was previously awarded a Polar Medal for services with the Oxford University Arctic Expedition to North East Land in 1935–36.

**Retirement.**—Mr. C. Smith, Senior Experimental Officer, retired on December 31, 1954. He joined the Office in 1920 after service during the First World War in the West Yorkshire Regiment and as Observer in the Royal Flying Corps, when he was shot down and captured. During his 34 years' service, Mr. Smith has served both at Headquarters and at aviation outstations, including two tours of duty overseas in the Middle East. From 1946 until his retirement he served at Headquarters in the branch dealing with the Royal Air Force Overseas.

## WEATHER OF DECEMBER 1954

Mean pressure was below normal between Greenland and Scandinavia, as much as 13 mb. in places between Iceland and Norway but generally about 8 mb. At the Azores the mean pressure was 3 mb. above normal. The resulting mean pressure distribution was associated with westerly winds across the Atlantic and western Europe. The mean pressure over the central region of Russia was about 1044 mb.; this was about 8 mb. above normal.

The mean temperature was above normal over the whole of western Europe, generally 3-4°F. but as much as 9-10°F. in northern Scandinavia.

In the British Isles the weather was mainly stormy and mild though there was a colder period from about the 5th to the 12th or 13th. In the south the second half of the month was mainly dry.

During the first few days depressions moved east-north-east across the North Atlantic and passed between Iceland and Scotland giving unusually mild weather; on the 2nd temperature reached between 55° and 60°F. over almost the whole country. There was frequent rain, heavy at times in the north and west; for example, 3·35 in. at Borrowdale, Cumberland, 3·24 in. at Ribbleshead, Yorkshire and at Patterdale, Westmorland, and 2·01 in. at Glenshiel, Ross and Cromarty on the 1st, 2·94 in. at Oakley Quarries, Merionethshire and 2·91 in. at Corris, Montgomeryshire on the 2nd and 2·43 in. at Glenquoich, Inverness-shire on the 3rd. On the 4th a depression crossed northern Scotland and was accompanied by north-westerly gales over much of the country, a gust of 85 kt. being recorded at Harlech in north Wales. Temperature fell with the influx of the north-westerly winds. Subsequently the track of depressions veered and on the 6th and 7th a weak system moved south-east across the British Isles bringing snow as far south as southern England. On the 8th a depression on a parallel track deepened off Ireland, moved towards Wales and crossed northern England and Scotland on the 9th and 10th giving widespread and severe gales. There was heavy rain, particularly in the south and east, on the 8th and moderate rain locally in the north on the 9th. Thunderstorms occurred rather widely in the south and east on the 8th, and were associated with heavy rain, hailstones up to  $\frac{1}{2}$  in. in diameter, and minor tornadoes locally in south-east England including the west London area, where there was considerable damage to buildings; 2·09 in. was registered at Princes Risborough, Buckinghamshire. The period 5th to 12th or 13th was generally rather cold; at Eskdalemuir temperature remained below freezing point throughout the day on the 7th. With the departure of this deep depression less active systems travelled across the Atlantic to the British Isles; unsettled weather persisted until the 14th with some rain in most places every day. The 14th was sunless over almost the whole country though temperature rose to 55°F. in places. For most of the third week an anticyclone extended from west to east across Europe and frontal activity was confined mainly to western and northern districts (2·75 in. of rain fell at Glenquoich on the 17th and 2·15 in. at Glenshiel on the 18th). In the south there were sunny periods but a good deal of fog, particularly during the nights of the 15th, 16th and 17th. From the 20th the dominant system was an anticyclone which came from America and intensified to west-south-west of the British Isles; on the 21st, however, a deep depression moving round it from Iceland towards Denmark brought a period of rather cold, locally severe, north-westerly gales over most of the country and a gust of 90 kt. at Kinloss in north-east Scotland. Rain or showers occurred in most places and on the 22nd rainfall was heavy in Argyllshire and inland in north Wales; for example, 2·30 in. at Dalnes and 2·22 in. at Llangurig, Montgomeryshire. From the 25th to the 29th the anticyclone off our south-west coasts moved very slowly east and mild air from the Azores region spread to all districts; weather was mainly dull and also dry in the south but with heavy rain at times in the north (2·10 in. at Corrykinloch, Sutherland on the 28th). By the 30th the anticyclone over Germany had linked up with high pressure over Scandinavia and there was little rain anywhere except on the south-west coasts of Ireland.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	62	17	+3·6	89	—2	108
Scotland ...	59	12	+1·9	137	+4	80
Northern Ireland ...	58	29	+3·2	120	+3	58

# RAINFALL OF DECEMBER 1954

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	1·57	66	<i>Glam.</i>	Cardiff, Penylan ...	3·92	78
<i>Kent</i>	Dover ...	1·39	45	<i>Pemb.</i>	Tenby ...	3·73	75
"	Edenbridge, Falconhurst	2·12	64	<i>Radnor</i>	Tyrmynydd ...	7·10	86
<i>Sussex</i>	Compton, Compton Ho.	3·88	94	<i>Mont.</i>	Lake Vyrnwy ...	7·79	110
"	Worthing, Beach Ho. Pk.	2·64	88	<i>Mer.</i>	Blaenau Festiniog ...	16·48	130
<i>Hants.</i>	Ventnor Park ...	3·47	103	"	Aberdovey ...	6·19	130
"	Southampton (East Pk.)	2·92	80	<i>Carn.</i>	Llandudno ...	2·51	87
"	South Farndoroug	2·49	86	<i>Angl.</i>	Llanerchymedd ...	3·32	76
<i>Herts.</i>	Royston, Therfield Rec.	1·65	71	<i>I. Man</i>	Douglas, Boroug Cem.	7·20	146
<i>Bucks.</i>	Slough, Upton ...	2·01	80	<i>Wigtown</i>	Newtown Stewart ...	6·59	122
<i>Oxford</i>	Oxford, Radcliffe ...	2·02	82	<i>Dumf.</i>	Dumfries, Crichton R.I.	4·28	100
<i>N'hants.</i>	Wellingboro' Swanspool	2·59	110	"	Eskdalemuir Obsy. ...	8·61	123
<i>Essex</i>	Shoeburyness ...	1·10	60	<i>Roxb.</i>	Crailing... ...	2·62	97
"	Dovercourt ...	1·48	69	<i>Peebles</i>	Stobo Castle ...	5·17	136
<i>Suffolk</i>	Lowestoft Sec. School ...	1·54	66	<i>Berwick</i>	Marchmont House ...	2·39	85
"	Bury St. Ed., Westley H.	2·25	93	<i>E. Loth.</i>	North Berwick ...	1·75	82
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·16	85	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	2·67	114
<i>Wilts.</i>	Aldbourne ...	3·02	93	<i>Lanark</i>	Hamilton W. W., T'nhill	6·05	140
<i>Dorset</i>	Creech Grange... ...	3·77	85	<i>Ayr</i>	Colmonell, Knockdolian	...	...
"	Beaminster, East St. ...	3·63	76	"	Glen Afton, Ayr San. ...	9·35	146
<i>Devon</i>	Teignmouth, Den Gdns.	3·41	81	<i>Renfrew</i>	Greenock, Prospect Hill	8·71	117
"	Ilfracombe ...	4·45	92	<i>Bute</i>	Rothsay, Ardenraig ...	6·05	111
"	Princetown ...	8·39	72	<i>Argyll</i>	Morven, Drimnin ...	8·73	111
<i>Cornwall</i>	Bude, School House ...	2·98	68	"	Poltalloch ...	10·97	172
"	Penzance ...	4·70	83	"	Inveraray Castle ...	17·34	175
"	St. Austell ...	5·39	88	"	Islay, Eallabus ...	6·15	104
"	Scilly, Tresco Abbey ...	3·64	78	"	Tiree ...	5·55	106
<i>Somerset</i>	Taunton ...	2·43	73	<i>kinross</i>	Loch Leven Sluice ...	4·32	110
<i>Glos.</i>	Cirencester ...	2·55	76	<i>Fife</i>	Leuchars Airfield ...	3·02	122
<i>Salop</i>	Church Stretton ...	2·74	78	<i>Perth</i>	Loch Dhu ...	13·77	137
"	Shrewsbury, Monkmore	1·90	78	"	Crieff, Strathearn Hyd.	6·00	134
<i>Worcs.</i>	Malvern, Free Library...	1·66	60	"	Pitlochry, Fincastle ...	6·12	151
<i>Warwick</i>	Birmingham, Edgbaston	2·35	87	<i>Angus</i>	Montrose, Sunnyside ...	2·58	92
<i>Leics.</i>	Thornton Reservoir ...	2·77	103	<i>Aberd.</i>	Braemar ...	6·27	176
<i>Lincs.</i>	Boston, Skirbeck ...	2·23	104	"	Dyce, Craibstone ...	3·35	99
"	Skegness, Marine Gdns.	1·58	72	"	New Deer School House	5·13	150
<i>Notts.</i>	Mansfield, Carr Bank ...	...	...	<i>Moray</i>	Gordon Castle ...	4·07	151
<i>Derby</i>	Buxton, Terrace Slopes	8·24	145	<i>Nairn</i>	Nairn, Achareidh ...	3·64	178
<i>Ches.</i>	Bidston Observatory ...	2·74	103	<i>Inverness</i>	Loch Ness, Garthbeg ...	8·45	183
"	Manchester, Ringway...	5·02	155	"	Glenquoich ...	25·06	171
<i>Lancs.</i>	Stonyhurst College ...	6·71	138	"	Fort William, Teviot ...	16·33	160
"	Squires Gate ...	3·71	119	"	Skye, Broadford ...	...	...
<i>Yorks.</i>	Wakefield, Clarence Pk.	2·38	98	"	Skye, Duntuilum ...	5·99	96
"	Hull, Pearson Park ...	2·24	93	<i>R. &amp; C.</i>	Tain, Mayfield... ..	4·92	173
"	Felixkirk, Mt. St. John...	2·19	91	"	Inverbroom, Glackour...	...	...
"	York Museum ...	1·97	88	"	Achnashellach ...	15·47	163
"	Scarborough ...	1·64	69	<i>Suth.</i>	Lochinver, Bank Ho. ...	6·78	122
"	Middlesbrough... ..	1·69	87	<i>Caith.</i>	Wick Airfield ...	5·49	178
"	Baldersdale, Hury Res.	4·67	121	<i>Shetland</i>	Lerwick Observatory ...	6·13	128
<i>Nor'l d.</i>	Newcastle, Leazes Pk....	1·80	77	<i>Ferm.</i>	Crom Castle ...	4·00	97
"	Bellingham, High Green	4·10	113	<i>Armagh</i>	Armagh Observatory ...	3·73	119
"	Lilburn Tower Gdns. ...	2·45	93	<i>Down</i>	Seaforde ...	4·81	117
<i>Cumb.</i>	Geltsdale ...	5·01	131	<i>Antrim</i>	Aldergrove Airfield ...	3·74	109
"	Keswick, High Hill ...	8·46	126	"	Ballymena, Harryville...	6·04	136
"	Ravenglass, The Grove	4·68	102	<i>L'derry</i>	Garvagh, Moneydig ...	...	...
<i>Mon.</i>	A'gavenny, Plás Derwen	3·31	67	"	Londonderry, Creggan	5·79	132
<i>Glam.</i>	Ystalyfera, Wern House	7·15	86	<i>Tyrone</i>	Omagh, Edenfel ...	5·42	128

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METEOROLOGICAL OFFICE

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## TOTAL-RADIATION FLUXMETER

By J. MacDOWALL, B.A.

This instrument was designed at Kew Observatory to measure the net flow of radiation through a horizontal surface. In principle the method of doing this is quite simple; it is only necessary to place a horizontal plate, which is blackened on both surfaces, in this radiation field and then to measure the temperature difference between the upper and lower surface<sup>1</sup>. The problem is complicated somewhat when a device of this sort is used in the open for meteorological purposes, first, because of the wide range of wave-length to which the instrument must respond with equal sensitivity, and secondly, because a means must be found to eliminate the effect of the wind blowing on the plate and causing large variations in the energy interchange between the surfaces of the plate and the air. It is not possible to enclose the plate completely whilst still satisfying the first requirement, because there is no readily available material equally transparent over the wave-length range of meteorological interest, i.e. from about  $0.3 \mu$  to beyond  $40 \mu$ . The device for overcoming this difficulty is to ensure, by artificial means, that the plate is always operating in a blast of air. This sustained blast, directed equally over the plate, keeps the energy interchange between the surfaces of the plate and the air at a high level which is not appreciably altered when the free wind varies. With this radiometer the response is kept constant to 2 per cent. in winds up to 20 m.p.h. Instruments of this type have been constructed by G. Falkenberg<sup>2</sup>, and independently by W. Morikofer<sup>3</sup> and J. T. Gier<sup>4</sup>. In Falkenberg's "vibration pyranometer" the effect was obtained by rapidly vibrating the horizontal plate in its own plane so that even under calm conditions it was effectively operating in rapidly moving air. The other two instruments used a stationary plate ventilated by a small blower. The instrument to be described is very similar to the one designed by Gier.

**Construction.**—*General.*—The instrument consists of three parts: the radiation-sensitive element in the form of a thin 3-in.-square plate, a blower to maintain the steady blast of air, and a nozzle which directs the air from the blower symmetrically over the upper and lower surfaces of the element. A photograph of the complete radiometer is shown facing p. 80. It will be noticed that the sides of the nozzle are extended alongside the element by two side plates; the function of these is to constrain the air flow over the element and to provide a little protection against deflection of the blast by broadside winds. Morikofer at the 1951 meeting of the International Union of Geodesy

and Geophysics maintained that it was essential to use an aerodynamically-shaped nozzle and an element in the form of an aerofoil. This instrument is not aerodynamically designed, but it was found most important for the disposition of the element, side plates and nozzle mouth to be symmetrical about a plane through the centre of the element. Any inaccuracy in this arrangement, or any asymmetry in the design of one of these parts, will lead to incomplete wind compensation (discussed below). Power for the blower was drawn from the mains and regulated with a simple carbon-pile voltage regulator to  $24 \pm 1$  V. A variation in the voltage of this size was found to keep the ventilation velocity constant to 0.7 per cent.

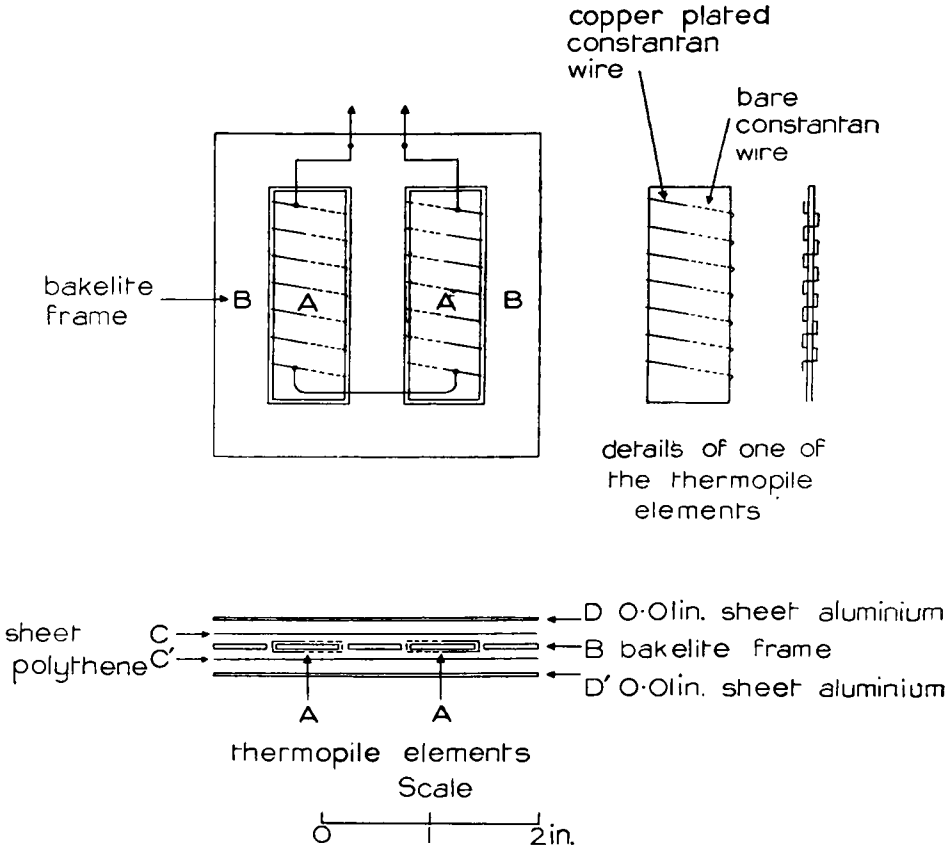


FIG. 1—RADIOMETER ELEMENT

*Sensitive Element.*—Fig. 1 shows the radiometer element in more detail. It has a sandwich-like structure, bakelite in the centre with  $1/100$  in. sheet aluminium on top and bottom. The aluminium surfaces are separated from the bakelite core by thin sheet polythene. Two slots are cut out of the central bakelite sheet forming a frame for the thermopile. This is made by winding about 60 turns of 46 s.w.g. constantan wire around bakelite strips whose size is slightly smaller than the slots in the bakelite frame. One half of each turn of wire on the strips is copper plated, so that a series of copper-constantan thermo-junctions is formed down the centre line of the top and bottom surfaces of each strip. These thermopile strips fit inside the bakelite frame and the connexions between the strips and to the external leads are made to the copper-plated part of the last turn on each strip. The whole sandwich is



stuck together with Everett's wax. When the element is mounted in position at the mouth of the nozzle, a specially selected optical black is used to paint the aluminium surfaces.

**Characteristics of the radiometer.**—*Effect of wind speed on the sensitivity.*—

The effect of wind was examined in the laboratory by placing the radiometer in a crude wind tunnel formed by the floor, a large horizontal plane and a powerful blower. By altering the distance between the radiometer and this blower different wind speeds could be simulated. A 2,000-W. tungsten-filament lamp, whose supply was hand regulated, provided a constant source of radiation. Two positions of the radiometer were tested:—

- (i) Wind in opposition to radiometer ventilation
- (ii) Wind at right angles to radiometer ventilation.

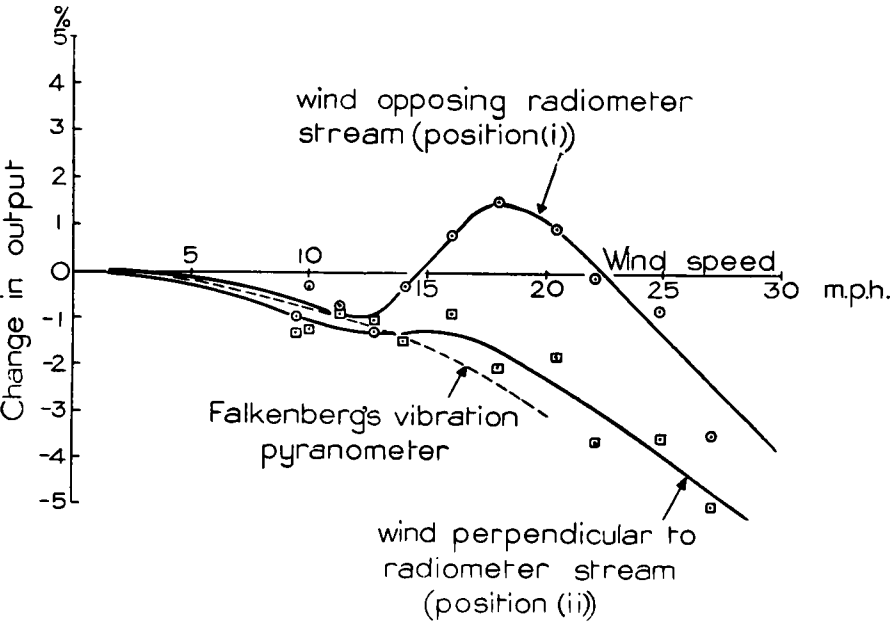


FIG. 2—EFFECT OF WIND ON THE OUTPUT OF THE RADIOMETER

In Fig. 2 the percentage change in the output of the radiometer is plotted against the wind speed for the two positions (i) and (ii). The dotted curve shows the result of a similar experiment performed by Falkenberg with his “vibration pyranometer”. Table I gives Gier’s figures.

TABLE I—CHANGE IN THE OUTPUT OF GIER’S RADIOMETER

	Wind speed (m.p.h.)										
	5.7	7.3	9.8	11.4	15.0	15.3	19.8	20.5	23.6	25.0	27.6
	<i>per cent.</i>										
Position (i)	4.8	...	...	0.0	-2.5	...	-16.0	...	...	-11.0	-11.0
Position (ii)	...	-2.5	-3.4	...	...	-4.2	...	-6.3	-8.3	...	...

During the course of this experiment the importance of correctly aligning the position of the element, nozzle and side plates was discovered. More extensive wind-tunnel tests were performed with a Mk II instrument of large design and without the protective side plates. This instrument was tested in position (ii). If the radiometer blast of air was moving south, then the wind directions used

were east and west. Table II shows the final results of this experiment<sup>1</sup>. The importance of alignment, though not mentioned by Gier, has been noted by Fransilla<sup>5</sup> who incorporated a device for testing this condition and vanes for adjustment of the air flow.

TABLE II—EFFECT OF WIND ON THE OUTPUT OF THE MK II INSTRUMENT IN POSITION (ii)

	Wind speed (m.p.h.)						
	0.0	5.0	10.2	16.0	20.5	24.5	29.3
	<i>per cent.</i>						
East wind	100.0	99.5	99.3	98.5	98.9	99.8	100.5
West wind	100.0	99.7	99.5	98.6	97.4	97.4	97.8

*Aperture of the radiometer.*—The amount of the sphere that can be “seen” by the element is defined on two sides by the side plates and on the third side by the leading edge of the nozzle; the fourth side is unobstructed. On three sides the sensitive central area of the element will only partly “see” portions of the upper hemisphere between  $+22^\circ$  and  $+6^\circ$  elevation, similarly for the lower hemisphere. No radiation within  $6^\circ$  above and below the horizon is accepted on these three sides. If the radiometer were placed in a field of radiation isotropic over the upper hemisphere, calculation shows that its effective aperture is 97 per cent. of the hemisphere<sup>1</sup>. When used in day-time it is undesirable for the shadow of the side plates to be too near the central sensitive area. This instrument was only required to work for periods of about one hour, so it was orientated according to the sun’s position.

*Paint.*—The upper and lower surfaces were painted with special optical black. The emissivity of this paint has been investigated by the National Physical Laboratory in the visual range and for black-body radiation at  $2,580^\circ$ ,  $1,000^\circ$  and  $200^\circ\text{C}$ . It is shown by equation (3) on p. 70 how, during the course of calibration, the emissivity of a piece of tinned copper painted with this optical black is determined. The temperature of this sample was about  $20^\circ\text{C}$ . ( $\lambda_{\text{max}} \approx 10\mu$ ). The emissivity of the painted surface showed no significant variation in these ranges.

*Cosine law for surface of radiometer.*—When the radiometer is placed in a parallel beam of radiation, the output should be proportional to the cosine of the angle of incidence. This was investigated and shown to be satisfactory.

**Calibration of the radiometer.**—For meteorological work this instrument must be equally sensitive to radiation in the wave-length range from about  $0.3\mu$  to  $40\mu$ . The paint used for the surface of the element did not show any appreciable variation of emissivity with wave-length. It was still considered necessary to determine the sensitivity of the radiometer when used in fields of long-wave ( $> 3\mu$ ) and short-wave (approximately  $0.3\mu - 3\mu$ ) radiation, both in the laboratory and in the open. Four separate methods were used, two of them in the laboratory with long-wave and short-wave radiation, whilst the other two were both done in the field, one at night when the radiation is long wave only, and the other during the day when the radiation is a mixture of long-wave atmospheric and terrestrial radiation with short-wave solar and sky radiation. The results of these four methods are tabulated in Table III.

$\text{V.}/\text{mW.}/\text{cm.}^2$ 

*Laboratory calibration with long-wave radiation.*—One of the difficulties in calibrating a radiometer with the radiation of a “low-temperature” body is to keep radiation from the surroundings constant, also care must be taken to see that no heat is convected (either by forced or natural convection) from the body to one surface of the radiometer. To these ends a copper calibrating box, shown in Fig. 3, was constructed. This box was painted black on the inside and covered with felt on the outside. In the top of this box a square aperture B was cut and holes were made at each end; one C just large enough to allow the radiometer to be placed directly underneath the aperture, the other D to allow air blown through the radiometer to escape. Flaps E, E' were fitted to the edges of this latter hole and were adjusted so that there was no flow of air through the aperture B when the radiometer was in position and blowing.



This condition was checked by placing a thin sheet of paper over the aperture. The efficiency of the box as a radiation enclosure was tested by placing a shutter over the aperture and measuring the output of the radiometer over 24 hr. If left undisturbed for 2–3 min. the box was found to be effective in so much that it reduced any flux inside the box to less than 0.01 mW./cm.<sup>2</sup>. A large cavity black body, originally used by W. H. Dines, was placed over the aperture. One junction X of a calibrated thermo-couple was soldered to the calibrating box directly underneath the radiometer, the other junction Y was placed in the water bath which surrounded the black body. The dimensions of the aperture, sensitive element and the distance of the radiometer below the aperture were measured. From these measurements the effective aperture, which Bossy and Pastiels<sup>6</sup> call the “rapport surface-angle”, was calculated<sup>1</sup>.

Now, if  $T_1$  is the temperature of the cavity black body,  $T_2$  the temperature of the calibrating box,  $D$  the output of the radiometer,  $\varepsilon$  the emissivity of the inside surface of the box,  $F$  the flux of radiation normal to the radiometer surface,  $\psi$  the effective aperture and  $\sigma$  Stefan’s constant, then, neglecting water vapour and carbon-dioxide absorption,

$$F = \psi\sigma (T_1^4 - \varepsilon T_2^4), \quad \dots \dots (1)$$

and, since the temperature difference between the surfaces of the radiometer is proportional to the flux of radiation,

$$F = \lambda D, \quad \dots \dots (2)$$

therefore

$$\frac{D}{T_2^4} = \frac{\psi\sigma}{\lambda} \left[ \left( \frac{T_1}{T_2} \right)^4 - \varepsilon \right]. \quad \dots \dots (3)$$

Now in the calibration  $T_1$  was varied from 50° to 25°C. and  $T_2$  varied between 20° and 21°C. By plotting  $D/T_2^4$  against  $(T_1/T_2)^4$  we get a straight line and so determine  $\lambda$  and  $\varepsilon$ , the calibration constant of the radiometer and the emissivity of the bottom surface of the calibrating box. From the air temperature and humidity these values are corrected for the effect of water vapour and carbon-dioxide absorption<sup>7</sup>.

*Laboratory calibration using short-wave radiation.*—The radiation for this calibration was produced by a 2,000-W. lamp, and intensity of the radiation was measured by means of a Linke-Feussner actinometer carefully set at the same distance from the lamp as was the radiometer. When comparing two instruments of such widely differing apertures care must be taken to see that all contributions to the radiation flux through the radiometer are accounted for by the Linke-Feussner actinometer. For although the major part of the radiation field underneath a 2,000-W. tungsten-filament lamp consists of the short-wave radiation from the incandescent filament, there exists an appreciable field of long-wave radiation due in the most part to the large and heated box which surrounds the 2,000-W. lamp. To eliminate effects of this sort the radiometer was placed in between two large sheets of glass, which act as a filter opaque to all radiation whose wave-length is greater than about 3  $\mu$ . Any contribution to the flux of radiation due to a temperature difference between the glass sheets can be measured by reversing the position of the Linke-Feussner actinometer, pointing it first at the lamp through one glass sheet and then at the other glass sheet. The voltage to the lamp was hand regulated, and a time schedule was adhered to throughout the experiment because the temperature in the laboratory rose by 2°C. during this experiment.

The Linke-Feussner actinometer was itself standardized, both on the sun and in the laboratory, against the Ångström pyrheliometer. The output of the Linke-Feussner actinometer for a radiation intensity of 1 gm. cal./cm.<sup>2</sup>/min. was found by these two methods to be  $10.8 \pm 0.2$  mV. and  $10.8 \pm 0.1$  mV. respectively.

*Field method at night (long-wave radiation).*—At night the radiation field is purely long-wave radiation of atmospheric and terrestrial origin. It is only on cloudless nights, however, that the radiative flux can be measured. This is done by pointing a Linke-Feussner actinometer first at the sky and then at the ground<sup>7</sup> and comparing the result of this measurement with the output of the radiometer.

*Field method during the day (long- and short-wave radiation).*—During the day the radiative flux consists of a mixture of short-wave radiation from the sun and sky, mixed with atmospheric and terrestrial long-wave radiation. The long-wave component can only be measured under cloudless conditions. On these days the output of the radiometer was compared in the field with the radiative flux computed by means of a Moll-Gorczynski solarimeter and the Linke-Feussner actinometer. By pointing the solarimeter first at the sky and then at the ground the flux of short-wave radiation was computed. Each component of the long-wave radiation was measured by two readings with the actinometer, one using a glass filter and one without the glass filter.

**Conclusion.**—The radiometer provides a convenient method for the measurement of net radiative flux near the ground, and is particularly adapted for continuous measurement. The instrument will not function correctly in rain, or in fog, as the surfaces wetted would act as a “wet-bulb”. Prolonged exposure to rain or hail would entail repainting and subsequent recalibration. Experience at Kew Observatory with a continuously recording Mk II instrument has been that light rain does not affect the calibration of the instrument but in fact performs the useful function of washing away deposits of soot which have a bad effect on the cosine characteristic. An instrument of this type has been functioning continuously for some time at Kew Observatory, and during the first six months’ use the calibration constants varied only within the range of  $\pm 5$  per cent. A photograph of this installation is shown facing p. 80.

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#### ERRATUM

February 1955, PAGE 56, line 9; for “the sum of run-off and rainfall in the period” read “the sum of run-off and evaporation in the period”.

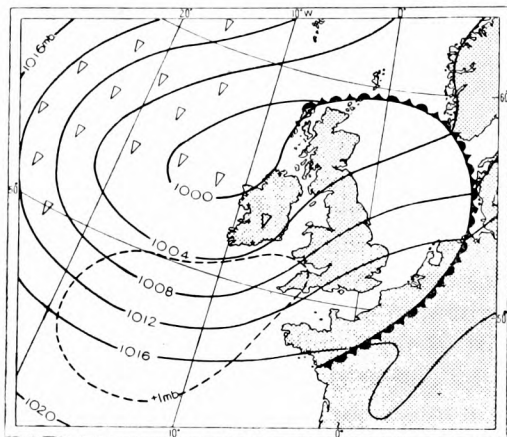
## OBSERVATIONS OF SMALL SHOWER CLOUDS

By I. C. BROWNE, Ph.D., G. J. DAY, B.Sc. and F. H. LUDLAM

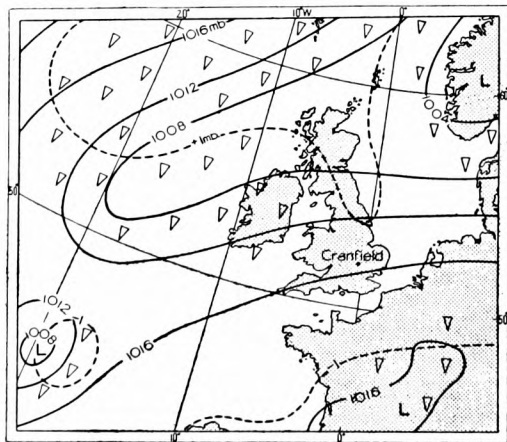
**Summary.**—Observations are recorded of the development of cumulus inland over England on three successive days; on two days the clouds attained a maximum depth of about 6,000 ft., which was just sufficient to permit the formation of showers, evidently by the coalescence mechanism since the minimum summit temperatures were barely below  $0^{\circ}\text{C}$ .

**Synoptic situation.**—During the period August 4–14, 1952, the Cavendish Laboratory, Cambridge, the Meteorological Office and the Department of Meteorology, Imperial College, London, participated in investigations of cumulus clouds inland over England in the vicinity of Cranfield, Bedfordshire, using aircraft of the Meteorological Research Flight, Cambridge University Air Squadron, and the Royal Aircraft Establishment, and gliders of the Imperial College. The following account is a summary of observations made on the last three days.

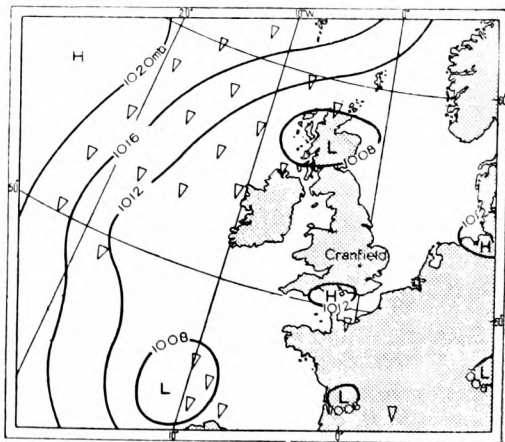
On these days a complex low-pressure area extending from west of Ireland to Scandinavia remained almost stationary (Fig. 1). A cold front moved eastward across England overnight on August 11, and on the three following days a west-south-westerly stream of well modified polar maritime air flowed over England and Wales. Surface winds reached 15–20 kt. on August 12 and



August 12



August 13



August 14

FIG. 1—SURFACE WEATHER MAPS 1200 G.M.T., AUGUST 12–14, 1952

Full lines are isobars, pecked lines are isallobars, and triangles denote showers.

10–15 kt. on August 13, but the speed of the air stream was decreasing, and by August 14 the low-level winds over England had become light and variable in direction.

**Diurnal course of cumulus development.**—Each morning cumulus formed overland in otherwise almost cloudless skies and developed during the day, as shown in Fig. 2. The development reached a peak in the afternoon, but each day the vertical growth of the cumulus was restricted by a persistent inversion which was found at heights varying between about 7,000 and 11,000 ft.

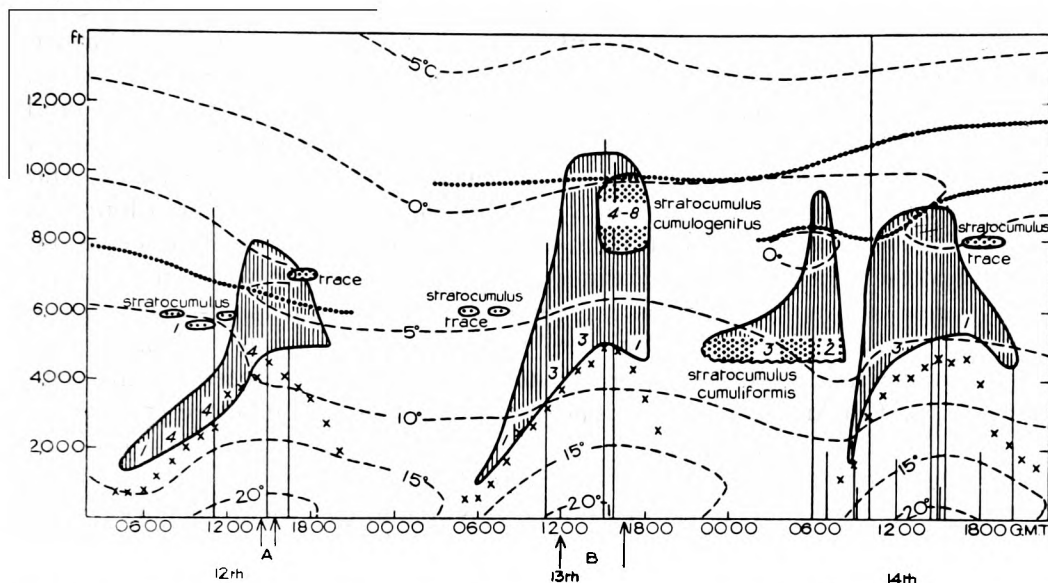


FIG. 2—DIURNAL VARIATIONS IN CLOUDS NEAR CRANFIELD, AUGUST 12–14, 1952

The areas of vertical hatching show the variations in the base levels and summit levels of cumulus clouds, and the crosses beneath indicate the convective condensation level computed from the means of hourly screen dry-bulb and dew-point temperatures at seven neighbouring stations. The stippled areas show the occurrence of stratiform clouds. Figures inserted into shading denote, in oktas, the proportion of sky covered by the appropriate clouds. Vertical lines show aircraft and balloon soundings; the isotherms and inversions (heavily dotted lines) were drawn after analysis of these soundings and routine radio-sonde observations.

Period A: Showers 40–50 miles to the north-west observed by radar; echo tops 10,000–11,000 ft.

Period B: Showers in neighbourhood, radar-echo tops 9,000–11,000 ft.

On August 12 traces of cumulus and fractocumulus were present in the fresh cold air mass before sunrise (about 0445 G.M.T.), forming over the neighbouring hills (a few hundred feet above the surrounding country) independently of solar heating of the ground. On August 13 the first cumulus formed over hills about  $\frac{1}{2}$  hr. after sunrise, and on August 14, when the air was almost calm, not until 4 hr. after sunrise and then not especially over the hills.

On each day the first clouds formed some 1,000–1,500 ft. above the ground, and thereafter the cloud base rose rapidly to 4,000–5,000 ft. by mid afternoon. The convective condensation level computed from the means of screen dry-bulb and wet-bulb temperatures at seven stations, including and within 50 miles of Cranfield, was usually a few hundred feet below the observed cloud base, in agreement with the findings of Petterssen and others<sup>1</sup>. However, after the

time of maximum screen temperature the computed condensation level fell rapidly until it was about 3,000 ft. below the cloud base, which remained at approximately the same height or fell a few hundred feet in the evening (Fig. 2). The last traces of cloud persisted until an inversion had formed from the lower ground up to about 300 ft., and may have been formed over hill slopes facing the sun and maintaining a rather higher surface temperature.

On these, as on some other days, there was a notable tendency for a few small patches of thin layer cloud to form at heights estimated at 6,000–9,000 ft. during the periods when the cumulus tops were below their level; usually they did not occur during the early afternoon when the cumulus tops were higher. These clouds often formed in lenticular patches and presumably were formed as wave clouds over the small hills but they appeared to move with the wind, individually soon evaporating, and were not obviously related to any ground features. From above they appeared darker than the cumulus tops with a reddish-brown tinge. It is difficult to account for the appearance and behaviour of these clouds and similar patches of stratocumulus often found in association with cumulus but formed quite separately. On the occasions being discussed they may have formed as wave clouds when the humidity in a damp layer below the inversion increased as a result of a large-scale vertical motion, perhaps produced by the convection occurring beneath, and disappeared when the cumulus penetrated their level and caused mixing with drier layers. On August 13 these clouds began to form a little before 1500 G.M.T. amongst, but quite independently of, the cumulus tops at 9,000–10,000 ft. Soon afterwards the bigger cumulus tops began to spread, and produced persistent large patches of stratocumulus cumulogenitus which, in places, were as much as 2,000 ft. thick. About the time of this development the larger cumulus produced showers, although their tops were not noticeably higher than before. This recalls other observations noting the association of stratocumulus “canopies” over non-supercooled shower clouds<sup>2</sup>. In the central parts of the larger cumulus on each day the up-draughts were estimated occasionally to reach 3–4 m./sec.

During the night of August 13–14 extensive patches of thin cellular stratocumulus formed, and about dawn sprouted cumuliform towers (see the photographs on the left-hand page in the centre of this Magazine) so that in some places they were reported as altocumulus castellatus. These clouds, however, were formed at the level of the cumulus base of the previous evening, probably as a result of a large-scale vertical motion or radiative cooling or a combination of both. The increased vertical development after dawn can only be attributed to the effect of continued large-scale vertical motion in the almost calm air mass; Fig. 2 shows that a considerable cooling had occurred since the previous evening at levels between 5,000 and 8,000 ft., which could not be accounted for by advection. This upper convective cloud soon disappeared when the cumulus formed by solar heating developed.

A very detailed examination of temperature and humidity changes in the lower troposphere, together with a consideration of large-scale motions, will be required for the satisfactory explanation of the diurnal course of convection and such curious developments as those mentioned.

**Shower formation.**—On August 12 and 13 an attempt was made to stimulate shower formation by flying some 200 ft. below the base of large cumulus and dispersing about 25 gm. (about  $10^{10}$  particles of diameter  $10\mu$ )



of finely ground and carefully dried rock salt over a flight path of about  $\frac{1}{2}$  mile. On no occasion was there any visible result.

On all three days, however, it was found during traverses of the largest clouds that, at all heights above about 1,000 ft. above their bases, the cumulus contained large droplets of radius estimated at  $150\text{--}200\mu$ , which could be seen to strike the aircraft windows, occasionally with a tapping noise. Their concentrations were estimated to be about  $1\text{--}5/\text{m}^3$ . It was concluded that these clouds were already well provided with giant sea-salt nuclei of mass about  $10^{-9}$  gm., which it is known<sup>3</sup> occur in about this concentration up to cumulus base in sea air with surface winds of Beaufort force 4 and which are capable of growing, principally by coalescence, to radii of  $150\mu$  when lifted 4,000–6,000 ft. through cumulus of this base temperature (about  $10^\circ\text{C}.$ ) in up-draughts of  $1\text{--}3$  m./sec. (Ludlam<sup>4</sup>). Those observed within about 1,000 ft. of the cloud base were present in noticeably smaller concentrations, and probably had settled from greater heights after leaving the cores of the up-draughts. It seems that only the small horizontal dimensions of the clouds and their slight lean in the wind shear (consistently  $2\text{--}3$  kt./1,000 ft. throughout the cloud layer) prevented the majority of the larger cumulus from producing slight showers on all three days.

On August 12, R. F. Jones at the East Hill radar station observed isolated showers to occur some 40–50 miles north-west of Cranfield for about an hour at the time of maximum surface temperatures. Evidently in this area the cumulus development was enhanced for the radar echoes had tops at 10,000–11,000 ft. The aircraft of the Meteorological Research Flight observed slight precipitation of drizzle-drop size just beneath some clouds.

On August 13 isolated showers again formed about 40 miles north-west of Cranfield; the first radar echoes, with tops at 9,000–11,000 ft., were observed at 1200 G.M.T. About 1230 others formed to the south-west and towards 1500 showers approached the Cranfield area from the south-west. These were examined by aircraft, and it was found that the heavier showers were falling from a group of cumulus whose summits protruded a few hundred feet through an extensive shelf of stratocumulus cumulogenitus. The temperature at the level of the cloud tops was  $-1^\circ\text{C}.$ —slight wing icing was noticed by one aircraft in the cloud tops, but there was no trace of any ice crystals—no higher tops could be seen and the shower was evidently produced by the coalescence mechanism. The photographs in the centre of this Magazine show the appearance of the cumulus before shower formation and the top of the shower cloud flown through. Fig. 3 is a diagrammatic representation of the radar record of showers from a similar cloud mass  $1\frac{1}{2}$  hr. later.

The depth of the clouds observed to give showers on the afternoons of August 12 and 13, that is 5,600–6,000 ft., was evidently the minimum required for shower production by the coalescence mechanism; the showers were only slight, the rate of rainfall amounting to a few millimetres per hour. On August 14 the maximum cloud depth was only 5,000 ft., and no showers occurred. Probably on the other two days heavier showers would have been produced by the coalescence mechanism had the clouds been able to grow a further several thousand feet. Clearly the occurrence of crystals in the higher summits need then have little or no significance for the shower production, although they might cause visible “glaciation” of the cloud tops.

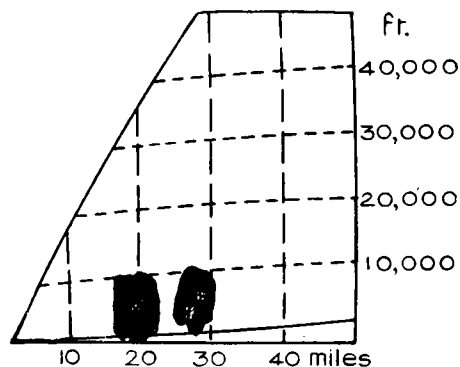


FIG. 3—HEIGHT-RANGE-INDICATOR DISPLAY OF RADAR ECHO, NORTH-EAST OF EASTHILL (25 MILES SOUTH-SOUTH-EAST OF CRANFIELD), 1613 G.M.T., AUGUST 13, 1952

**Acknowledgements.**—The investigations mentioned were made with the help of a grant from the Research Fund of the University of London, and with aircraft and airfield facilities generously provided by the College of Aeronautics, Cranfield, the Meteorological Office, the Royal Aircraft Establishment, and the Commanding Officer of the Cambridge University Air Squadron.

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## NIGHT COOLING UNDER CLEAR SKIES AT A COASTAL STATION

By W. E. SAUNDERS, B.Sc.

Night cooling under clear skies at inland stations has been investigated by the present writer for Northolt<sup>1</sup> and Exeter<sup>2</sup>, and by T. H. Parry for Shawbury<sup>3</sup>.

An account is now given of similar work in regard to St. Eval, a coastal station situated on the cliffs of north Cornwall, some 340 ft. above sea level.

The observations for all clear nights during 1950 and 1951 were examined. The evening temperature discontinuity was found to be quite pronounced on most occasions. The observed times are given in Fig. 1. The scatter is believed to be partly due to the fact that in most cases the time of discontinuity had to be deduced from observations at only hourly intervals. The mean curve appears to show two sharp rises in the spring, but the scatter at this season is such that these features are uncertain. Something similar was noted by Parry<sup>3</sup>.

The screen-level temperature of discontinuity  $T_i$  was expressed in terms of the maximum screen temperature  $T_{\max}$  and the dew point at the time of maximum temperature  $T_d$ . With wind off the sea, taken as surface-wind directions  $230^\circ$  to  $40^\circ$  inclusive, the air temperature over the sea (often the sea-surface temperature)  $T_s$  was taken in place of  $T_{\max}$ , to allow for the fact that evening cooling would take place in air that was over the sea during the afternoon. Following the practice at inland stations, where it was found that

$T_r$  differed according as there was or was not an inversion in the afternoon air mass with base 900 mb. or below, the lapse rate was examined in each case. It was found that the difference is only noticeable if the inversion is fairly pronounced. A convenient separation of the occasions into inversion or non-inversion cases appears on the present data to be given by the requirement that an inversion of  $4^{\circ}\text{F}$ . should or should not be present within 125 mb. of the surface pressure.

Defining an inversion in this way, the regression equations were:—

*Non-inversion*  $T_r = \frac{1}{2} \{ T_{\max} \text{ (or } T_s) + T_d \} + C$

where  $C = -1.4^{\circ}\text{F}$ . (91 occasions, standard deviation  $0.92^{\circ}\text{F}$ .)

*Inversion*  $T_r = \frac{1}{2} \{ T_{\max} \text{ (or } T_s) + T_d \} + C$

where  $C = -4.0^{\circ}\text{F}$ . (12 occasions, standard deviation  $0.80^{\circ}\text{F}$ .)

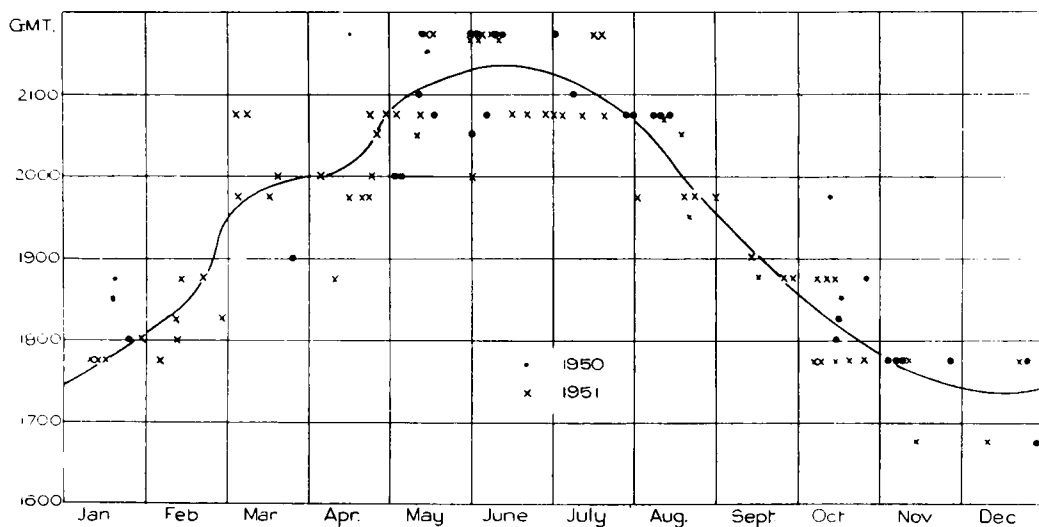


FIG. 1—ANNUAL VARIATION OF TIME OF TEMPERATURE DISCONTINUITY

St. Eval, 1950–51

The fact that a more pronounced inversion is required to produce a significant difference in  $T_r$  at an exposed coastal station than at the inland sites previously considered seems to support the view that the suppression of turbulence under the inversion is the cause of the observed greater cooling.

The standard deviations obtained are rather smaller than those obtained for Exeter<sup>2</sup> which is near the coast but which shows many characteristics of an inland station. Sea temperatures were not taken into account in that work, but the present results suggest greater accuracy would be obtained if  $T_s$  were substituted for  $T_{\max}$  on occasions of wind blowing from the English Channel.

Following the procedure at inland stations the temperature itself was taken as the parameter for forecasting the subsequent cooling. The theoretical reasons for this choice are given in the Northolt paper<sup>1</sup>. The calculated values of  $T_r$ , using the regression equations given above, were plotted against the observed night minimum  $T_{\min}$ . Cases in which there were obvious advective effects were omitted, also a few cases in which wind direction changed from on shore to off shore during the cooling period. The results for light winds, taken as mean gradient wind speed not greater than 22 kt., are given in Fig. 2.

A possible explanation for the absence of a difference between the winter and summer curves at St. Eval is that there is less change in ground condition between winter and summer. This is probably because on this exposed coast surface winds tend to be maintained on many occasions when they fall calm inland. This, coupled with a well drained site, prevents the grass remaining permanently wet as it does inland in winter. Two further differences

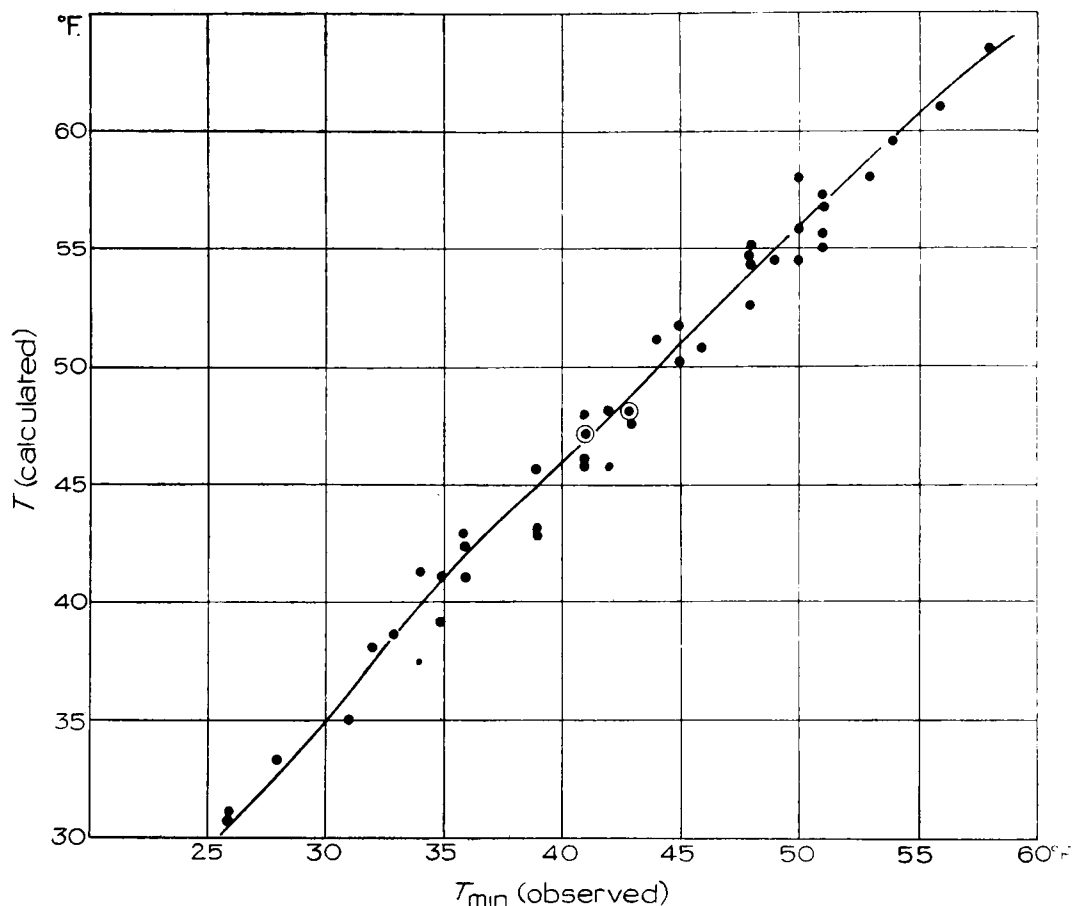


FIG. 2—RELATION BETWEEN NIGHT MINIMUM TEMPERATURE ( $T_{\min}$ ) AND CALCULATED TEMPERATURE AT THE TIME OF EVENING DISCONTINUITY ( $T_r$ )

St. Eval, Mean gradient wind speed  $\leq 22$  kt.

from what has been found inland are (i) that the difference between non-inversion and inversion cases cannot be carried forward into the period of “subsequent” cooling (except, of course, in so far as it is automatically carried forward in the calculation of  $T_r$ ), and (ii) that there was no apparent midsummer decrease in the amount of cooling. With regard to this latter point, it was shown on theoretical grounds that at Northolt<sup>1</sup> this decrease should amount to about 3°F. in mid June. The total “subsequent” cooling is much smaller at St. Eval, about 6°F. as compared with about 15°F. By the same argument the maximum midsummer reduction should be little more than 1°F., and therefore probably too small to show on the curve. The standard deviation of individual cases from the mean curve in Fig. 2 is 1.2°F.

With stronger winds (mean gradient wind speed exceeding 22 kt.) it was found at Northolt and Exeter that the minimum temperature in degrees

Fahrenheit could be derived from an expression:—

$$T_{\min} = T_r (\text{calculated}) - \Delta,$$

where  $\Delta$  varied with the gradient wind speed. At St. Eval only nine occasions of strong winds and clear skies could be found in the two years, and a relation in this form could not be established. One difficulty is, of course, that some strong winds at St. Eval, even when off shore, have only a very short land track from the English Channel coast. However, the amount of cooling is small, and the best relation appears to be:—

$$T_{\min} = T_r (\text{calculated}) - 2.7$$

with a standard deviation of  $1.9^\circ\text{F}$ . for all cases of mean gradient wind greater than 22 kt.

The correction to apply in using Fig. 2 at the neighbouring airfield of St. Mawgan, where the observational data are insufficient for separate curves to be constructed, has been deduced by Mr. P. J. Drinkwater as follows:—

$$T_{\min} (\text{St. Mawgan}) = T_{\min} (\text{St. Eval}) - 1.5$$

which is measured in degrees Fahrenheit and is based on 24 comparisons.

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## METEOROLOGICAL OFFICE DISCUSSION

### Forecasting for long-distance flights

The subject for discussion on Monday, December 20, 1954, at the Royal Society of Arts, was "Forecasting for long-distance flights". The opener, Mr. T. N. S. Harrower, dealt mainly with the operational and forecasting procedures in use at London Airport with particular reference to transatlantic flights.

The title "long-distance flight" is usually given to a flight of over 1,000 nautical miles. A diagram showing some international routes, including those over 1,000 nautical miles, for which forecasts had been prepared at London Airport was shown (see Fig. 1). This diagram also included the main international aerodromes in which London Airport is interested. The longest flight for which full forecasts have been provided on a routine basis is London-Detroit, the shortest operational distance for this flight being about 3,350 nautical miles.

**Responsibilities of the forecasting service for international civil flights.**—The aim of a meteorological service for international long-distance civil flights is to contribute towards the safe, regular, efficient and economic operation of services. The foremost considerations of all airline operators are the safety and comfort of passengers and the economic operation of their aircraft. To fulfil these requirements the meteorological service has to provide, well in advance of a flight, a regular series of forecast surface and upper air charts at levels of use to the operator, a regular series of landing forecasts for appropriate aerodromes, detailed information on route winds, cloud structure, freezing levels, ice formation and turbulence, following up with crew briefing and documentation. Finally a form of amendment procedure is required, effective until a landing is made.

**Forecasting for transatlantic flights.**—In order to make the reasons for the forecasting techniques apparent, the function of the operations staff of the transatlantic companies was outlined.

It is the responsibility of the operations officer to plan the flight to ensure the safety and comfort of passengers, to make the operation as efficient and economical as possible and to run the flight to schedule. He advises the captain of the ratio of fuel to pay load for each flight, advises in the selection of the best track across the Atlantic for the aircraft taking into account his discussions with the forecaster on the expected wind field, track weather and landing forecasts. Forecast charts depicting the anticipated surface and upper air situations over the

Atlantic are provided to operators at regular intervals to cater for departures taking place from 3 to 10 hr. after the time of issue. On these charts the operations officer carries out a pressure-pattern analysis by one of the current techniques, and, subject to the suitability of route and terminal weather, usually selects a "best-time" track, not in many cases the shortest-distance track, for the crossing. This "best-time" track might also be a "best-fuel" track for the engine-power settings chosen.

The equivalent headwind, defined as that uniform wind which, directed along the aircraft's track at all points, results in the same duration of flight as that required by the actual system of winds, is used to determine the amount of fuel to be carried. Sufficient fuel is added to reach a chosen alternative aerodrome, plus a certain percentage reserve to allow for forecast, navigation and engine-fuel-consumption errors, and a final amount for "stand-off" allowance if the aircraft has to land at the alternative aerodrome. If this fuel is insufficient to carry the aircraft safely across the Atlantic on a direct route, a route is chosen to include a stop for refuelling at an intermediate aerodrome such as Prestwick, Shannon, Keflavik or Santa Maria. A final discussion is held with the forecaster on all the aspects of route and terminal weather for the selected track.

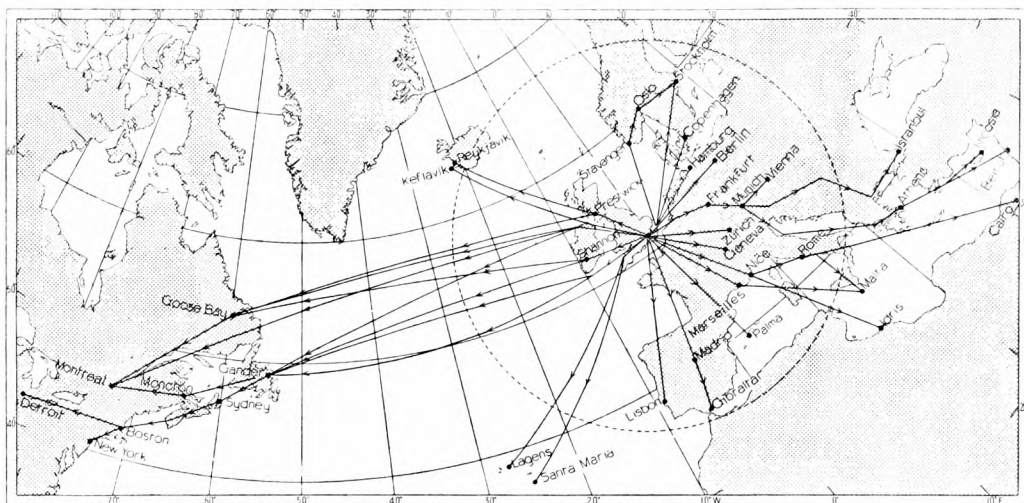


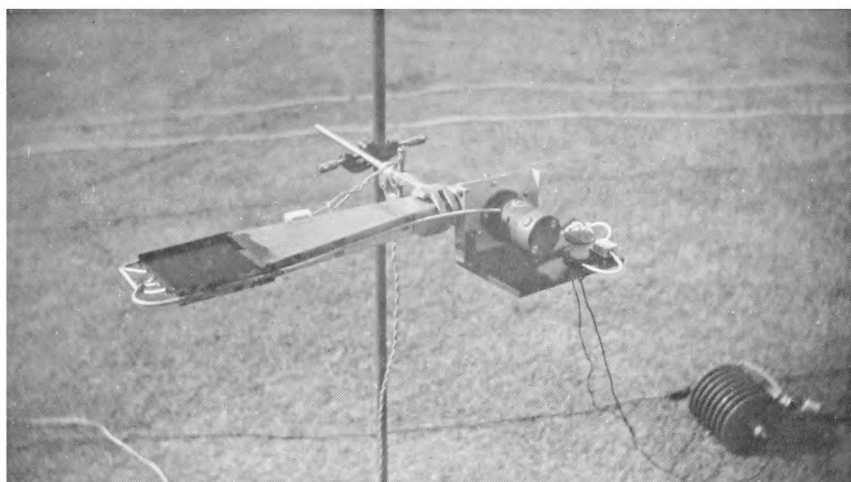
FIG. 1—SOME INTERNATIONAL ROUTES FOR WHICH FORECASTS HAVE BEEN PREPARED AT LONDON AIRPORT

The circle has a radius of approximately 1,000 nautical miles from London.

A slide showing some transatlantic tracks for which forecasts were prepared at London Airport during 1954 was exhibited. A great many transatlantic tracks tend to deviate north of the shortest great-circle track because of more favourable wind fields on many occasions. For example, pressure-pattern tracks between London and Montreal frequently cross the Greenland ice-cap and these tracks are flown regularly by Trans-Canada Airlines. It was pointed out at this stage that direct transatlantic flights from London, which are not landing at Shannon, must not fly over the Republic of Ireland, the main exit routes from London being either south or north of Ireland *via* a point near  $51^{\circ}\text{N}$ .  $10^{\circ}\text{W}$ . in the south or Malin Head in the north of Ireland.

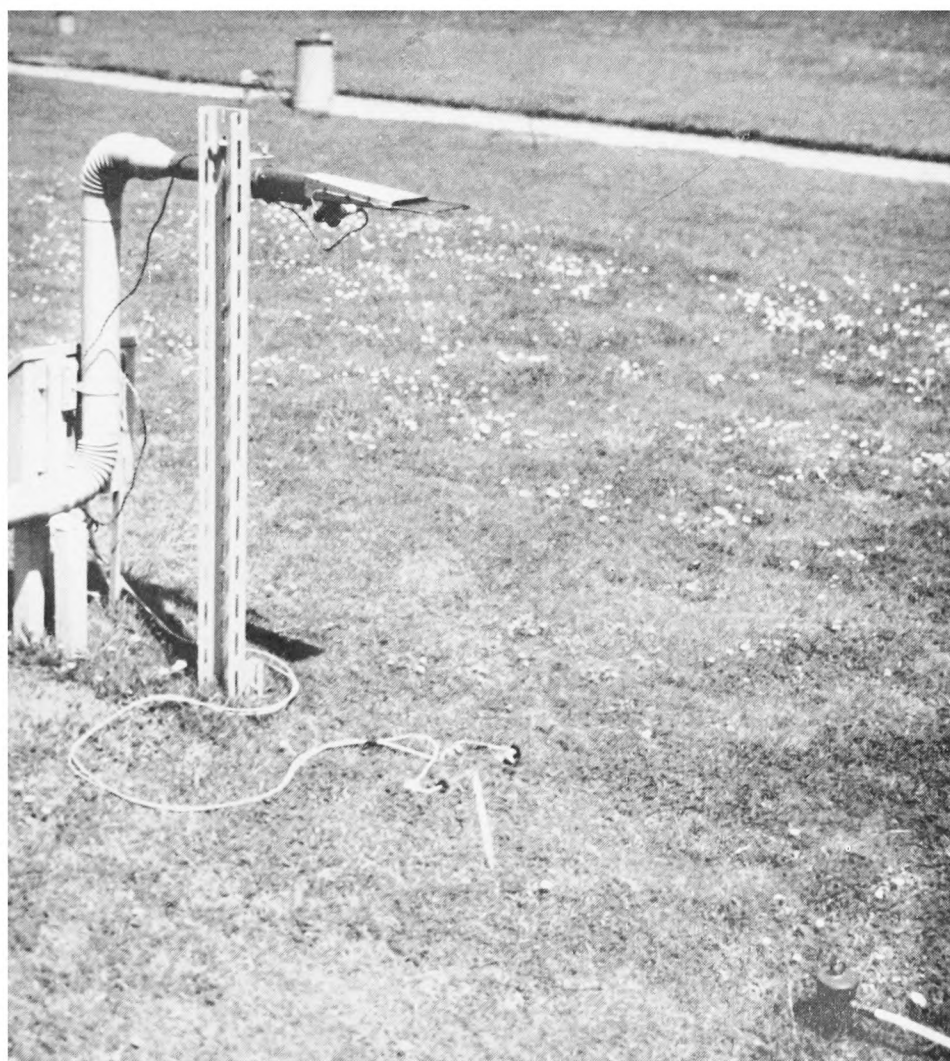
Another slide was shown illustrating various routes from London to Gander with improvements in the equivalent headwind required to compensate for increased distances compared with the shortest operational route *via*  $51^{\circ}\text{N}$ .  $10^{\circ}\text{W}$ . and great circle, a distance of 2,052 nautical miles. The assumed aircraft ground speed was 200 kt. For example, a track *via*  $51^{\circ}\text{N}$ .  $10^{\circ}\text{W}$ . and composite great circles *via*  $59^{\circ}20'\text{N}$ .  $30^{\circ}\text{W}$ . to Gander requires a gain in the equivalent headwind of 19 kt. The great-circle track from London to Gander *via* Malin Head (a favourite), a distance of 2,084 nautical miles, requires a gain in the equivalent headwind of 3 kt. A track *via* Keflavik would require a gain in the equivalent headwind of 34 kt. before it would be worth while as a non-stopping track between London and Gander. However, the track *via* Keflavik, with a landing there, is a favourite if the equivalent headwind on any direct track is too high for a full load to be carried. A route *via* Santa Maria to Gander requires a gain in the equivalent headwind of 77 kt. It can easily be appreciated that this track, with a landing at Santa Maria from London, is rarely flown, and then only as a last resort when either most unfavourable winds or weather make a northerly track unsuitable.

*Forecasting technique.*—The basic tools in use are familiar to all forecasters. The main charts for surface and upper air analyses are 1 : 15,000,000 scale covering an area from the



*Reproduced by courtesy of D. B. B. Powell*

COMPLETE RADIOMETER  
(see p. 65)



*Reproduced by courtesy of D. B. B. Powell*

MK II RADIOMETER AT KEW OBSERVATORY  
(see p. 65)





0547 G.M.T.



0628 G.M.T., showing increased vertical development of clouds

*Photographs by Operation Cumulus*

STRATOCUMULUS CUMULIFORMIS TO SOUTH-SOUTH-EAST OF GRANFIELD,  
AUGUST 14, 1952  
(see p. 72)





*Photograph by Operation Cumulus*

CUMULUS FROM 21,000 FT., 1100 G.M.T., AUGUST 13, 1952



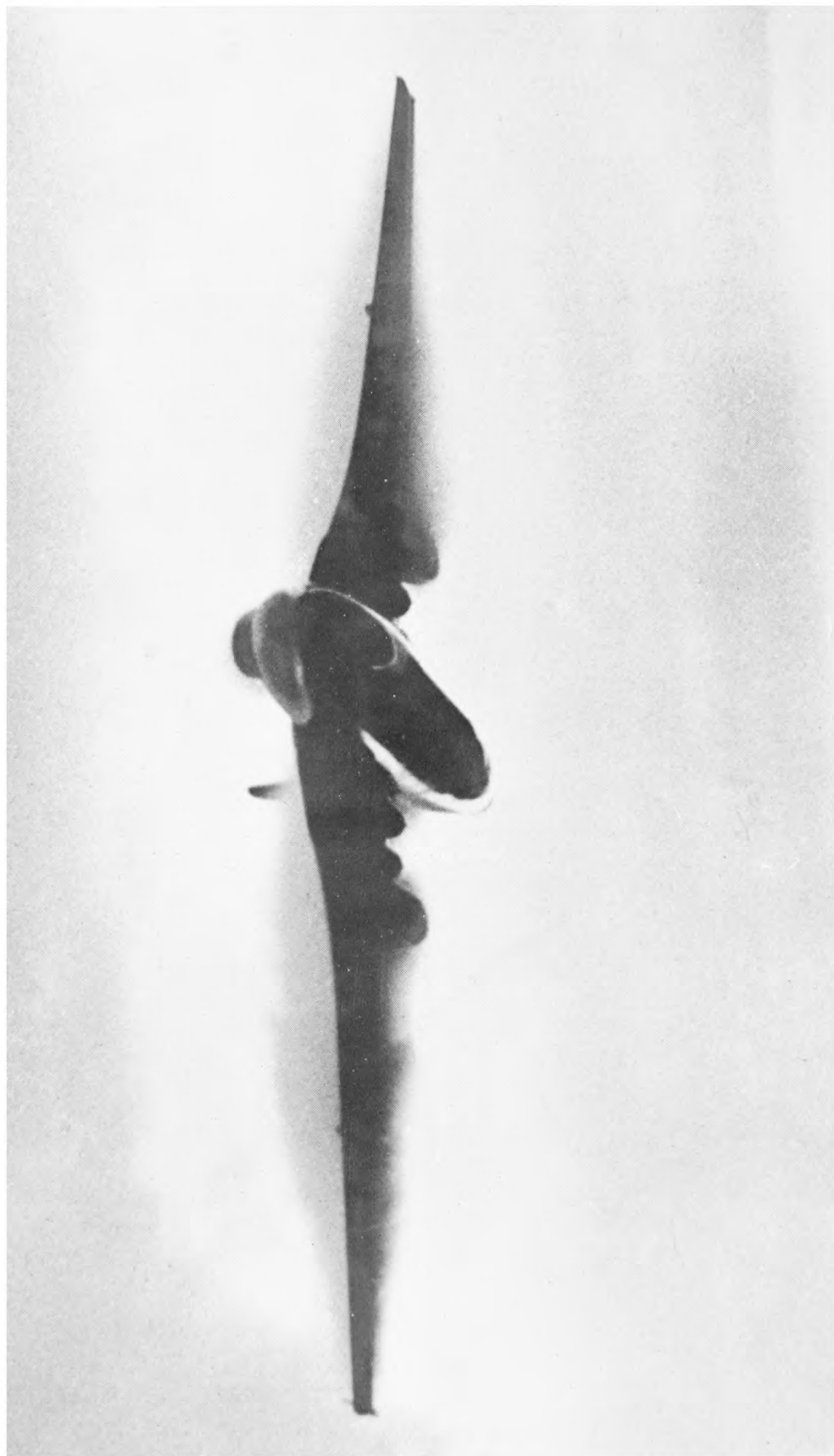
*Photograph by Operation Cumulus*

CUMULUS FROM 10,500 FT., 1340 G.M.T., AUGUST 13, 1952



*Photograph by Operation Cumulus*

TOP OF SHOWER CLOUD FROM 11,500 FT., 1436 G.M.T., AUGUST 13, 1952  
(see p. 72)



Photograph by P. A. Reuter

CONDENSATION CAUSED BY HIGH-SPEED AIRCRAFT AT LOW LEVELS  
(see p. 93)

eastern Pacific to the Middle East and from northern Greenland to the Caribbean. Upper air analyses are carried out at 850, 700, 500, 300 and 200 mb.

The charts are analysed by the usual accepted methods, the 700-mb. being built up by gridding the 1000-mb. contours with the 1000-700-mb. thickness pattern, the final chart being modified, if necessary, to take into account all the observations appearing on the 700-mb. chart. The 500-mb. chart is constructed by gridding the 1000-500-mb. thickness pattern with the 1000-mb. contours, the 300-mb. chart by gridding the 500-300-mb. thickness pattern with the 500-mb. contours, and the 200-mb. chart is drawn directly from the absolute heights and winds reported taking into consideration previous history, unreliable observations and the lower-level patterns already obtained.

The main forecast charts prepared for present scheduled transatlantic services are those for the surface (M.S.L.), 700 and 500 mb., these being sufficient to cover west-bound operating heights. These charts are of a composite nature; they are designed so that the forecast situation on any particular part of the chart is constructed to coincide with the arrival of the aircraft at that part. Time does not permit the production of a special chart for each flight. A compromise is reached by constructing composite charts four times daily with mid times of departure from London at 0130, 0730, 1330 and 1930 G.M.T. Except in situations which are changing rapidly, these charts are also used to cover departures from  $3\frac{1}{2}$  hr. before to  $3\frac{1}{2}$  hr. after the mean time of the chart. In practice, with present aircraft speeds, it is found that to allow 1 hr. for every 5 degrees of longitude gives the best practical results for the main east-west tracks. For example, a chart valid for a mean time of 1330 G.M.T. at London will be valid for 1930 at  $30^{\circ}$ W. and for 0430 the next day at  $75^{\circ}$ W.

The three-dimensional situation is always studied carefully before the surface forecast chart is prepared, and account is taken of regions of probable cyclonic and anticyclonic development as suggested by Sutcliffe's thermal-vorticity theory, areas of likely subsidence and cooling are considered, and extrapolation, synoptic models, sometimes long-wave patterns and all the many other techniques leavened with empirical knowledge are employed.

The composite prontour charts are built up from the 1000-mb. forecast contours, taken from the surface forecast chart, by the graphical addition of the forecast thermal pattern to 700 and 500 mb. directly.

Mr. Harrower explained a slide which showed in tabular form the times of issue of the main forecast charts, their validity, the times of the basic synoptic charts on which the forecast charts are based, and the times elapsed between the basic observations and the forecast chart at certain places. For example, the forecast chart issued at 0700 G.M.T. is based on midnight surface observations and 1500 observations of the previous day. The mean time of validity of this chart is 1330 at London, 0030 the next day at Gander and 0430 at New York. The periods elapsed since the basic surface observations are  $13\frac{1}{2}$  hr. at London and  $28\frac{1}{2}$  hr. at New York and for upper air observations  $22\frac{1}{2}$  hr. at London and  $37\frac{1}{2}$  hr. at New York.

*Forecasting terminal conditions.*—Forecasts of terminal conditions are extremely important for long-distance flights, particularly forecasts of visibility, amount and base of low cloud, wind velocity and type of precipitation. 24-hr. forecasts of these conditions are exchanged as a routine every 6 hr. between all international aerodromes and amended immediately as necessary. Normal forecasting methods are employed to produce these forecasts, in which, of course, long local experience of one particular aerodrome by the forecaster concerned plays an important part.

*Forecasting track weather.*—Track weather is forecast by normal methods, the basis of the forecast being the three composite charts applicable to the flight. Much useful information is gleaned from aircraft reports and all the latest surface and upper air data available are taken into account.

*Final procedures for transatlantic flights.*—When the operations officer has decided which route he wishes the aircraft to fly, subject to agreement by the captain of the aircraft, taking into account terminal weather conditions, the expected equivalent headwind and the verbal briefing received about the expected weather on the selected track, a cross-section of the route weather is prepared by the forecaster some 2-3 hr. before the flight is due to commence. About 1-2 hr. before the estimated time of departure the crew of the aircraft arrive at the meteorological office, and are given a very full verbal briefing comprising a description of the latest fully analysed surface and upper air charts with an appreciation of expected developments, an explanation of the forecast route and terminal weather, particular emphasis being placed upon expected regions of icing, cloud structure and turbulence. The forecast surface and upper air charts are explained with reference to forecast wind patterns, orientation and strength of jet streams or strong-wind belts, and any other meteorological factors which might affect the flight.

*Individual meteorological flight watch.*—The responsibility of the meteorological office does not end with the departure of the aircraft. An individual meteorological flight watch is maintained for the majority of transatlantic aircraft leaving or arriving at London Airport to ensure that amendments to the forecast and other significant facts are passed to the aircraft in flight.

On the receipt of a flight plan from the operator a skeleton aircraft-progress chart is made out, which contains the route, planned zone times and flying altitude of the aircraft. Each hour a position and weather report is received from the aircraft and plotted on the progress chart. This report contains, in its most comprehensive form, position, details of wind, weather, cloud structure, temperature, icing and turbulence. From these it can be seen if the aircraft is on time and if the winds and weather are as forecast. Amendments to the forecast for any part of the route can be sent at any time until the aircraft passes into the next Air-Traffic-Control zone. For direct flights this is normally at 30°W. longitude.

Likewise progress charts are maintained on certain east-bound flights, based on data received from the departure point and from the aircraft. Before the aircraft reaches 30°W. a signal is sent to it giving the latest forecast winds at the operating height on the track to the designated terminal, with any hazardous weather, such as severe frontal conditions, likely to be encountered.

The systematic plotting of data received from these aircraft has been of great value to the Atlantic and upper air forecasters in the preparation of future forecasts, the development of the synoptic situation and in briefing air crews, in addition to the prime purpose of keeping a meteorological flight watch on the aircraft.

**Forecasting for a particular flight.**—By means of slides the complete forecasting for a particular flight from London to Gander was illustrated. The surface, 700-mb. and 500-mb. forecast composite charts applicable to the flight were shown. At the upper levels the synoptic

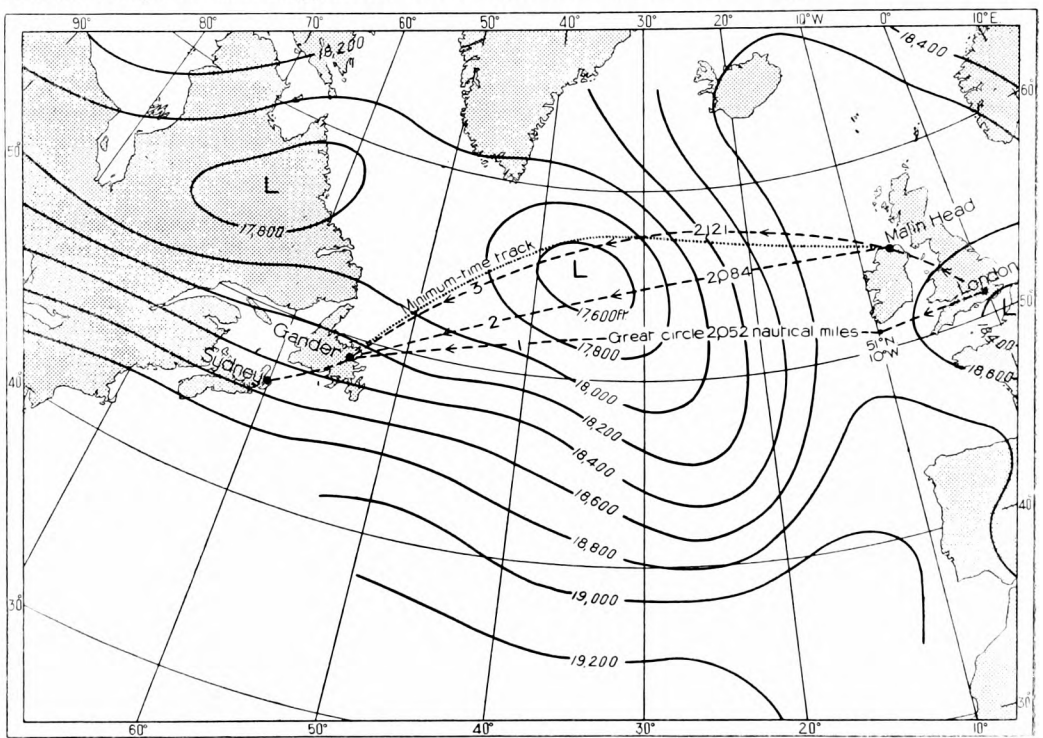


FIG. 2—COMPOSITE FORECAST 500-MB. CHART

Estimated time of departure at London, 1000–1700 G.M.T., May 31, 1954.  
Estimated time of arrival at Gander, 2100 G.M.T., May 31–0400 G.M.T., June 1, 1954.  
London–Gander track analysis  
with the same type flight planning for each track

Track	Equivalent headwind	Average ground speed	Distance	Flight time
	kt.	kt.	n. miles	hr. min.
1. London–51°N. 10°W.—great circle–Gander ... ..	17	202	2,052	10 9
2. London–Malin Head–great circle–Gander ... ..	11	207	2,084	10 3
3. London–Malin Head–polar curve–Gander ... ..	–7	225	2,121	9 24

Saving on track 3 over track 2 = 1,200 lb. = 6 passengers and luggage  
Saving on track 3 over track 1 = 1,450 lb. = 7½ passengers and luggage.

picture was dominated by a low centred at about  $55^{\circ}30'N$ ,  $35^{\circ}30'W$ . The track analysis for a British Overseas Airways Corporation Constellation flight from London to Gander on May 31, 1954, flown mainly on the 500-mb. surface, was explained (see Fig. 2). The shortest operational track from London to Gander is *via*  $51^{\circ}N$ ,  $10^{\circ}W$ , and great circle, a distance of 2,052 nautical miles. The track finally selected was London-Malin Head-polar curve-Gander, a distance of 2,121 nautical miles. The equivalent headwind on this track was  $-7$  kt. (a tailwind of 7 kt.) against an equivalent headwind of  $+17$  kt. on the shortest track. The selected track was expected to result in a saving of time of 33 min. over the shortest track. This time saving is equivalent to 7 adult passengers plus 1 baby and their luggage, and the track was chosen subject to suitable weather on the route and at the terminals. This track is very near to the minimum-time track from Malin Head to Gander worked out by time-front methods. The pictorial cross-section of flight weather and the aerodrome forecast sheet for the flight were shown, and finally the flight-watch chart with the hourly position and weather reports from the aircraft plotted against a background of the 500-mb. forecast chart was described.

Next an interesting slide of the individual meteorological flight watch supplied to an east-bound British Overseas Airways Corporation Stratocruiser flying from New York to London was illustrated. In this particular case excellent reports of wind velocity received from the aircraft filled in a gap in the existing charts and enabled more accurate subsequent wind forecasts to be issued to the same aircraft.

**Mediterranean flights.**—The forecasting technique is essentially similar for long-distance Mediterranean flights except that normally the track is fixed and no advance track selection is required. However, important topographical forecasting considerations enter into forecasts for these flights, many of which are routed over or near the Alps.

*Forecasting for Comet I flights.*—Considerable experience was gained in forecasting for Comet I flights from London to Rome or Cairo. Forecast 200-mb. charts were provided. The operators were most interested in forecast wind and temperatures during the ascents to 35,000 ft. usually attained after 200 nautical miles, cruise winds and temperatures between 35,000 and 40,000 ft. and descent winds and temperatures for the final 200 nautical miles. Accurate terminal forecasting was particularly important for Comet I's as it was necessary to try to plan diversions while the aircraft was still at 40,000 ft. because at low heights fuel consumption became excessive.

**Comet III operations.**—In view of the probable introduction of Comet III operations across the Atlantic within the next few years, British Overseas Airways Corporation and Pan American World Airways have been flying a "paper Comet" across the ocean daily since March 1, 1954. This phantom aircraft is allocated a crew who plan the flight at London Airport, and all the normal planning and operational, including diversionary, measures are taken, just as if the aircraft was actually making the flight. The flight is timed to leave London Airport at 1000 daily and the meteorological office provide a fixed-time forecast 200-mb. chart valid for 1500 G.M.T. and available at 0700. This chart is largely based on the 1500 G.M.T. information of the previous day, but as much account as possible is taken of the 0300 G.M.T. 200-mb. information available up to 0600 on the day in question.

The next slide (see Fig. 3) illustrated the flight planning of a Comet III from London to New York on the basis of a forecast 200-mb. prontour chart for 1500 G.M.T., October 3, 1954. The main features of the chart were a low centred off west Greenland with a strong westerly gradient between Newfoundland and Ireland. The object was to get the aircraft from London to New York with a full load with as few stops as possible. Intermediate stops waste time, cost money and are always avoided if possible. It can be taken that it is extremely unlikely that the Comet III could fly from London to New York with full load unless the meteorological situation is very abnormal, and a one-stop operation is the best that can be hoped for with a full load. Track analysis with one stop at Gander showed that the flight could be made, but the pay load would only be 4 passengers. A flight with full pay load of 75 passengers could be made on the direct great circle between Shannon, Gander and New York, but with two stops. Finally, although the distance was 388 nautical miles more, a one-stop flight with 75 passengers could be made *via* Keflavik. The route from Keflavik is a polar curve which takes the aircraft over the Greenland ice-cap and Montreal to New York. Allowing 1 hr. for each stop this flight would take 1 hr. 32 min. less time than a two-stop flight *via* Shannon and Gander.

**Some of the difficulties in forecasting for long-distance flights.**—*Terminal weather.*—The normal ever-recurring difficulties of forecasting poor visibility, amount and base of low cloud are experienced. Companies tend to expect the onset and dispersal of fog and low cloud to be accurately timed, and minimum landing conditions are so tight that an accuracy to within 50 yd. in visibility and 100 ft. in cloud base is desired. This is difficult to forecast even within an hour or so, and is inspired if correct 24 hr. ahead, as required by long-range TAFOTS\* sent to places like New York for planning purposes.

*Wind and temperature.*—With regard to wind and temperature forecasting up to 500 mb., the technique seems to be satisfactory in most cases, although at times the orientation and strength

\* TAFOT = Terminal forecast, now known as TAFOR.



of jet streams cause concern. Unexpected developments can usually be picked up in time to amend forecasts before the aircraft departs or through individual meteorological flight watch channels. It is very rare for aircraft to have to return from mid Atlantic because of errors in forecasting the upper wind field. Isolated returns are usually due to unexpected surface weather deteriorations at the terminal airport.

Aircraft reports, in addition to the normal radio-sonde wind data, have proved valuable, in some cases giving the first clues to unexpectedly strong wind belts. Forecasting at 200 mb. is still in the trial stage, difficulties being caused by the sparse network over the Atlantic and sometimes doubtful results over Europe. Over America, where the equipment and technique is more uniform than over Europe and the network good, reasonable 200-mb. charts can be constructed provided the intrinsic errors in the temperature and height values at 200 mb. are always borne in mind. The actual wind velocity reports carry a lot of weight in the chart construction.

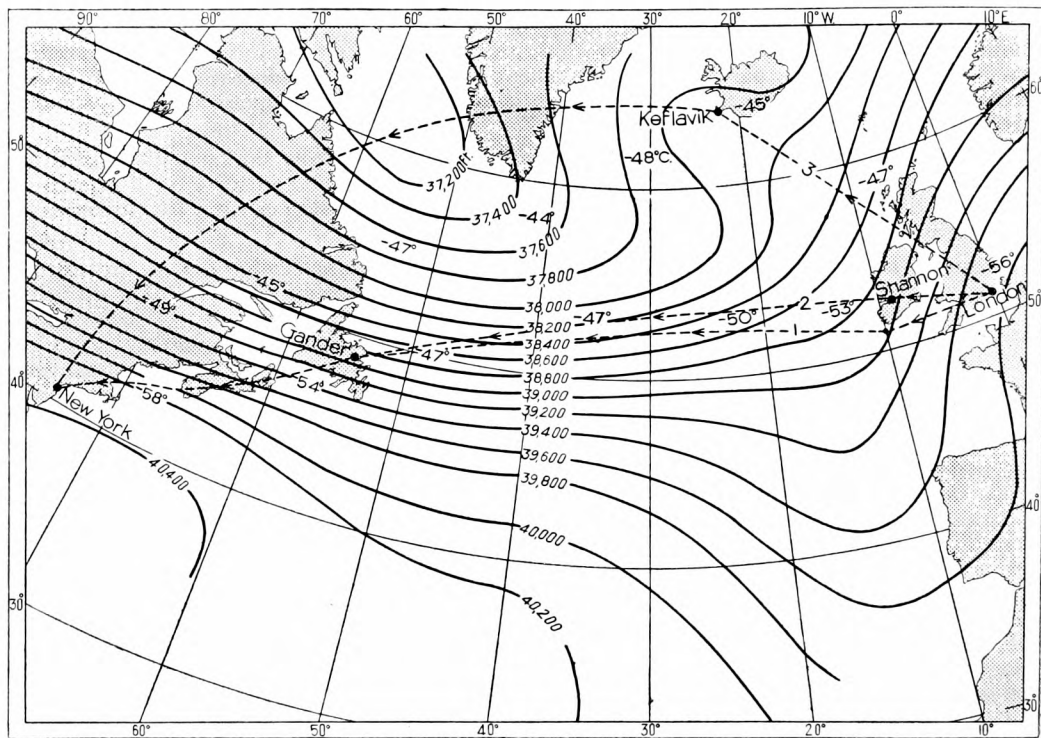


FIG. 3—FORECAST 200-MB. CHART FOR 1500 G.M.T., OCTOBER 3, 1954  
London-New York track analysis

Track	Stops	Distance	Air time	Flight time*	Load
		n. miles	hr. min.	hr. min.	passengers
1. Composite great circle <i>via</i> Gander	1	3,051	9 24	10 24	4
2. Composite great circle <i>via</i> Shannon and Gander ... ..	2	3,044	9 31	11 31	75
3. Composite great circle and polar curve <i>via</i> Keflavik ... ..	1	3,432	8 59	9 59	75

\* Flight time is air time plus 1 hr. for each stop.  
Equivalent headwind, Shannon-great circle-Gander, 73 kt.

*Icing.*—It is difficult to produce accurate forecasts over long routes. Aircraft reports have often proved useful. Provided the area where heavy or severe icing is likely can be forecast, with modern de-icing equipment areas of slight and sometimes moderate icing do not appear to present the same problem to the present-day civil aircraft as in the past. However, forecasts are always provided for areas and heights where any type of icing might be found.

*Turbulence.*—The present state of knowledge does not permit the forecasting of the occurrence of clear-air turbulence with high accuracy. However, preferred locations and conditions of existence for this phenomenon can be indicated, although experience and many talks with pilots seem to show that severe turbulence of this nature is not nearly so common over the

Atlantic as over or near the mountains of Europe, at least up to 23,000 ft. Turbulence in association with cumulonimbus cloud is usually to be expected, but all civil pilots avoid cumulonimbus if at all possible, partly because of a respect for conditions likely to be encountered in this type of cloud and also for the comfort of passengers. Crews at briefing are always extremely interested in the position of large cumulus or cumulonimbus cloud; if at all possible the flight is planned at an altitude well above the forecast tops, if this is not possible the clouds are avoided at a lower level if they are visible.

The opener closed on an optimistic note. The procedures and techniques up to the 500-mb. level, at least, are well proved and practicable. Most transatlantic aircraft, about 70-100 out and in during a week for London Airport alone, arrive at their destination with small errors in their flight-planned time.

Finally, Mr. Harrower thanked Mr. Dundee, Senior Operations Officer of British Overseas Airways Corporation at London Airport, and his staff for their most helpful co-operation in supplying some of the data used in the construction of the track-analysis diagrams.

*Dr. Stagg*, opening the general discussion, welcomed the visitors from the airline companies and outside interests and emphasized that any contribution to the discussion, favourable or otherwise, would be welcomed.

*Mr. Durst* showed two slides exhibiting the standard errors in 24-hr. wind forecasts to be expected for routes of various lengths at various heights, in a wind régime of the type found over the North Atlantic. The data showed that the errors increase with height up to a certain level and probably decrease above that level, that they are smaller for a long route than a short one, and are smaller in summer than in winter.

*Mr. Kirk* observed that the vital step in the forecasting organization is the production of the forecast surface chart. In practice the "composite" technique introduces no difficulty, and the forecaster is faced with the same problems as any central organization responsible for the issue of fixed-time prebaratics. The forecaster at London Airport is vitally concerned with developments in the western Atlantic, an area where rapid changes occur. He has to think in terms of pressure gradients and is interested in the influence his final result will have in determining the choice of tracks for transatlantic crossings. His chart will be interpreted at its face value for all planning purposes and any amendments at a later stage are difficult to make, and unpopular with everyone. The basic method is one of extrapolation modified by estimated development. Ideas on development are to some extent based on physical factors such as the distribution of land and sea, orographic features and ocean-temperature gradients plus experience. In the Mediterranean the pattern of development is often determined by these factors, and the problem of forecasting the surface-pressure distribution is relatively simple compared with the North Atlantic. *Dr. Sutcliffe's* development theories had proved helpful in developing insight but their practical application is often disappointing. The 500-mb. chart, however, with the associated 1000-500-mb. thickness pattern is undoubtedly the forecaster's main upper air tool. An auxiliary chart showing the movement of selected thickness lines has also been found helpful. *Mr. Kirk* illustrated his remarks by a series of interesting and impressive slides showing three examples of development in the North Atlantic area, and pointed out the salient features of the forecasting problem in each case.

*Mr. Hurst* described the organization and trial training of the Royal Air Force New Zealand Air Race Flight formed at Wyton in June 1953 for the race to New Zealand on October 8, 1953. The pre-race training fell into several categories including non-stop flights round the United Kingdom, flights to the Mediterranean, Shaibah and finally air-race timing flights to Shaibah, Ceylon and the Cocos Islands. The forecasting for these flights can be split up into route winds and temperatures, landings and descent conditions, and general conditions *en route*. An interesting slide showed how, within limits, the lower a jet aircraft flies the higher will be its speed for a given Mach number but at the expense of range. The lowest height used in practice was about 25,000 ft., otherwise greater air density gave buffeting. With regard to high-level cloud conditions, vast stretches of cirrostratus were common, especially on the Colombo-Cocos leg, at heights up to 45,000 ft. or above. They were often 5,000 ft. or more thick, and were troublesome in that they might contain embedded cumulonimbus heads. A slide illustrating this was shown. In one training flight an aircraft in cirrostratus at 42,000 ft. near Colombo was suddenly thrown up 3,000 ft., lost an engine ("flame out"), and had to descend to 10,000 ft. to relight. *Mr. Hurst* then described the meteorological documentation. The race started from London Airport and was won by one of the Royal Air Force Canberra aircraft.

*Mr. Harley* spoke of the work done at London Airport in preparation for Comet III transatlantic flights. As Comets fly about twice as high as present aircraft, many forecasting problems required study both by meteorologists and the aircraft operators. Such problems are the characteristics and rates of change of wind fields at 200 mb., methods of constructing charts, probable forecast errors and the relative frequency of use of different tracks. He dealt with the production of the 200-mb. forecast chart for 1500 G.M.T. outlined previously by the opener. A serious difficulty of construction is the number of ascents, especially from ocean weather ships, which fail to reach 200 mb., while the wide spacing of ships' reports make precise location or forecasting of jet streams impossible over the ocean. The basic chart used for the preparation

of the 200-mb. forecast chart is the 1500 G.M.T. chart of the previous day. It would obviously be preferable to use the 0300 basic data of the day in question, but this is impracticable at present because, apart from the pressure of work for real flights, the 200-mb. North American data, including ships' reports, are received usually 6-9 hr. after the time of observation.

Records are kept of figures of geostrophic equivalent tailwind on the great circle, Shannon to Gander, from the forecast and actual 200-mb. charts. Summaries of figures for the spring, summer and autumn of 1954 show the wide range of values experienced in spring and autumn, and the narrower range in summer, though the mean value is then well above that of the spring.

To measure the success, or usefulness, of the forecast equivalent tailwinds use is made of Priestley's formula\* :—

$$P = \left( 1 - \frac{\varepsilon^2}{\sigma_{24}^2} \right)^{\frac{1}{2}},$$

where  $\varepsilon$  is the standard error of the 24-hr. forecast and  $\sigma_{24}$  the root-mean-square variation of the actual equivalent tailwind in 24 hr. Thus, if the variability of the equivalent tailwind is small it is hard for the forecaster to achieve a useful improvement over "flying on the actual". As the "error" is the difference between the forecast and the corresponding actual equivalent tailwind, uncertainties in the construction of the actual chart increase on the average the apparent error. In spring and autumn when there are considerable real 24-hr. variations, the calculation above gave success figures of 33 per cent. and 63 per cent. respectively, but in summer, when real 24-hr. variations are certainly much smaller, the figure was only 10 per cent. From another aspect, perhaps of more interest to operators, the autumn forecasts gave about 85 per cent. of errors less than 20 kt., as against about 90-95 per cent. at 500 mb. usual in this season.

Mr. Chambers (Superintendent of Meteorology, B.O.A.C.) said that he had often been asked why so many forecasters were required at London Airport, and he thought the reasons were obvious from Mr. Harrower's opening statement which indicated the diversity of routes covered and the detailed procedures carried out. His further remarks were based on general impressions and were not intended as criticism against London Airport where he could truthfully say that the standard of meteorological service is not bettered anywhere on B.O.A.C. routes. Some experienced Atlantic pilots seem to be of the opinion that the standard of forecasting over the North Atlantic routes is no better today, and is possibly a little worse, than it was during the Ferry Flights of 1945-46. He considered the reasons for this belief were that in the earlier days forecasting and briefing were performed by a relatively small team of individuals who specialized in the work and who had ample time to give individual service to each flight. With the rapid expansion of civil aviation in post-war years and the economic necessity of keeping staff to a minimum, the meteorological service was streamlined, so that one set of forecast charts and, in some cases, one route forecast were supplied for all flights within a certain time interval, independent of the exact time of departure and the exact track to be flown. It seems rather important, therefore, that we should resist any further reduction in the individual-type service for long-distance flights since it would probably lead to the lowering of the pilots' confidence.

Another impression of the air crews is the apparent apathy shown by forecasters at de-briefing. It is fairly safe to say that the forecaster is often too busy to devote the full time necessary to de-briefing. In general it can be said that meteorological offices everywhere were under-staffed, and there is little doubt that this had an adverse effect on efficiency. It is certain that civil demands on the meteorological services will continue to increase. B.O.A.C. would like to see the position and intensity of jet streams included in actual and forecast upper air charts, particularly over the North Atlantic. For high-level operations in this area, jet streams were likely to be of great significance in view of wind strength and clear-air turbulence. He felt that, at briefing, too much emphasis was often placed on the forecast weather included in the folder. The forecast itself usually gives a clear indication of the most probable development, and during briefing it is important to discuss the less probable developments which might take place. This applies to terminal as well as to conditions *en route* and the terminal weather forecast plays a very important part in flight planning. With the introduction of regular exchanges of TAFOTS, there has been a tendency for departure meteorological offices to be rather reluctant to offer advice on terminal weather other than that contained in the TAFOT. A TAFOT is a statement of what the forecaster at the terminal considered to be most probable, while the less probable developments might influence the routing and/or fuel reserve of a flight. For this reason it is important that forecasters should have a sound knowledge of the aerodrome weather characteristics at the terminals concerned.

Mr. Harrower in reply, said that the forecasters at London Airport all worked extremely hard. For example, at present there are about 750 departures and a corresponding number of arrivals a week. This will increase to about 1,200 or so departures a week next year. He believed that pilots and especially operators are judging forecasts more critically now than in 1945-46. The pressure is mainly economic. Nowadays if an aircraft arrives early due to forecast errors it is interpreted as a possible loss of pay load. In 1945-46 the main emphasis

\* CROSSLEY, A. F.; Measures of success in forecasting. *Met. Mag., London*, 83, 1954, p. 139.



was on getting the aircraft to the other side safely. At London Airport there is certainly no apathy by forecasters at de-briefing. Every crew coming in for de-briefing is welcomed. Unfortunately very few crews, especially transatlantic crews, come to the meteorological office for de-briefing, their completed cross-sections being brought up later by the operations staff. It is doubtful if at all times we could place the jet streams accurately enough over the Atlantic to justify including them in actual and forecast charts. At briefing all relevant details of jet streams are passed on to the air crews. At London Airport forecasters always discuss TAFOTS with air crews at briefing. It is doubtful if views differing from the statements contained in the TAFOTS are used in pre-flight planning as in many cases operators' regulations laid down that the flight planning would be conducted strictly on the official TAFOT received.

*Mr. Saunders* spoke about R.A.F. Coastal Command long-distance flights made at low levels, below 2,000 ft., at low speeds. The aircraft make routine flights to mid Atlantic of about 15-16 hr. The most important elements in the forecast, prepared 18-20 hr. ahead of the end of the period of validity, are visibility, cloud base, low-level winds, and terminal and alternative conditions. Amendment procedure is of great importance. Shortage of information over the Atlantic is the main difficulty encountered. Ships' reports, excellent in many respects, would be still more useful to forecasters if free use were made of special-phenomena groups to give times of significant changes, and if course and distance run were also included. More ships in the western approaches east of 10°W. would be helpful. Much use is made of low-level BISMUTH flights. Detailed analysis of surface charts is essential to this work. In particular, fronts should be carried on as long as any surface discontinuity can be traced and double-structured warm sectors are often justified. Development and movement of areas of sea fog and low cloud can often be forecast accurately from the movement of these shallow discontinuities. The speed of fronts over the Atlantic is clearly of importance to forecasting for long-distance low-level flights. Recent work (in co-operation with Hinkel) has shown that warm fronts over the Atlantic move at 84 per cent. of the geostrophic wind component normal to the front, as compared with the results given by Petterssen (60-80 per cent.), Byers (50-70 per cent.) and Matthewman (67 per cent.), all of whom presumably selected their fronts mainly over land. A slightly more accurate method is to measure the geostrophic component normal to the front in the cold air 75 miles ahead of the front. For Atlantic fronts this gives a value of 99 per cent. as compared with Matthewman's value of 79 per cent. for fronts over the British Isles.

*Cmdr Frankcom* doubted if it would be practicable to introduce special-phenomena groups into the reporting from merchant ships, bearing in mind that the observations are made by voluntary observers, and in many ships there is only one radio operator on board and observations have to be transmitted when he is on duty. In any case the proposal would need international consideration. His impression was that all "selected" ships invariably report their course and speed. "Supplementary" ships, however, are not supplied with barographs, and therefore are unable to report tendency and consequently do not report course and speed. It is true that merchant ships do not normally report within the 100-fathom line, which approximately coincides with 10°W. in the vicinity of the British Isles, because of congestion of shipping and preoccupation with navigational problems. However, an invitation was recently issued to "selected" ships to report within that area (particularly in the North Sea) when circumstances permitted. Turning to upper air observations from ocean weather ships, he thought that it would be found that those from the British vessels normally reach over 45,000 ft. Observations from the ocean weather ships of certain other nationalities only reach a considerably lower height, and it is perhaps for this reason that the mean heights of the observations of all the ships seem low. He was surprised to hear that observations from station C take a long time to reach London Airport. It should be relatively easy to overcome this difficulty by consultation with the Chief of the United States Weather Bureau, as there seems to be no reason why reports of any specific ocean weather station should be delayed.

*Mr. Harley* pointed out that he had been specifically referring to the 200-mb. data which are normally received 6-9 hr. after the time of observation.

*Capt. Cane* (B.O.A.C.) felt considerable concern regarding the apparent time lag in communications on the transatlantic meteorological network, producing weather information unacceptable to jet operations if, as had been indicated, the forecast for the arrival times on the other side of the Atlantic is sometimes based on information over 30 hr. old. It is essential that communications are speeded up and made reliable in order to provide highly accurate and comparatively short-term destination and alternative-landing forecasts. With regard to the *en route* meteorological information at present available from aircraft, and upon which considerable reliance is placed at the moment, it should be remembered that with the trend towards smaller operating crews and the change-over to high-frequency radiotelephony as a method of communication, the amount of meteorological data transmitted from the air would diminish. He would also like to emphasize that accurate prediction of icing is a matter of importance to jet operations since there is a fuel penalty in the operation of the de-icing systems on this type of aircraft. He hoped that some method could be found to improve the reliability of the present methods of prediction.

*Mr. Harrower* replied that with regard to the age of data on which forecasts were based, it is true that for some forecast charts issued at London Airport the longest elapsed time between

the basic data and the mean time of validity of the chart could be  $22\frac{1}{2}$  hr. for basic upper air information at London increasing to  $37\frac{1}{2}$  hr. at New York, but this is not necessarily due to lateness of data but that main upper air data are only received every 12 hr., the time data take to reach London, chart plotting, analyses, forecasting, and, as far as New York was concerned, an allowance of 15 hr. as an average flight time between London and New York for the slower aircraft. The present position regarding the reception of Canadian and American data at London Airport could be summarized as follows: the main channel by which this information is received is the meteorological radio-teleprinter link New York-Santa Maria-Paris then teleprinter *via* Dunstable to London Airport. Under normal conditions data are received at London Airport as follows:—

- (i) A good coverage of surface data for Canada and the United States with ships 3–4 hr. after time of observations
- (ii) TAFOTS from Canada and the United States 1–3 hr. after time of issue
- (iii) A good coverage of upper air data for 300 and 200 mb. 6–9 hr. after time of observation.

A large amount of data has to come by this channel, and unfortunately there seem to be quite a few occasions when the radio-teleprinter link appears to be affected by adverse atmospheric conditions and data are received very late if at all. This, of course, causes great dismay to the forecasters at London Airport and makes their task even more difficult than usual. Referring back to TAFOTS, these are also duplicated by direct signal from Canada, and these messages over the normal telecommunications channel come in very well, the main TAFOTS from Canada normally being received at London Airport by this method within the hour from time of issue. Mr. Harrower felt that it would undoubtedly have an adverse effect on forecasting if aircraft meteorological reports, especially from the Atlantic, should be cut any more. It should be remembered that the only direct information we have of the upper air conditions over the Atlantic is from the widely spaced ocean weather ships and the too infrequent meteorological reconnaissance flights. Reports from aircraft have been used to improve in-flight forecast amendments to the same aircraft and to improve forecasts for following flights. Following air crews are always extremely interested in what the previous flight is finding and the forecaster is helped considerably. The value of the reports are returned manifold to the operators themselves, and any decrease in reports would ultimately be felt by the operators. He pleaded for more high-level reports from jet aircraft. The importance of the accurate prediction of icing is appreciated in relation to jet aircraft and every endeavour is made to provide careful forecasts. However, here again, aircraft reports made in flight could be of the greatest value. Mr. Harrower had de-briefed many Comet I crews at London Airport, and could not remember any crew ever saying that ice formation had caused them any concern whatsoever.

Mr. Bradbury asked about the mechanics of the analysis of the 200-mb. chart. Mr. Harrower explained that at London Airport they are experimenting with the analysis of this chart. The chart is drawn directly with due regard to the absolute heights reported, the wind velocities carry great weight and an attempt is made to take into account previous history and the lower-level charts already constructed. Forecasting is carried out largely by extrapolation but an attempt is made to take into account modifications expected by developments.

Mr. Illsley inquired about the use made at London Airport of long waves (Rossby's formula) in forecasting. Mr. Harrower replied that time did not usually permit the application of the formula quantitatively, but that on some occasions, with well defined long waves, he had found the ideas useful in a qualitative manner.

Mr. Maidens pointed out, arising from the view expressed earlier, that Atlantic forecasts are now not quite so satisfactory as in 1945, that there have been changes in the basic information received from this area. In 1945 meteorological reconnaissance flights were being made in quite considerable numbers, and included several daily flights from the United Kingdom, Gibraltar, the Azores and from the eastern seaboard of the United States. Now there is only one such flight, from Aldergrove. He would like to hear the value of the flights discussed, and learn the views of forecasters on any possible ways in which the usefulness of the present BISMUTH sortie could be enhanced.

Mr. H. E. Smith (B.O.A.C.) remarked that in high-speed jet-aircraft operations a marked degree of importance was associated with terminal forecasting in particular. Relatively speaking, the *en-route* phase is of secondary importance, and the existing order of errors in the *en-route* forecast would be less significant if a really confident picture was available prior to departure time of terminal and alternate-aerodrome weather. It was his opinion that the existing period TAFOT system is unacceptable for planning jet operations in such areas as the North Atlantic, as he considered that what is required is more specific information relating to short-time periods for terminal and alternate aerodromes. In some respects forecasting for terminals should be easier since the normal time of flight would be halved by the future jet aircraft. He believed that in order to provide an efficient Air-Traffic-Control service it would be necessary to maintain a standard pattern of selective routes and that these routes must be kept to a minimum. This might also relieve the load on the Meteorological Office to some degree.

From the point of view of B.O.A.C., the Comet III "paper" operation was proving particularly important, and they were most appreciative of the co-operation they continued to get from the Meteorological Office.

Mr. Harrower, replying, said that at London Airport they were very much alive to the importance of accurate forecasting of terminal conditions for jet aircraft. When the Comet I flights were coming into London Airport, special short-term TAFOTS had been sent to the aircraft in flight before it reached the point where it would commence its descent, in order that the captain could decide whether to continue his descent to London Airport or carry on to one of his alternates. He did not think that a "really confident picture" could always be presented of the terminal conditions before departure time under present conditions of knowledge of forecasting.

Mr. Armstrong suggested that if, as stated by previous speakers, the number of in-flight meteorological reports from civil aircraft are going to decrease, the BISMUTH flight might report all the way across the Atlantic on one day and return reporting again on a following day.

Mr. Cowan observed that there had been much talk about the desirability now, and more so in the future, for more and more accuracy in wind and terminal forecasts. At present, under regulations of the International Civil Aviation Organization, a large amount of documentation has to be given to each air crew at briefing. The preparation of this documentation takes up the major part of the forecaster's time in the preparation of flight forecasts. The forecast requirements for jet aircraft in the future had been discussed and it should be noted that, in the past, it took 2-3 hr. to prepare a fully documented forecast for a Comet I flight to Rome lasting 2½ hr. It can be seen that if the forecaster is to drive for greater accuracy in his forecasts, much of the documentation must be eliminated, in order to give the forecaster more time to consider his actual forecasts.

Mr. Gold said he too was both surprised and disappointed to learn that the upper air information from the western Atlantic is not received until 6 hr. or more after the time to which it referred. That is a great handicap for the forecaster. He was astonished at the suggestion that weather reports from transatlantic aircraft might be diminished. These reports are necessary in the interests both of the safety and of the economy of flight and seemed to him one of the most important activities of the crews. He also pleaded for the presentation of actual rather than cumulative frequencies. The former speak more directly and do not disguise the facts as slopes and differences.

A speaker for Royal Dutch Airlines said the work load in cockpits of modern aircraft is now very high apart from making meteorological reports.

Dr. Stagg, in closing the discussion, thanked the visitors for their contributions and assured everyone that the Meteorological Office was not complacent about these problems, and every effort would be made to improve still more the forecasting for long-distance flights.

## **METEOROLOGICAL RESEARCH COMMITTEE**

The 18th meeting of the Instruments Sub-Committee of the Meteorological Research Committee was held on October 22, 1954.

Two papers from Kew Observatory were discussed; one by Mr. J. MacDowall<sup>1</sup> described the development of a total-radiation fluxmeter and the other by Mr. M. J. Blackwell<sup>2</sup> was concerned with the automatic integration of solar radiation. Other papers, by Mr. P. Goldsmith<sup>3</sup> and Mr. G. E. W. Hartley<sup>4</sup>, were considered which dealt with a method of increasing the range of the Dobson-Brewer aircraft frost-point hygrometer, and a remote-recording electrical anemograph. Problems associated with the measurement of rainfall at sea were also discussed.

The 32nd meeting of the Synoptic and Dynamical Sub-Committee was held on November 4, 1954.

A paper by Mr. A. F. Jenkinson<sup>5</sup>, on the relation between standard deviation of contour height and standard vector deviation of wind, was considered. Another paper considered was one by Mr. H. D. Hoyle<sup>6</sup> concerning the speed and direction of motion of simple warm-sector depressions. Prior to these papers the Sub-Committee had discussed at some length the future programme of research into the problem of air flow over mountains.

The 30th meeting of the Physical Sub-Committee was held on November 11, 1954.

Preliminary arrangements for field trials to explore the feasibility of increasing rainfall were discussed. A paper by Dr. Best<sup>7</sup> which was relevant to the problem of smoke pollution was considered. The paper discusses the complicated problem of assessing the maximum concentration at ground level of gas from a heated elevated source. Dr. Robinson introduced a paper<sup>8</sup> by Mr. Lander and himself on the determination of the vertical convective heat flux from observations of the fluctuations of wind and temperature near the ground.

#### ABSTRACTS

1. MACDOWALL, J.; A total-radiation fluxmeter. *Met. Res. Pap., London*, No. 858, S.C. I/85, 1954.

The instrument, designed to measure net flux of radiation through a horizontal surface near the ground, consists of a freely exposed plate 3 in. square of thin aluminium sheets separated by bakelite and polythene and blackened on both surfaces. A blower and nozzle direct air symmetrically on both surfaces to minimize the effect of variable winds. The temperature difference between two surfaces is measured by an inserted thermopile. Trials are described showing effect of wind speed, aperture, and sensitivity of paint to different wave-lengths ( $0.5 - 10\mu$ ). Calibration is discussed. The instrument is satisfactory except in rain or fog.

2. BLACKWELL, M. J.; Report on the automatic integration of solar radiation at Kew Observatory. *Met. Res. Pap., London*, No. 862, S.C. I/87, 1954.

Apparatus for obtaining daily values of total (sun + sky) solar radiation from a Moll-Gorczyński solarimeter by use of an amplifier and integrating motor is described, with method of calibration. The accuracy of the present apparatus is assessed as 2-3 per cent. Future improvements, including a method of obtaining hourly values, are suggested.

3. GOLDSMITH, P.; A method of increasing the range of the Dobson-Brewer aircraft frost-point hygrometer. *Met. Res. Pap., London*, No. 859, S.C. I/86, 1954.

The Dobson-Brewer hygrometer fails below  $-130^{\circ}\text{F}$ . because ice deposit becomes unrecognizable. This is overcome by supplying the hygrometer with compressed air. Test flights showed that increasing pressure from 238 to 1013 mb. can increase the range of the hygrometer by  $20^{\circ}\text{F}$ . First results suggest a "tropopause-like" inversion of humidity at about 44,000 ft.

4. HARTLEY, G. E. W.; A remote-recording electrical anemograph. *Met. Res. Pap., London*, No. 867, S.C. I/88, 1954.

A recorder designed to work with the Meteorological Office generator anemometer, Mk IB, and modified to give quick response and record gusts accurately and a system for remote recording of wind direction are described. Both have proved satisfactory; specimen records are shown.

5. JENKINSON, A. F.; Relation between standard deviation of contour height and standard vector deviation of wind. *Met. Res. Pap., London*, No. 869, S.C. II/173, 1954.

Standard vector deviation  $\sigma$  of wind between the friction layer and 300 mb. outside the tropics is expressed in knots as  $\sigma = 0.064 s \operatorname{cosec} \phi$  where  $s$  is the standard deviation of contour height in feet. Above 300 mb. the constant decreases to 0.033 at 100 mb. This formula and the standard deviation of surface pressure are used to construct world maps of standard vector deviation of wind above the friction layer in January, April, July and October. Estimated standard vector deviation at 300 mb. in the northern hemisphere is shown for January and at 500 mb. over the Atlantic (from standard deviation of 500-mb. height) for January, April, July and October.

6. HOYLE, H. D.; An investigation into the speed and direction of motion of simple warm-sector depressions. *Met. Res. Pap., London*, No. 872, S.C. II/175, 1954.

Motion in 12 hr. of 16 unoccluded depressions over the Atlantic during January-June 1951 was compared with contour winds and 1000-500-mb. thermal wind over an area (diameter 600 nautical miles) round the centre.

	Relation with winds at the levels					1000-500-mb. thermal
	1000 mb.	700 mb.	500 mb.	300 mb.	Warm sector	
Correlation coefficient	0.47	0.86	0.90	0.89	0.81	0.92
Mean track error	...	$-5.5^{\circ}$	$-2.9^{\circ}$	$-4.1^{\circ}$	$-6.1^{\circ}$	$-0.6^{\circ}$

A check of 18 cases in 1950 gave a correlation of 0.94 with the thermal wind. Marked diffuence ahead of surface centre increased speed.

7. BEST, A. C.; Assessment of maximum concentration at ground level of gas from a heated elevated source. *Met. Res. Pap., London*, No. 878, S.C. III/175, 1954.

Three formulae (O. G. Sutton; Bosanquet, Carey and Halton; and Oak Ridge) for computing maximum gas concentration at ground from a high hot chimney are compared. The differences in computed values are small and are mainly due to differences in computing the rise of the smoke plume above the orifice. A combination of the Oak Ridge empirical and Sutton's formula is recommended.

8. LANDER, A. J. and ROBINSON, G. D.; On the determination of the vertical convective heat flux by observations of wind and temperature near the ground. *Met. Res. Pap., London*, No. 873, S.C. III/171, 1954.

Earlier measurements at Kew were continued, mostly at a height of 150 cm., and the complete results are tabulated, including heat flux calculated from simultaneous fluctuation of vertical components of winds and temperatures, and that given by Bowen ratio. The former averages only 0.44 of the latter. Both methods are discussed and considered to be satisfactory at the Kew site, so that the discrepancies cannot yet be accounted for. Swinbank's results are also tabulated but do not help. Appendices describe the apparatus and the method of determining heat flux.

## ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on December 15, 1954, Professor P. A. Sheppard, a Vice-President, in the Chair, the following papers were read:—

*Sumner, E. J.—A study of blocking in the Atlantic-European sector of the northern hemisphere\**

Mr. Sumner examined blocking situations in the zonal flow over the North Atlantic and Europe during the period January 1949–December 1952. The 0300 G.M.T. 1000–500-mb. thickness charts and the 500-mb. contour charts were used. Blocking was taken as the local and rather sharp diminution of zonal flow within the area, occupied elsewhere and previously by the main westerly flow.

The essential feature of blocking action is the formation of a high-pressure area with the introduction of a meridional component into the previously westerly flow. Depressions, instead of moving more or less directly eastwards, subsequently move round the blocking centre on either its northern or southern sides. Mr. Sumner took an occasion of blocking as existing from the time of the first chart on which it appeared to the last on which it could be recognized without restriction to the length of time between these charts. Previous writers had stipulated longer periods, ten days in one instance. He presented statistics of the monthly frequency of blocking patterns, distributions of the centre of the blocking anticyclone with latitude and longitude, the duration of spells of blocking, and of the location and displacements of the centre. Distinction was drawn between centres moving east and centres moving west. The statistics showed that blocking patterns existed on more than half the days of the period and that the average spell duration was 16.5 days. They were most frequent in May and November and least frequent in July. The frequency in May and minimum in July had been shown to exist also in the Pacific by Rex. Points raised in the discussion were how to ascertain if the block will move eastwards or westwards, whether differences existed from year to year, the infrequency of blocking action in the southern hemisphere which suggests blocking is geographic in origin, and the type of weather over the British Isles during a blocking period. Mr. Sumner, in reply, said the movement of blocking centres agreed well with Rossby's wave formula, that there was much blocking action in each year examined, and that the weather in the British Isles during a blocking period greatly depended on the position of the high-pressure centre.

*Pothecary, I. J. W.—Short-period variations in surface pressure and wind†*

Mr. Pothecary described the short-period small variations in pressure associated with large oscillations in wind direction and small ones in wind speed lasting for about two hours, which moved north-eastward across southern and central England between midnight and 0400 G.M.T. on July 5, 1952, against the wind direction in the lower layers. He suggested the oscillations were primarily set up on an inversion at about 830 mb. between an upper warm layer moving from the south-east and lower cold air moving from the north-east. Calculation based on formulae published in 1925 by Goldie gave an amplitude of 250 m. in the oscillations on the inversion. Detailed autographic records illustrated the effects. Mr. Pothecary saw the initial stimulus of the oscillations in the outbreak of thunderstorms which occurred over the western English Channel on the evening of the previous day which gave a sudden and considerable outflow of cold air blocking the easterly flow and setting up the oscillations on the surface. Points raised in the course of the discussion were the frequency of occurrence of such oscillations and their relations to the vertical distribution of wind and temperature and to the weather.

\* *Quart. J. R. met. Soc., London*, 80, 1954, p. 402.

† *Quart. J. R. met. Soc., London*, 80, 1954, p. 395.

*Kraus, E. B.—Secular changes in the rainfall regime of SE. Australia\**

Dr. Kraus's paper was read by Prof. Gordon Manley. The basis of Dr. Kraus's paper is that 30-yr. running means of rainfall in south-east Australia show an increase in summer rainfall and a decrease in winter rainfall from the period centred about 1895. A diagram of the rainfall in spring in southern New South Wales showed many fewer springs of above average rainfall since 1895 than before that year.

Correlation of rainfall in the area with the strength of the westerly circulation at 300 mb. obtained from radio-soundings made in south-east Australia since 1944 had a positive value in winter, except on the eastern side of the mountains where Föhn-wind effects account for the change of sign, and a negative value in summer. The signs of the coefficients are reasonable on general principles. Strong upper winds inhibit the formation of large cumulus clouds from which most summer rainfall comes. It appears that there has been a marked clearance of the westerly circulation since about 1900. The changes in the monsoon rainfall of Queensland support the same view. The discussion dealt mainly with the selection of an appropriate period over which to take running means.

## LETTER TO THE EDITOR

### Unusual behaviour of the wind at Luqa airport, Malta

Mr. Lamb's interesting and detailed account, in the *Meteorological Magazine* of September 1954, of the surface wind and pressure fluctuation at Luqa on October 16, 1953 does not take the topography of the island of Malta into serious consideration as a possible explanation of the phenomenon. The coastal cliffs, to the southward of Luqa, rise sharply to 400–450 ft. after which the land falls gradually to about 250 ft. and rises to 300 ft. at Luqa airfield. Qrendi lies near the top of the ridge and Hal Far near the eastern edge. Topography of similar shape and only 330 ft. high (near Barton-on-Humber) is known to have produced a marked accentuation of lee waves due to the Pennines.

The powerful down-currents (over 1,000 ft./min.), deduced from Qrendi radio-sonde readings, strongly suggest the presence of lee waves and the wind and the temperature distributions with height suggest that form of lee effect called "rotor streaming" by Förchttgott.

The Malta incident may be compared with reports from the lee of Dartmoor on December 1, 1952. On this occasion, with easterly winds, there were two reports of violent turbulence at 4,000 and 5,000 ft. to the north of Plymouth. Another report from an aircraft flying from Start Point to Plymouth stated "Strong vertical currents between 3,000 and 5,000 ft. Several variations in altitude of 2,000 ft. in quick succession." Except at the Plymouth end of the flight where the hills up wind rise to about 1,300 ft., the ground at no point reaches 700 ft. The lee nature of the phenomenon is emphasized by the other reports to the north of Plymouth. These incidents occurred between 1200 and 1500 G.M.T. The afternoon ascent from Cambourne showed an inversion of 5°F. from 920 to 910 mb. and of 1°F. between 910 and 860 mb. The wind was 80° 17 kt. at the surface and 80° 30 kt. at 900 mb. At 750 mb. it had decreased to 73° 10 kt. and had backed at 700 mb. to 29° 11 kt. There was no cloud.

The increase of wind up to the inversion and the decrease above, together with the temperature distribution, are similar in each case. Peculiarities in surface wind in lee-wave conditions have been reported from Hartside, Great Hucklow and Ronaldsway.

H. S. TURNER

*Northolt Airport, November 10, 1954*

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\* *Quart. J. R. met. Soc., London*, 80, 1954, p. 591.

[I find the suggestion that the cliffs on the coast south of Luqa could have given rise to the wind effects observed on October 16, 1953, a very surprising one. This surprise is partly due to the magnitude of the observed effect, which is attributed by Mr. Turner to a 400-ft. cliff with a very gently undulating landscape to leeward. Secondly, no other example of this phenomenon has been noticed in years of anemograph records at Luqa, i.e. surely too rare an occurrence to be set up by a cliff which is always there. Nevertheless, I am disposed to believe that the 800-ft. high plateau, which lies 3 miles and more west of Luqa and is bounded on most sides by steep escarpments, played some part in checking the pulses of the light westerly breeze which intruded at intervals under the inversion on the morning of October 16, 1953.—H. H. LAMB.]

## NOTES AND NEWS

### **Condensation phenomena at the Exhibition of the Society of British Aircraft Constructors at Farnborough**

Considerable interest was aroused at last year's aircraft display at Farnborough by the appearance of a condensation effect on some low-level runs by high-speed aircraft. The photograph facing p. 81 (which is reprinted from *Flight*) is a good example of this phenomenon. The effect was observed as a bluish-white spray extending over the whole upper surface of the wings from leading to trailing edges. The "spray" travelled with the aircraft and was quite unbroken, but left no trace in the wake of the aircraft, nor were there any wing-tip trails.

Occurrences of a like nature have been observed on other occasions accompanying high-speed aircraft but not usually in such a pronounced form. Two sets of circumstances no doubt contributed to making this a particularly good example for viewing from the ground: the high humidity of the air in the layers near the ground (the dew point was 61°F. which is a rather high value for England) and the infrequency with which high-speed flights are made so near the ground.

Condensation phenomena in the wake of high-speed aircraft, other than condensation trails, are as yet imperfectly understood but there is little doubt that this is a condensation effect associated with the development of areas of low pressure on the wing surface, leading to adiabatic cooling of the air below its dew point. The magnitude of the pressure drop (and hence the cooling effect) and the area of wing affected vary from aircraft to aircraft and increase with the speed of the aircraft. Thus at high speed large areas of the wing surface may be at reduced pressure and at first sight this may appear to be an adequate explanation of the appearance of vapour on the wing. The aircraft, however, is moving so rapidly relative to the air that it is difficult to visualize visible condensation occurring in the very short time that any particular volume of air is subjected to the reduction of pressure as it moves past the wing. A further effect of high-speed flow may help to resolve this difficulty. In high-speed flight the flow of air past the wing becomes detached from the wing surface leaving a boundary layer of slowly moving air in contact with much of the wing surface, and although the thickness remains very small this boundary layer will increase in depth and extent as the speed increases. It is thought that it is in this layer that the condensation effect is produced leading to a visible cloud which remains attached to the wing. The reduced pressure effect and associated condensation would extend some distance outward from the

boundary layer but turbulent mixing in the wake of the aircraft would soon cause the air to return to its normal state so that the cloud would be dissipated. There would then be a cloud of limited but uniform extent over the wing surface travelling along with the aircraft, as was in fact observed. In conditions of high humidity, as occurred on the show day, the dissipation of the cloud would be somewhat slower than usual and so give a more pronounced effect.

R. F. JONES

## METEOROLOGICAL OFFICE NEWS

**Retirements.**—*Mr. J. Durward, C.M.G.* retired from the post of Deputy Director (Services) on December 31, 1954. At a ceremony in Victory House, on January 3, 1955, the Director presented Mr. Durward with a picnic set and cheque subscribed for by his colleagues; in speaking of Mr. Durward's career the Director referred especially to the valuable services he had rendered at international conferences.

Mr. Durward, in returning thanks, gave a vivid and humorous sketch of his career in the Office. His association with meteorology began because he was the only man in the British Army in France in the summer of 1915 who could make pilot-balloon ascents, an accomplishment learnt at Aberdeen University on a few Saturday afternoons. He recounted several anecdotes relating to international conferences and to some forced landings in aircraft which had ended in happy, even humorous, circumstances.

Mr. Durward has accepted a temporary appointment in the Meteorological Office.

*Mr. A. C. Brawn*, Senior Scientific Assistant, retired on January 31, 1955. He joined the Air Ministry in 1919 after service in the 7th London Regiment during the First World War. He was seriously wounded in 1917. He was transferred to the Marine Branch in 1923 and when the Port Meteorological Office, London, was opened in 1930, Mr. Brawn was posted as assistant to the Port Meteorological Officer, serving there until his retirement, except between 1940 and 1945 when he was attached to the Port Meteorological Office at Liverpool.

**Academic successes.**—Information has reached us that the following have passed the General Certificate of Education (Advanced level); we offer them our congratulations.

Pure and applied mathematics and physics, D. J. Reid, R. J. Snowdon;

Applied mathematics, O. M. Hill.

**Ocean weather ships.**—Three of the British weather ships were at sea on Christmas Day. *Weather Explorer* was on passage to station A, *Weather Recorder* was on duty at station I and *Weather Watcher* at station J.

R.A.F. aircraft of Coastal Command, which regularly drop mails in water-tight containers to these ships when on duty, made a special effort to enliven the Christmas proceedings. The following extracts from the Masters' Reports show what happened:—

*o.w.s. Weather Recorder.*—The crew of the aircraft sang carols and dropped a Christmas tree and mails.

*o.w.s. Weather Watcher.*—The aircraft brought and dropped cigarettes and greetings from the Lord Mayor of Birmingham. The wind was SW.-W., force 7, on Christmas Day.



## WEATHER OF JANUARY 1955

Mean pressure was below normal over a large area extending from Europe across the North Atlantic to most of North America. The deficit of pressure was very pronounced over the North Atlantic in the region of 47°N. 45°W. where the mean pressure was nearly 20 mb. below normal, the actual value being about 990 mb. The mean pressure was above normal north-west of the British Isles, the excess reaching 10 mb. or more in places in Iceland and on the east coast of Greenland.

Mean temperature was 5–10°F. above normal over many parts of southern Europe and the Mediterranean region. Over central and northern Europe the mean temperature was mostly below normal, generally from 2° to 3°F.

In the British Isles the main features of the weather were the two spells of wintry conditions during the first three weeks separated by a very brief mild spell, and the mild ending to the month.

During the first week pressure was high to the north of the British Isles and cold air with easterly winds spread across the whole country on the 1st and remained for over a week. Weather was mainly dull and cold with a few light snow showers particularly on the east coast, until on the 4th a complex low-pressure system settled in the Bay of Biscay and associated fronts brought prolonged snowfall to most of England and Wales, with hail and thunder in the south-west; by the evening it lay 3–6 in. deep in many Midland and south-eastern districts and was the heaviest snowfall in the London area since 1947. The snow continued to move north on the 5th, turning to drizzle in many places, and with day temperatures later generally rising to above 40°F. (49°F. at Scilly on the 7th), the thaw quickly set in, and the next few days were mainly quiet and cloudy with some local mist and fog. London recorded its first sunshine of the month on the 9th but in parts of eastern England there was none during the first 13 days. By the 10th mild air from the Atlantic brought dull skies but temperature above 50°F. over most of England and Wales; the mild weather was short-lived, however, as a break-through of polar air the same night reduced the general level of temperature by 10–15°F. The cold spell which followed, like the one experienced earlier in the month, lasted over a week but was more severe. This change was preceded by widespread rain, heavy locally in the west on the 9th; among the heavier falls were 2·30 in. at Blaenau Festiniog, Merionethshire, 2·60 in. at Faltstone, Northumberland and 2·19 in. at Alston, Cumberland; parts of eastern England recorded up to 0·75 in. during the 24 hr. up to the evening of the 10th. On the night of the 13th–14th a belt of snow crossed southern England and the following morning it lay 8–9 in. deep in many areas near London and 13 in. deep locally in Somerset; that night screen temperature fell to –1°F. at Fort Augustus and to 10°F. as far south as Bristol. During the 16th a vigorous depression moved east across southern districts, and in the London area the passage of the associated cold front was marked by an unusual concentration of smoke which moved away southwards; in parts of London for a time there was complete darkness. On the north side of the depression there were strong winds and widespread snow and rain over England, Wales and Northern Ireland, while in Scotland there were frequent snow showers in the cold northerly winds, and many villages in the extreme north of Scotland (including the islands of Orkney and Shetland) were isolated for a week owing to severe drifting. Glenrossal, Sutherland, reported more than 1 ft. of snow lying for 10 days from the 14th and a maximum depth of level snow of 18–20 in. on the 18th. The depression, however, brought a thaw to the south-western part of the country, the temperature at Penzance reaching 54°F. on the 15th whereas at Kinloss on the same day the maximum temperature was only 20°F. Fog was fairly frequent night and morning from the 11th persisting all day locally on the 12th, 15th and 16th. A weak ridge of high pressure settled over the country on the 19th and after a mainly sunny day temperatures over the snow-covered ground fell to as low as 9°F. at Elmdon and 7°F. at Dyce where the ground temperature was –1°F. On the 20th and 21st mild air from the south-west brought rain, fog and a rapid thaw to practically the whole country. For most of the remainder of the month the highest pressure was over central Europe and weak frontal systems moved north-east across the British Isles, giving mild, cloudy weather, with one or two sunny days in most districts. The month ended with two or three days of spring-like weather in the south with temperatures reaching 53–56°F. in many areas.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	57	4	–2·3	114	–1	77
Scotland ...	58	–5	–3·1	75	–3	115
Northern Ireland ...	54	10	–3·0	125	–2	116

# RAINFALL OF JANUARY 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	2·48	133	<i>Glam.</i>	Cardiff, Penylan ...	3·55	96
<i>Kent</i>	Dover ... ..	4·92	230	<i>Pemb.</i>	Tenby ... ..	4·20	112
"	Edenbridge, Falconhurst	4·02	160	<i>Radnor</i>	Tyrmynydd ... ..	4·79	76
<i>Sussex</i>	Compton, Compton Ho.	4·22	133	<i>Mont.</i>	Lake Vyrnwy ... ..	4·71	81
"	Worthing, Beach Ho. Pk.	4·01	172	<i>Mer.</i>	Blaenau Festiniog ...	8·54	84
<i>Hants.</i>	St. Catherine's L'house	3·71	150	"	Aberdovey ... ..	2·47	63
"	Southampton (East Pk.)	3·57	134	<i>Carn.</i>	Llandudno ... ..	2·54	105
"	South Farnborough ...	3·03	145	<i>Angl.</i>	Llanerchymedd ...	4·15	131
<i>Herts.</i>	Harpenden, Rothamstead	2·62	127	<i>I. Man</i>	Douglas, Borough Cem.	5·12	153
<i>Bucks.</i>	Slough, Upton ... ..	2·36	127	<i>Wigtown</i>	Newton Stewart ...	4·05	98
<i>Oxford</i>	Oxford, Radcliffe ...	2·46	136	<i>Dumf.</i>	Dumfries, Crichton R.I.	3·54	110
<i>N'hants.</i>	Wellingboro' Swanspool	1·94	105	"	Eskdalemuir Obsy. ...	5·81	108
<i>Essex</i>	Southend, W. W. ...	2·47	169	<i>Roxb.</i>	Crailling ... ..	1·96	102
"	Felixstowe ... ..	1·78	117	<i>Peebles</i>	Stobo Castle ... ..	2·57	86
<i>Suffolk</i>	Lowestoft Sec. School ...	1·79	107	<i>Berwick</i>	Marchmont House ...	4·88	84
"	Bury St. Ed., Westley H.	2·24	125	<i>E. Loth.</i>	North Berwick Gas Wks.	1·59	93
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·52	130	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·82	103
<i>Wilts.</i>	Aldbourne ... ..	3·10	124	<i>Lanark</i>	Hamilton W. W., T'nhill	2·47	75
<i>Dorset</i>	Creech Grange... ..	4·58	141	<i>Ayr</i>	Colmonell, Knockdolian	3·06	71
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METEOROLOGICAL OFFICE

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## SUMMER OF 1954

### **Colloquium at the Meteorological Office, Harrow**

The summer of 1954 was dull, wet and cool in many parts of the British Isles. To say how bad or unusual it really was must await the analysis of full climatological returns; nevertheless there was thought to be some advantage in having a preliminary discussion while memories of it were still fresh. Accordingly an informal meeting was held at the Meteorological Office, Harrow on October 29, 1954. It was attended by some 70 members of the Victory House, Harrow and Dunstable staff; Professor Gordon Manley and Mr. C. K. M. Douglas were present by invitation. The meeting took the form of a colloquium with the opening speakers representing British and world climatology, forecasting research, upper air climatology and marine climatology.

**Openers' contributions.**—*Dr. J. Glasspoole*, Head of the British Climatology Branch, described, in broad outline, weather for the United Kingdom as a whole for the three months, June, July and August 1954. The most striking departures from average occurred over England and Wales where the general rainfall was 3·1 in. more than the 1881–1915 average, the mean temperature 2·5°F. below, and the mean daily sunshine 1·7 hr. below the 1921–50 average.

Over England and Wales there were six wetter summers in the last 54 yr.; the two wettest were in 1912 and 1879 with 15·9 and 15·7 in. respectively, well above the total of 11·8 in. recorded in 1954. Nor was the frequency of rain-days during the past summer outstanding, seeing that since 1917 the summers of 1946 and 1927 had more rain-days, and 1946, 1927 and 1924 more wet-days; at representative stations for the summer of 1954 the mean numbers were 53 rain-days and 40 wet-days (out of 92 days).

The mean temperature of the summer was about equal to the normal temperature of June. This low value was due more especially to lower maximum than to lower minimum temperatures. Of the last 53 summers only two, 1922 and 1907, were cooler over England and Wales.

The mean sunshine recorded during the three summer months this year was less than that recorded in April, May or September. Indeed it was less than that normally expected in April or September in spite of the shorter days of these two months. The only summer with less sunshine since 1906 was in 1912 which was also a wet summer.

Dr. Glasspoole showed diagrams of running 10-yr. means in order to bring out the long-term weather trends. These suggest that the recent wet, cool and dull summer continues a trend which has already been in evidence for some years past.

*Dr. J. Pepper*, Head of the World Climatology Branch, described the features of this summer's weather in some other parts of the world, illustrating his remarks by the monthly charts of rainfall, pressure and temperature and their anomalies, constructed from the broadcast CLIMAT data. In Europe the summer was, in general, cooler and rainier than normal though for the individual months it was warmer or drier than normal in some regions. For example, in June temperature was above normal in many parts of Europe, and in July rainfall was below normal over France. In most European countries July was the coolest month and August the wettest. In Russia, however, it was warmer than normal in all three months.

A persistent feature was a large area with pressure below normal, including most of western Europe and the eastern Atlantic Ocean. From May to June the monthly mean pressure fell by some 10–15 mb. in the region from Greenland to Scandinavia while it rose about 6 mb. in the Azores region. The resulting pressure gradient gave winds stronger than normal from the Atlantic across the British Isles, westerly in June and north-westerly in July. In August mean pressure was below normal over a very large area including the whole of Europe and most of the North Atlantic Ocean.

The data in "World weather records"<sup>1</sup> show that in 1882 there was a bad summer similar to that of 1954. The pressure anomaly charts for 1911–40 show no year in which the pressure changes from May to June were quite comparable with 1954 in magnitude and extent; the nearest approach was in 1927, when the summer was a poor one.

Dr. Pepper next referred to the weather of the summer in some other parts of the world. In west Africa temperature was some 2–4°F. below normal, and rainfall 50 per cent. above normal in many places, while the seasonal depression over north Africa was about 2 mb. deeper than normal. In south Africa the season, winter, was much wetter and cooler than normal and the mean pressure was also below normal. In the United States the summer was on the whole warmer and drier than normal. The Indian monsoon rainfall in June and July was generally heavier than normal and so was the rainfall in Japan and Malaya.

Some factors which possibly affect the pressure distribution in the North Atlantic have been discussed by C. E. P. Brooks<sup>2</sup>. One of these factors is the mean pressure gradient between Nova Scotia and Greenland; if this is greater than normal, as it was this summer, Brooks suggests that cold water is brought down into the North Atlantic in larger volume than usual, and in summer this tends to be associated with poor weather in western Europe. Another factor is the strength of the NE. and SE. trade winds over the Atlantic, the argument being that these winds affect the strength of the Gulf Stream; in particular, if some 15–21 months previously the trade winds were below normal, the flow of the Gulf Stream would be weakened, with a lowering of sea temperature in the North Atlantic.

*Mr. A. Gilchrist*, of the Forecasting Research Division, considered the summer from the large-scale synoptic aspect. His contribution was illustrated mainly

with 5-day mean 1000–500-mb. thickness charts for the northern hemisphere on which the mean depression tracks were also displayed. These showed that the synoptic situations in the Atlantic during the summer were predominantly of two types:—

(i) A ridge in the 1000–500-mb. thickness pattern over the Atlantic and a trough over or near the British Isles, with depressions approaching the British Isles from the north-west. This type was particularly persistent for a period near the end of June and the beginning of July.

(ii) A very large trough in the 1000–500-mb. thickness pattern over the Atlantic with Great Britain on its forward edge and with depressions approaching the British Isles from the south-west. This type occurred about the beginning of June but more especially at the end of July and during the first half of August when it was very persistent. It was responsible for the large rainfall totals recorded in southern England during August.

Mr. Gilchrist suggested that (ii) is a much more unusual summer type than (i).

The 5-day mean thickness anomalies for the hemisphere showed that a pattern with three major long waves was established before the beginning of July and persisted throughout July and much of August. The associated positive thickness anomalies were situated over northern Canada, north European Russia, and north-east Siberia. With this basic pattern established, the Atlantic synoptic situation might then be expected to be predominantly of type (i) or type (ii), in either case with an upper trough over much of the Atlantic and western Europe.

*Mr. D. Dewar* dealt with upper air climatology for the period under review. Upper air temperatures over Crawley and Lerwick during June, July and August for each of the years 1945–54 were shown plotted as departures from the average for this period, together with a seasonal diagram showing the cumulative departure from average of the three months. Over Lerwick tropospheric temperatures were not unusually low, and were, in fact, above average at 700 and 500 mb. in June. Over Crawley temperatures were below average especially in July, and the persistence of low mean temperatures throughout all three months made 1954 an outstanding year. The stratospheric temperature anomalies, shown by the 200-mb. diagrams, were generally the reverse of those in the troposphere. An examination of daily values of temperature at these two stations shows that the low mean temperature was due more to the persistence of temperature below average than to the occurrence of very low temperature. Temperatures below the minima for the period 1945–53 were recorded at Crawley on only two days, early in July, and at Lerwick not at all.

A study of percentage wind frequencies at 700 and 500 mb. for 1954 and 1948–53 shows that over Lerwick there was a large deficit of wind in the south-to-west quadrant and an excess of wind between NW. and SE. through NE., produced largely by the August distribution. Crawley data show that in June and August the 1954 distribution was not remarkably different from that for 1948–53, apart from an excess of NE. winds, but in July there was a striking preponderance of W.–NW. winds.

To study conditions over the northern hemisphere, isotherms and contours of isobaric heights for 700, 500, 300 and 200 mb. for the three summer months of

1954 were compared with the corresponding average charts for the period 1949-53. Long-period normal charts for these months are not yet available. The comparison showed that in June and August 1954 there were few outstanding departures from average; the most noticeable were the areas over northern Canada and to the north-east of Scandinavia with temperatures above average in the troposphere in August. An interesting feature of these two months was that though temperatures were below average over England and western Europe they showed little difference from average in the Iceland-Greenland region. July showed a number of striking divergencies from normal. The isotherms indicated a very marked warm area north-east of Scandinavia and a cold pool over the North Sea; over the Hudson Bay region and eastern Siberia temperatures were above average. The contours showed that a trough to the west of Greenland on the average charts had been displaced to a position where it extended south-eastwards from Iceland over the North Sea giving a flow of polar air over the British Isles. Contour heights were also below average over central U.S.S.R. and the west of the United States, and above average over eastern Siberia, the Hudson Bay region, and to the north-east of Scandinavia, giving a well marked wave-like pattern with three maxima and three minima as already noted by Mr. Gilchrist.

*Mr. R. F. M. Hay* referred to the temperature anomalies over the North Atlantic during the winter of 1953-54 and the spring of 1954, which he illustrated with diagrams. At the ocean weather stations in the western North Atlantic there were fairly large positive anomalies of air temperature from December to March or April. At station I (south of Iceland) there were negative anomalies from May to September, exceeding 2°F. in June and July. At station J (400 miles west of Ireland) negative anomalies persisted from February to September, although they were less pronounced than at station I. The sea-temperature anomalies were positive at stations I and J until June but became negative in July and thus tended to follow rather than precede the air-temperature anomalies. In the Denmark Strait and Davis Strait the air-temperature anomalies were mostly positive throughout the period.

These results are corroborated by seasonal air-temperature anomalies obtained from observations from "selected" ships, and related to the normals for the period used in preparing atlases in the Marine Branch (1887-99, 1921-38). For the winter of 1953-54 anomalies of air temperature were mostly positive, and of sea temperature markedly so, particularly to the west and south-west of the British Isles, even after allowing for a secular warming of 1°F. or more which has occurred over the north-east Atlantic during the past half century. In the spring of 1954 similar positive anomalies for air and sea temperatures still showed to the west of the British Isles and were most marked in the area of the Gulf Stream south of Nova Scotia and Newfoundland; but the central and northern North Atlantic anomalies were mostly negative. As very few ship observations become available in the Marine Branch within six months of the period to which they refer, it is not yet possible to provide comparable data for the summer of 1954; however the air-temperature anomalies for June in the eastern half of the North Atlantic showed even larger negative values than for the spring, suggesting a continuation of advection of air from the north-west. The observations which indicated positive anomalies just south of Newfoundland and large negative anomalies in the adjacent area to the east seemed doubtful at first, but confirmation of their accuracy is

found in the weekly ice charts issued by the United States Hydrographic Office, which show that at the end of May bergs had drifted as far south as latitude  $40^{\circ}\text{N}$ . in longitude  $48^{\circ}\text{W}$ . This position coincides with that of the negative sea-temperature anomalies, leaving little doubt that the survival of the bergs in a position so much further south than usual was due to their transport by a current colder than normal.

The distribution of air-temperature and sea-temperature anomalies over the northern North Atlantic at the beginning of the summer of 1954 was thus broadly in agreement with the anomalies which would be expected in association with the 1000–500-mb. thickness pattern, as described by Mr. Gilchrist. The air-temperature anomalies followed this pattern and sea-temperature anomalies conformed with a delay of a month or two. There was no suggestion that the sea-temperature pattern resulted to any marked extent from advection of cold or warm water apart from the behaviour of the Labrador current already described.

Mr. Hay later added that it is unlikely that the large number of bergs had any relation to the character of the summer of 1954 in the British Isles. Annual statistics show that in previous years there has been no relation evident between the number of icebergs off Newfoundland and the wetness or coolness of the summer in this country. This is hardly surprising since all the bergs in the Labrador current originated from glaciers in north-west Greenland and take some one to two years to reach the Newfoundland banks. The bergs in the east Greenland current do not enter the Labrador current at all as they melt in the Davis Strait. A more likely cause of the large number of icebergs off south-east Newfoundland in May and June lies in the positive air-temperature anomalies which were found in the Davis Strait in winter and spring. This would help to speed up the breaking of the coastal ice and release at an earlier date than usual bergs which had been frozen in among the coastal ice at the start of the previous winter.

**General discussion.**—*Mr. E. N. Lawrence.*—The analysis of the recent British summer is not complete without considering conditions during the preceding winter and spring, including a survey of snow and soil moisture. The May 1954 chart shows a pressure anomaly of up to  $+8$  mb. for the Greenland–Iceland–Scandinavia region, while in the south of Europe there is a small negative pressure anomaly, suggesting an abnormal easterly wind component across Europe during May. Easterly winds are associated with low humidity and abundant sunshine and assist in drying out the soil. Aided by the mild winter, and its deficit of snow, this drying out induced a soil-moisture deficit on the continental scale by the end of May. The effects on the characteristics of the soil such as its thermal capacity, conductivity and porosity, would lead to high surface temperatures and tend to produce a more intense or prolonged summer monsoon effect. The latter was reinforced by the accumulation of cold air to the north-west of Europe during May. This theory of a strong monsoon effect is supported by the anomalies of the following months. June showed a pressure anomaly of  $-3$  mb. or more in high latitudes, a temperature anomaly of  $+2^{\circ}\text{F}$ . in central Europe and  $-2^{\circ}\text{F}$ . on the western seaboard. This situation persisted well into the summer. It would not be surprising if abnormally high pressure to the north-west of Europe were one of the prognostics of a bad summer in Great Britain, for this pressure anomaly probably reflects the intensity of the Eurasian monsoon. The normal change

in mean pressure between April and May<sup>3</sup> shows an isallobaric low of  $-5$  mb. over China and a high of  $3-5$  mb. over west and north-west Europe and the North Atlantic. Thus the anomaly in the May 1954 pressure reinforces this normal behaviour. The symptoms of a strong monsoon effect may well exist simultaneously throughout the Eurasian land mass, and the European pressure anomaly for May is probably only one of several prognostic aids available from a study of the earlier Asiatic monsoon.

*Mr. H. C. Shellard.*—This summer might not have attracted quite so much attention if May and September 1954 had not also given us such poor weather. It is important not to treat the weather of the three summer months as an isolated event. The effect of the inclusion of May and September on a comparison of the 1954 summer with earlier summers should be considered. The main differences are that over England and Wales as a whole, in spite of a May which was wet and dull and a September which was wet and cool, 1954 came out comparatively warmer and drier than when the three monthly period was considered; that 1912, mainly because of its exceptionally cold September, was, over England and Wales as a whole, not only duller and wetter but also cooler than 1954; and that for Scotland the inclusion of May and September, both of which had been wetter this year than any of the months June–August, brought the 1954 summer up from sixteenth to sixth in order of wetness this century. For London similar comparisons can be taken back into the nineteenth century, and it is found that for June–August both 1879 and 1888 were wetter, cooler and duller than 1954, but for May–September 1879 only was worse than 1954 in all three elements. This century London has had no summers worse in all three elements than that of 1954, either on the three-monthly or the five-monthly basis, though several have been worse in two elements.

*Mr. A. H. Gordon.*—CLIMAT charts provide a valuable tool in any attempt to explain why the weather behaves in a particular way for a given month or season. The physical climatological process is going on all the time the world over. In some areas the process is speeded up—those are the areas with anomalies of like sign to the average climatological change in the mean values of chosen parameters from one month to the next; in other areas the process is slowed down. Such areas can be identified on CLIMAT charts. It is conceivable that an acceleration or retardation in the speed of the climatological process in one place may be related to similar phenomena elsewhere and consequently with subsequent anomalies in the actual mean values. For this reason it would be useful to construct in addition, monthly CLIMAT charts showing the anomaly in the speed of the process of annual change.

*Mr. J. S. Sawyer.*—It is interesting to note that the distribution of rainfall and temperature anomalies over North America was essentially the same in the three months June, July and August, whereas the surface-pressure-anomaly pattern was almost reversed between June and August. Probably the most persistent synoptic type during the summer and particularly in July was that in which a ridge of high pressure extended northward in the Atlantic from the Azores with a north-west flow over the British Isles. This type is common in summer, particularly in July, and 1954 is remarkable, not for its occurrence but for the lack of intermission with warmer and sunnier weather situations.

*Cmdr C. E. N. Frankcom.*—One of Mr. Hay's maps shows the position of icebergs near the Grand Banks unusually far south. I suggest that it is not the



presence of the bergs themselves or the effect of their melting which would cause any appreciable effect on the sea temperature. The significance of this position of the bergs does not mean that they are necessarily any bigger than normal, but that they have disintegrated more slowly, and that there is either an increase in strength of the Labrador current or a decrease in its temperature compared with normal years. It seems that this might have an eventual effect on the temperature of the Gulf Stream. It would perhaps be worth while examining the records of the United States Coast Guard whose vessels make routine oceanographical observations in the Labrador current to see if they provide any evidence to support this.

*Mr. H. H. Lamb.*—I agree with Mr. Sawyer that the circulation pattern represented by a great warm ridge over eastern North America and much of the Atlantic giving a north-westerly weather type over the British Isles is a common one in summer, but in 1954 it was uncommonly predominant or persistent. The other chief type occurring this summer was associated with a thrusting far south of the mean thermal gradient and depression tracks over the eastern North Atlantic, as mentioned by Mr. Gilchrist. Elsewhere in the hemisphere the many anticyclones (albeit with central pressures only 1010–1020 mb.) in western Siberia and the Urals region through the high summer period in 1954 seemed a remarkably unusual feature, perhaps related to the unusual shape of the polar-basin anticyclone with pronounced lobes towards the Urals. This in turn might be related to the calm weather of February 1954 in the Barents Sea, favouring the production of more sea ice than in most years, though data about the ice in this region are still lacking.

*Dr. R. C. Sutcliffe.*—The opening speakers have provided a very full and useful description of the actual happenings of last summer, but there remains the problem of relating the weather anomalies to physical causes and mechanisms. In this respect we have hardly reached the stage of knowing what problems to formulate, what questions to ask. The world charts of weather anomalies shown by Dr. Pepper are characterized by considerable small-scale patchiness, but underlying this there is some suggestion of a coherent large-scale pattern. The anomalies of British weather appear to be connected with processes on at least the hemispherical scale. The summer of 1954 was characterized in the upper air by a quasi-persistent three-ridge wave pattern of large amplitude, with the crests over America, European Russia and eastern Siberia. In the Atlantic–European sector, this pattern was associated with the mean belt of upper flow lying well to the southward and with negative temperature anomalies extending into quite low latitudes. There are grounds for hoping that studies of the large-scale circulation patterns will throw light on the underlying causes of seasonal anomalies of weather.

*Prof. Gordon Manley.*—Among comparable summers in the past I was rather surprised not to hear more of 1922 which was persistently cool, dull and breezy—in German parlance one of “vigorous European monsoon”. To many southerners the noticeable feature of 1954 was the unusually cool breeziness, normally appropriate to our northern uplands. So far as my reduction of older records was valid I have taken out the rough data, which showed that 24 summers in the last 256 could be called consistently cool, the criterion being all three months 2°F. or more below overall average; that is about one in ten. 1954 ranked about fourteenth, and was thus not exceptionally unusual; what was unusual was the lapse of 32 years since the last cool summer.

Both 1922 and 1902 were cooler, but with regard to the majority of such cool summers if the overall mean is compared with the 30 "surrounding" years the deficit rarely exceeds that of 1954, namely 2.6°F. Only three significantly greater deficits occurred (1860, 1816 and 1725) of which the last two were associated with noteworthy ash eruptions. It would therefore appear that 1954 represents about as large a strain of the earth's circulation as we should fairly expect, in the absence of some additional factor such as violent eruptions.

*Mr. R. G. Veryard.*—I was interested to hear Prof. Manley refer to the possible association of climatic change with volcanic eruptions, as I have recently been studying the literature on the subject. The result has not been very enlightening. As is well known, Humphries<sup>4</sup> put forward the view that the net effect produced by volcanic dust in the upper atmosphere, as in the case of the explosions of Katmai, would be, if long continued, a lowering of the surface temperature by several degrees Centigrade. There certainly appears to be evidence that after volcanic eruptions there has been a reduction, at least in some areas, in the amount of direct solar radiation received at the earth's surface. On the other hand, Gentilli<sup>5</sup>, after examining world temperatures subsequent to the eruptions of Krakatoa (1883), Katmai (1912) and in the south Andes (1921), concluded that there is no climatological evidence that volcanic eruptions may cause a general lowering of temperature in the year immediately following, even in regions very near to the erupting volcano. Although dust in the atmosphere may not be so important a factor in determining the magnitude and times of occurrence of meteorological changes of insolation intensity at the earth's surface, as suggested by Humphries, nevertheless it can hardly be disputed that variations in the turbidity of the atmosphere may well be responsible for minor climatic changes. Such variations cannot be due solely to volcanic dust. Apart from the dust which we put into the atmosphere ourselves, there is the fine meteoric dust brought in at high levels which seems to form a permanent, but variable, part of our atmosphere. Maybe the resulting variations in the overall energy budget are very small but is it not possible that the local effects, i.e. in regard to the intensity and distribution of heat sources and the consequent modifications of the circulation pattern, are out of proportion to the relative amounts of energy involved?

*Mr. J. M. Craddock.*—I would like to emphasize that the abnormal weather of the British Isles was not an isolated occurrence but was accompanied by abnormalities over a large part of the northern hemisphere, certainly extending from north-west Canada across the Atlantic and Europe to north-west Siberia. This fact points to a large-scale disturbance of the circulation rather than anything purely local. It is also evident that the position of the long waves in the upper air flow has an important, almost a controlling, influence on the weather in particular regions so that any method of long-range forecasting must predict the position of the nearest long waves if it is to have any chance of success. Mr. Hay's data suggest that abnormalities of sea-surface temperatures are the results rather than the causes of persistent abnormalities in the temperature of the air above.

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## NIGHT COOLING CURVES FOR WAHN, GERMANY

By W. J. BRUCE

Parry<sup>1</sup> has produced a curve of the variation in time of the evening temperature discontinuity for Shawbury over the years 1949-53. A striking feature of this curve was the levelling out of the curve from mid March to the end of April. Similar curves have been prepared for Wahn for the years 1952 and 1953 as given in Fig. 1. Nights with average cloudiness of 2 oktas or less were used.

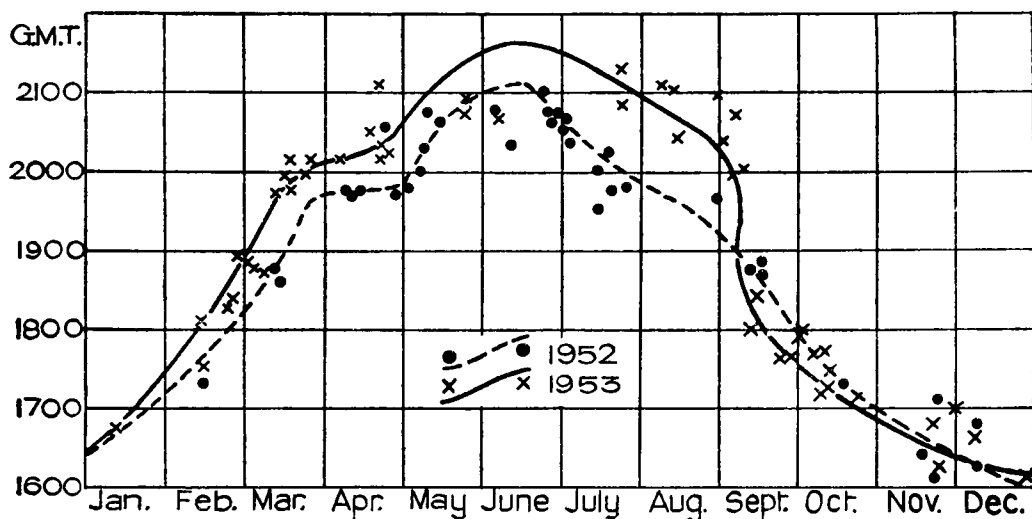


FIG. 1—VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY  
Wahn, 1952 and 1953

The marked irregularity from mid March to the end of April agrees well with that found by Parry. A further irregularity is apparent in late summer where the curve shows a pronounced fall. A closer examination of Saunders's curve for Exeter<sup>2</sup> shows the possible existence of two similar irregularities. In view of the agreement between the Wahn and Shawbury curves a suggested redrawing of that for Exeter is given in Fig. 2.

Saunders<sup>3</sup> explains any irregularity in the curves as an effect of moisture in the top soil, and relates it to rainfall or the change from generally dry to permanently wet top soil.

Curves of this nature show the time throughout the year when the surface air reaches saturation and dew forms. The levelling out of the curve in spring time shows that saturation is reached earlier than would be expected on the basis of a steady increase in time. The fall of the curve in early autumn, which is well marked in Saunders's curve for Northolt<sup>3</sup>, shows that similarly saturation has been reached earlier than would be expected on the basis of a steady decrease in time. This latter effect is attributed by Saunders to the seasonal transition to permanently wet top soil.

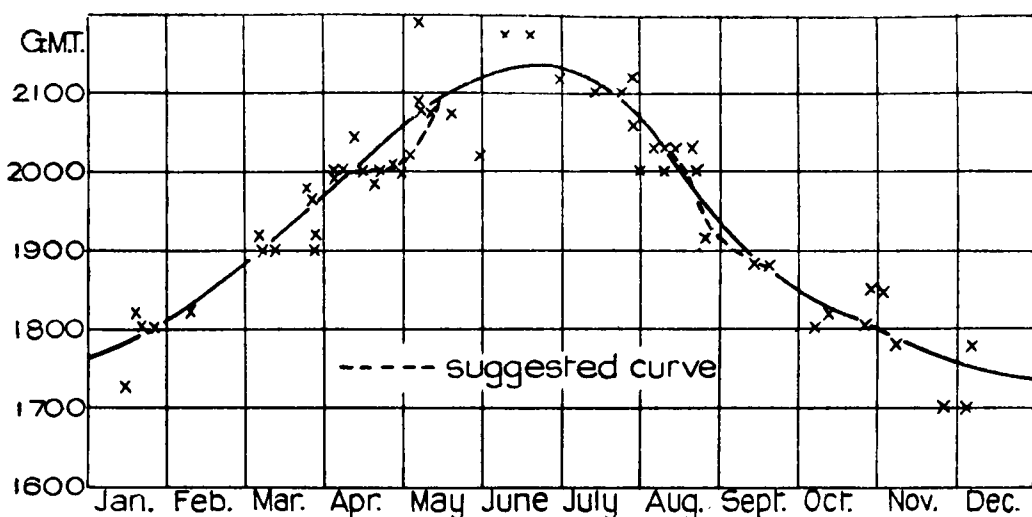


FIG. 2—VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY  
Exeter, 1950

If the spring irregularity is real as the above results would indicate, it cannot be explained by the drying out of the top soil. It is suggested that this feature of the curve in spring, which implies surface saturation at a time earlier than would otherwise be expected, can only be explained by invoking moisture associated with the initial growth of surface vegetation.

Consideration of all the curves indicates that the spring levelling is more sharply marked than the autumn steepening. It is suggested that this shows the period of growth of vegetation to be more regular than the onset of permanently moist surface soil in autumn.

The conclusion drawn from the foregoing is that the curve of the variation in time of the evening temperature discontinuity cannot be symmetrical about the summer axis.

The site of the thermometer screen at Wahn is on a gently sloping heathland within 5 miles of the Rhine, and the soil is predominantly sandy apart from shallow clay layers. It would be interesting to make a comparison of the variation in time of the evening temperature discontinuity recorded by thermometer screens set in different exposures, one near a wooded area and the other as far away as possible from vegetation.

[The discontinuous change in spring has recently been independently confirmed in similar work in regard to St. Eval (see p. 76). In view of this, and the evidence from Wahn and Shawbury, it certainly seems a real feature. Mr. Bruce's redrawing of the Exeter curve is probably justified, though perhaps nothing more than a smooth curve could have been drawn into it without the later evidence. In any case it seems much more pronounced on the lighter soils (Shawbury, Wahn and St. Eval) than on the heavy clays (Northolt and Exeter).

It has been suggested in recent correspondence elsewhere<sup>4</sup> that release of water from vegetation in the evening may be a cause of, or at least contribute to, the evening temperature discontinuity. In that case we should probably seek the explanation of the spring discontinuity in the behaviour of the grass at the time of rapid growth, as Mr. Bruce suggests.

The difference between the mean curves of Mr. Bruce's Fig. 1 are of interest. In 1953 the spring discontinuity set in early. There is little difference in May and June and Mr. Bruce's 1953 curve might have been flattened over these months. In July and August there are quite striking differences, amounting to about an hour in the mean. Autumn appears to have set in very suddenly in September 1953, and thereafter the curves are similar.—W. E. SAUNDERS.]

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### EXCEPTIONALLY SEVERE CLEAR-AIR TURBULENCE AND OTHER PHENOMENA ON APRIL 14, 1954

By D. C. E. JONES, B.Sc.

**Introduction.**—Very severe turbulence experienced in clear air at heights between 28,000 and 41,000 ft. has previously been described and the meteorological situations on these occasions discussed<sup>1,2</sup>.

Another unusual and exceptionally severe patch of turbulence was encountered without warning by a Canberra jet aircraft flying at 40,000 ft. There were also reports of very strong "standing waves" in the same air stream but at different times and several different locations.

**Description of the turbulence.**—At about 2130 G.M.T. on April 14, 1954 the aircraft was flying at 40,000 ft. on a heading of 84° true near Edinburgh. After flying in smooth air conditions at an indicated airspeed of 210 kt. (Mach number 0.7) the aircraft suddenly experienced severe turbulence. The pilot began to turn to the right to avoid the region of turbulence, but during the turn a severe gust lifted the port wing and rolled the aircraft on to its back. Full aileron control proved ineffective in preventing the roll, and while upside down the aircraft gained 500 ft. in altitude. Control was eventually regained and the aileron became effective again. The pilot then descended quickly and found that turbulence ceased below 38,000 ft. The aircraft returned to its base, landed safely, and no damage was found to have been suffered.

The only cloud in the vicinity of the incident was about 3 oktas of cumulus below 20,000 ft.

**Meteorological situation.**—Fig. 1 shows the surface chart for 0000 G.M.T. and Fig. 2 the 300-mb. chart for 0300 G.M.T. on April 15, 1954. The depression over southern Scandinavia was moving south-eastwards. An associated cold front was moving slowly southwards over northern England and was being followed by a secondary cold front which was over northern Scotland.

At high levels the whole of the British Isles and the North Sea were under the influence of a strong north-westerly air current. There are indications of a well marked jet stream with its axis extending from Iceland to the Shetlands to north-west Germany. Fig. 3 shows a cross-section from Valentia to Lerwick at 0300 G.M.T. April 15 which is the time nearest to that of the incident under discussion when temperature and wind soundings were made simultaneously.

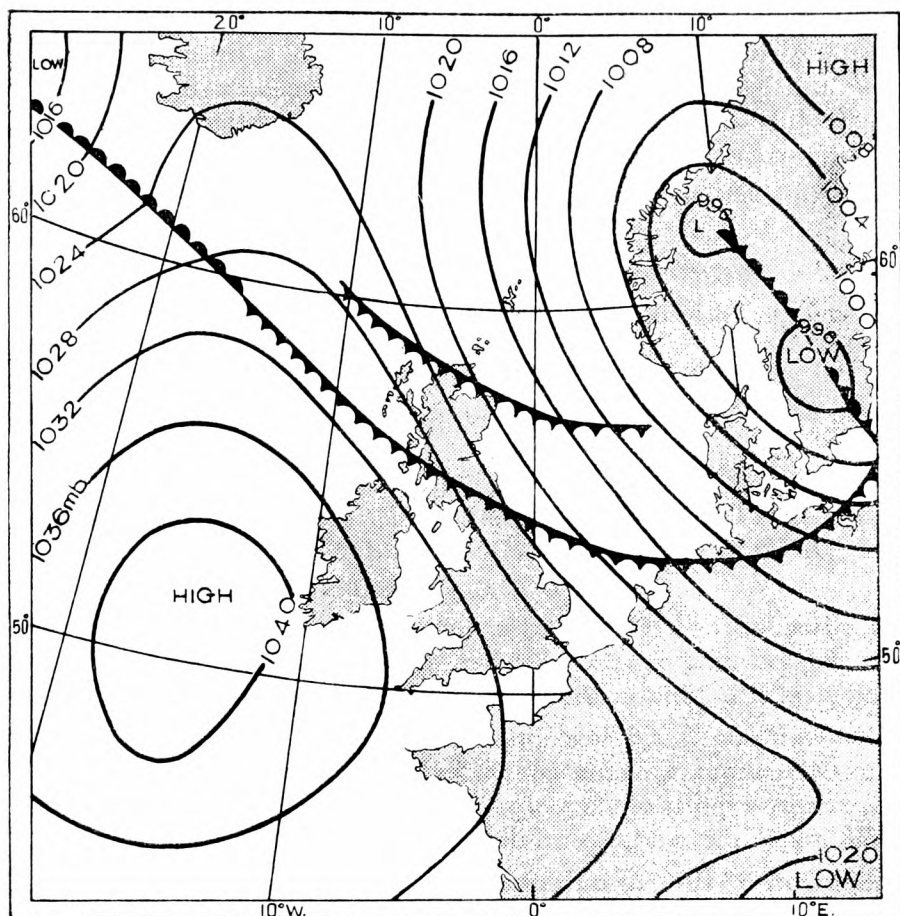


FIG. 1—SURFACE SYNOPTIC CHART, 0000 G.M.T., APRIL 15, 1954

Only upper winds were observed at 2000 on the 14th and those for stations in Scotland, Northern Ireland and northern England on the evening of the 14th are given in Table I.

TABLE I—WINDS AT 2000 G.M.T. APRIL 14, 1954

	Lerwick		Leuchars		Stornoway		Liverpool		Aldergrove	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
45,000	318	125*	314	43	293	22	351	32	312	47
40,000	318	138	309	68	312	40	309	50	287	42
35,000	316	135	303	83	296	88	309	53	289	46
30,000	316	118	300	80	295	89	313	60	298	49
27,000	316	118	302	77	302	82	316	65	308	55
24,000	315	132	310	67	313	75	322	59	306	58

\* This is the wind at 42,000 ft.; the wind at 45,000 ft., given in the *Daily Aerological Record* as 318° 144 kt., was computed from the last minute of the observation at the extreme range of the radar and is probably erroneous.

It will be seen that when the incident occurred the aircraft was flying in the upper troposphere, in a region of pronounced vertical and horizontal wind shear, on the warm side of the jet stream and above the level of the axis of the jet.

**Standing waves.**—After the flight the pilot stated that the only unusual feature he noticed before the onset of the very severe turbulence was found over the Midlands previously that evening. At a height of 40,000 ft. he noticed

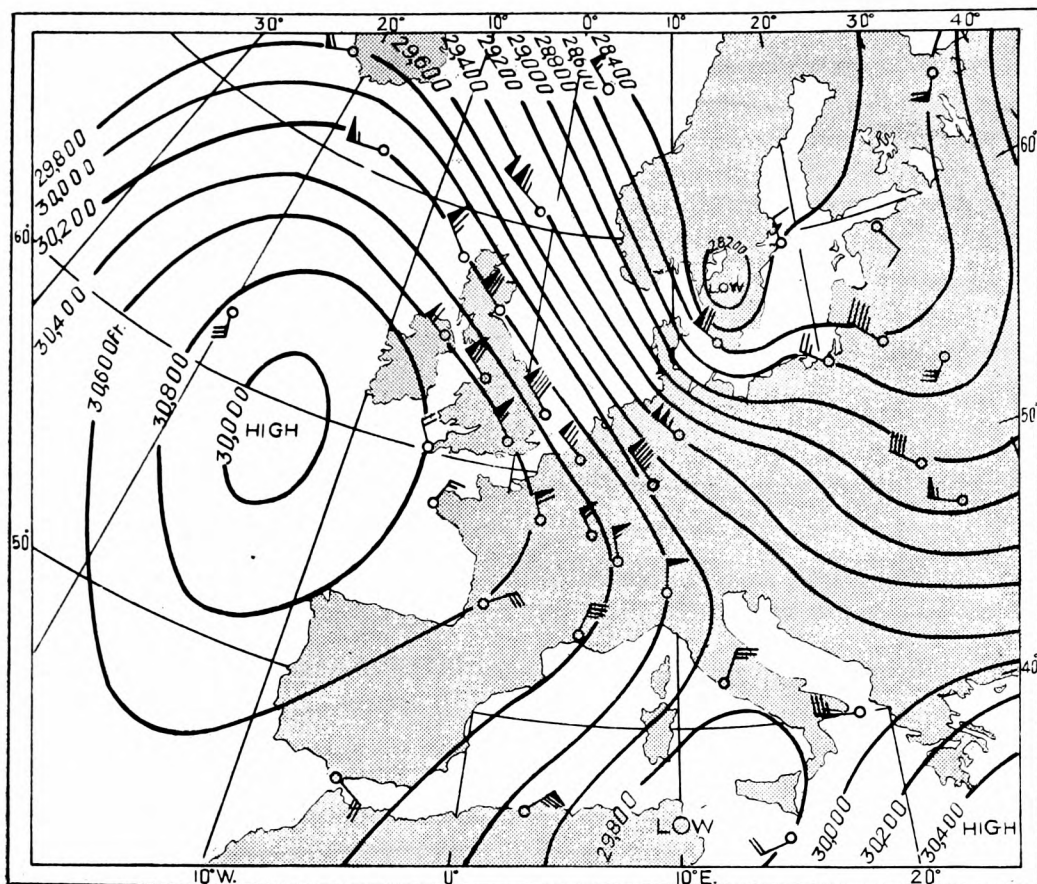


FIG. 2—300-MB. CONTOUR CHART, 0300 G.M.T., APRIL 15, 1954

up-currents and down-currents, and variations in the indicated airspeed which he thought were caused by standing waves.

Another interesting report showing the existence of strong vertical currents was received from the pilot of a jet fighter aircraft. While trying to fly straight and level at 35,000 ft. over Norwich at an indicated airspeed of 200 kt. at about 1100 the same day he noticed that the vertical-speed indicator and the altimeter were registering a rate of climb of 3,000 ft./min. He then tried to descend, and in his report states:—

I was now at 37,000 ft. I noticed that I was still in cirrus cloud. My rate of climb still showed 3,000 ft./min. and the altimeter reading rose quickly to just under 40,000 ft. I was still in cirrus cloud. I then opened the throttles and dived out to the south to carry out further R/T checks at lower altitudes.

My aircraft was heavily laden and should, once I had levelled off, have been unable to climb at anything more than 1,000 ft./min. at the beginning, and when the nose was down should have lost height at least at 2,000 ft./min., probably more.

There was no vestige of turbulence during the climbing incident which took place 10 miles south of Norwich.

The existence of standing waves in the air stream at lower levels has subsequently been confirmed by the large number of reports received from other aircraft, the heights at which they were reported varying from 4,500 ft. to 18,000 ft. and the rates of lift and sink ranging up to 2,000 ft./min.

**Discussion.**—There were other reports of high-level turbulence over the British Isles on April 14. The existence also of standing waves at various levels

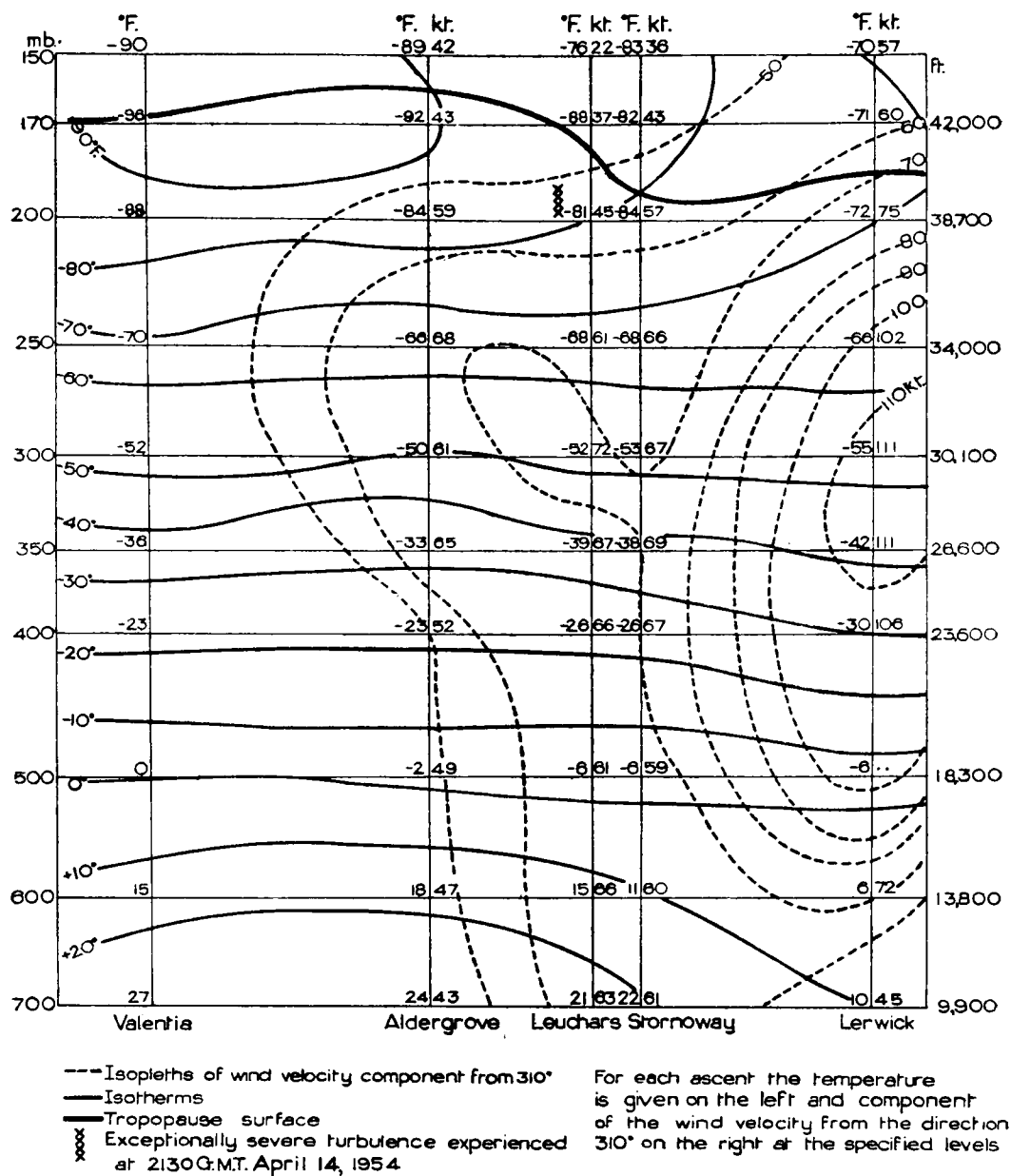


FIG. 3—CROSS-SECTION, VALENTIA-LERWICK, 0300 G.M.T., APRIL 15, 1954

at more or less the same time poses a problem as to whether the turbulence is in some way associated with standing waves which are generated when wind blows over a mountain range. Hislop tentatively suggested in his report on the British European Airways special investigational flights<sup>3</sup> that under certain conditions the waves might break—like the waves of the sea—and thus degenerate into turbulent motion. He quotes an occasion when a British European Airways Mosquito experienced smooth lift of about 1,500–2,000 ft./min. between 35,000 and 37,000 ft., which finally petered out into rather sluggish turbulence. It has also been suggested by Radok<sup>4</sup> that topography can be responsible at times for localizing and rendering turbulence severe within a favourable jet-stream region.



**Conclusions.**—The incident of the Canberra aircraft which encountered, in clear air, a gust of sufficient violence to turn it upside down while in normal flight focuses attention on the extreme severity of turbulence that may be encountered at high levels. So far as is known no such incident has previously been reported. It occurred on the warm side of the jet stream, about 250 miles from the axis and above the level of the axis. The depth of the turbulent layer was about 2,000 ft.

The simultaneous occurrence of high-level turbulence and standing waves raises a question as to whether there is any connexion between them, but no conclusive evidence one way or the other has been found so far. Further investigation of this aspect of turbulence is needed.

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### REMOTE-RECORDING ELECTRICAL ANEMOGRAPH

By G. E. W. HARTLEY, M.A.

This article describes a quick-response recorder used with a cup generator anemometer Mk IB to record wind speed, and a single-pen direction recorder developed in the General Instruments Branch of the Meteorological Office to record wind direction in conjunction with a wind vane using the magflip system of remote transmission.

**Wind speed.**—A recorder to work with the standard Meteorological Office cup generator anemometer Mk IB has been described in the *Proceedings of the Institution of Electrical Engineers*<sup>1</sup>. It was subsequently found that if the speed scale on the chart was that derived from wind-tunnel tests, isolated gusts were recorded as much as 15 per cent. low, because the response of the recorder was not quick enough to enable it to follow the generator, although steady flow was correctly recorded.

The recorder was therefore modified by changes in the transformer and rectifier, which necessitated their being housed in a separate case instead of inside the recorder, and by altering the coil winding of the recorder so that it took a considerably larger current from the generator, the extra power so obtained enabling stronger hair springs to be used in the recorder. With these modifications the recorder will now follow the generator, and gusts are correctly recorded, as well as steady speeds.

Comparisons between this recorder and a remote-recording pressure-tube anemograph were made at South Farnborough for some months, the generator anemometer being supported on a side bracket from the top of the tower on which the pressure-tube anemograph head is mounted. Charts from both were tabulated in the General Instruments Branch and the tabulations showed close agreement in both mean and maximum values.

Two more recorders of the same type were obtained; wind-tunnel tests showed that their scale values were in close agreement with those of the original recorder so that the same charts could be used for all three with confidence.

These two recorders have been connected to two generator anemometers mounted on the 40-ft. tower on the roof of the meteorological office at Harrow and have been in operation for some months; their charts show close agreement, though there are sometimes differences due to interference between the two anemometers and other instruments on the tower. The recorder is shown in Fig. 1 (facing) and its dimensions in Fig. 2.

Accuracy and consistency of performance are rather difficult to assess; but the original recorder was calibrated in the wind tunnel before and after the South Farnborough tests, and no change of calibration occurred; and during the wind-tunnel tests, the "wind" speed was brought to a given speed from several other speeds both higher and lower and the speed was correctly recorded with an error not exceeding  $\pm \frac{1}{2}$  kt.

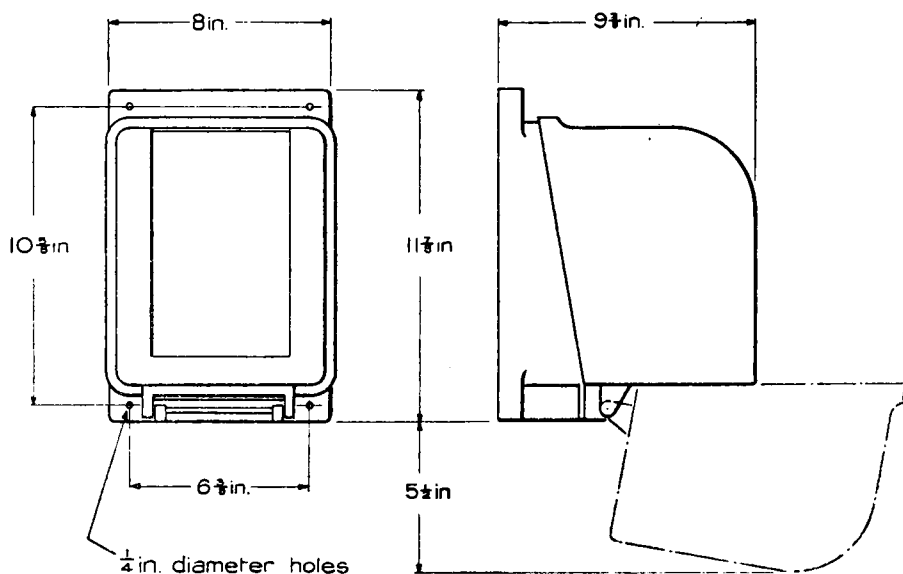


FIG. 2—DIMENSIONS OF THE QUICK-RESPONSE RECORDER

The inking system supplied by the makers of the recorder has proved very satisfactory; it consists of a fine tube, suitably shaped, one end of which dips in an ink-well situated at the axis of the pen movement, the other end carrying the writing nozzle and resting lightly on the chart. The spindle of the electrical movement carries a stirrup with V slots; the inking tube is pivoted on knife-edge supports which rest in these slots. The ink-well end of the tube moves only in the ink, not through it; the hole in the top of the ink-well through which the tube enters is only just larger than the tube so that very little dust can get in, and clogging of the tube does not occur. The weight of ink in the tube is constant, and the whole pen is balanced so that it will write with very little friction. Ink feed is by capillary, not siphon, action.

The chart is of 4 in. writing width, and has a speed of 1 in./hr. which can be altered to 3, 6 or 12 in./hr. by changing the driving gears. It is 65 ft. long, which gives a run of about 30 days using the 1 in./hr. time scale. A range of 0-90 kt. has been used, but it would be possible to provide a smaller range and larger scale for normal use, with an extra series resistance which can be switched in to increase the range and reduce the scale.

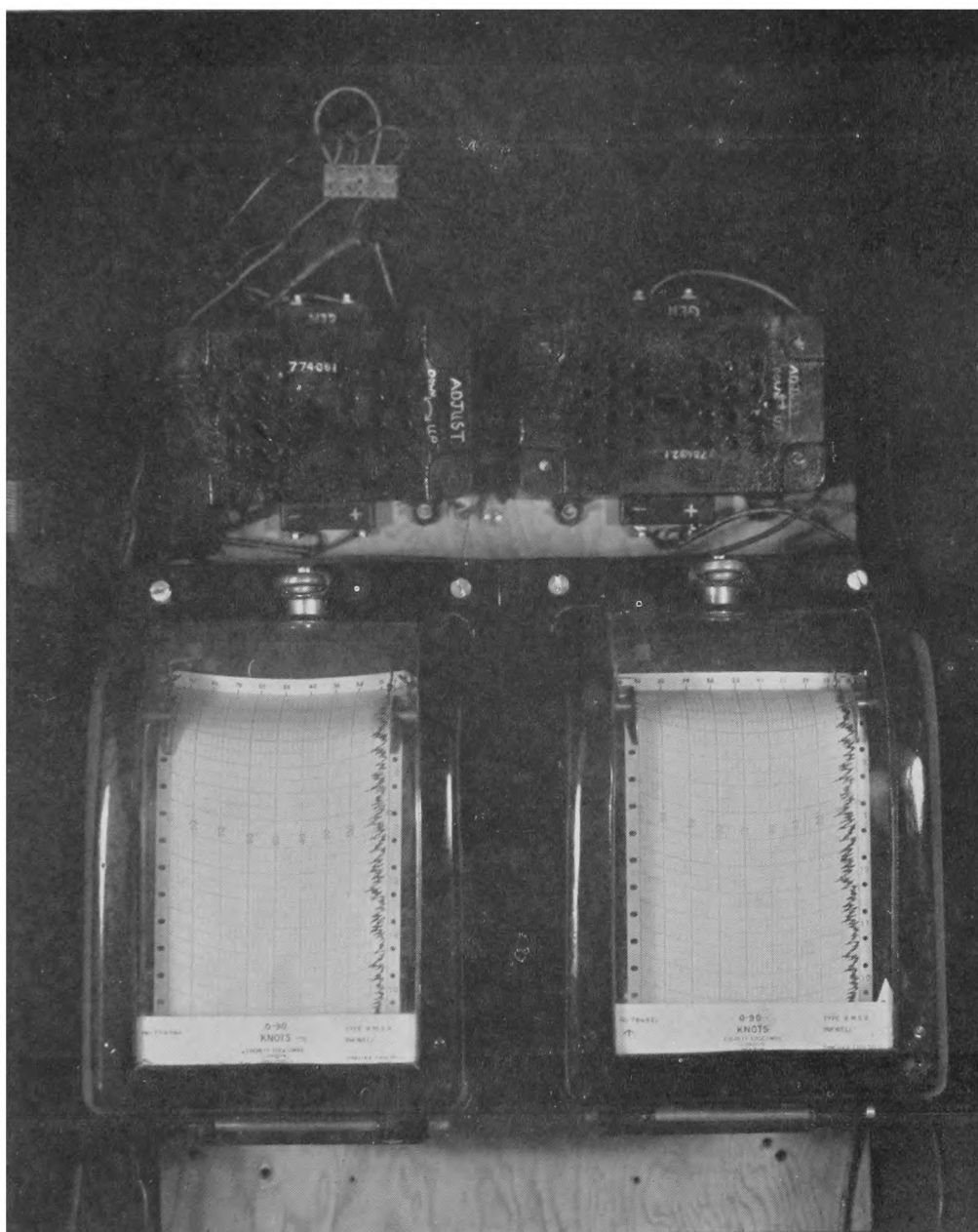


FIG. 1—QUICK-RESPONSE RECORDERS USED WITH CUP GENERATOR  
ANEMOMETERS MK 1B

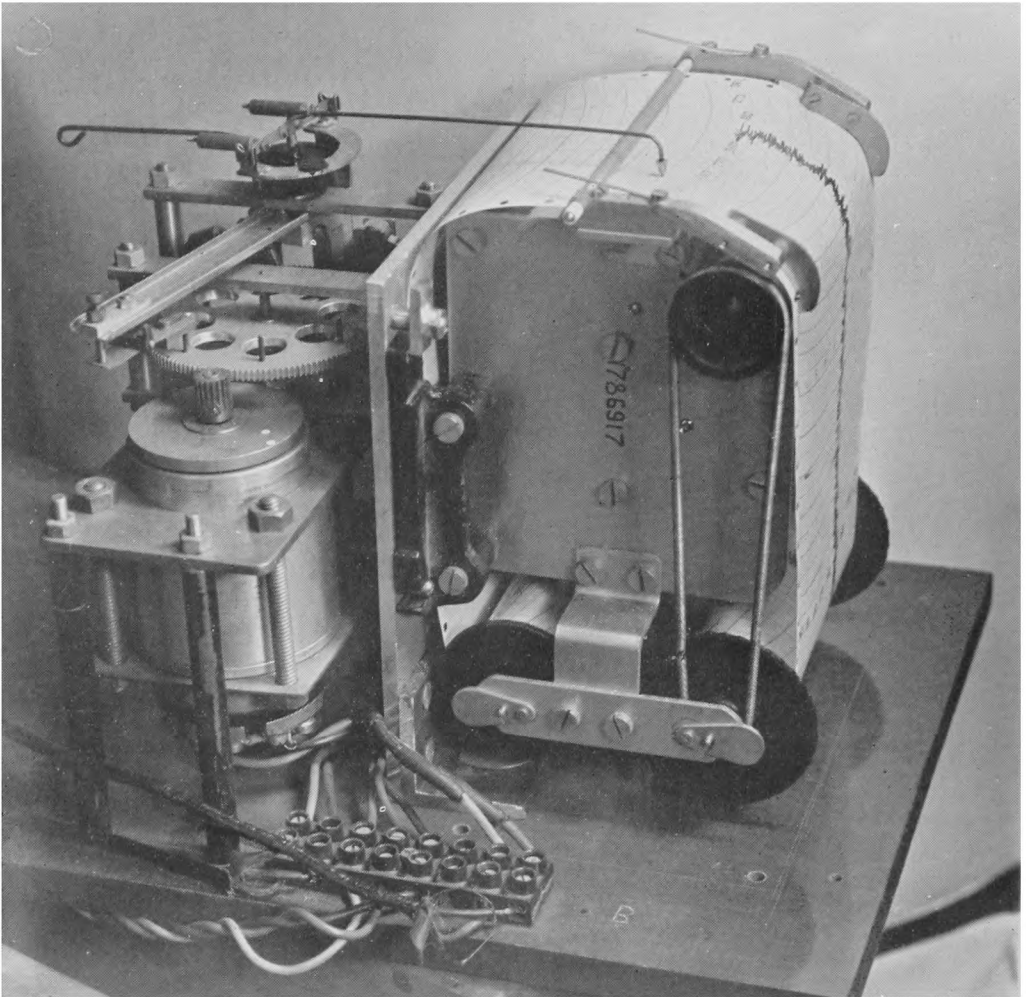


FIG. 5—WIND-DIRECTION REMOTE RECORDER

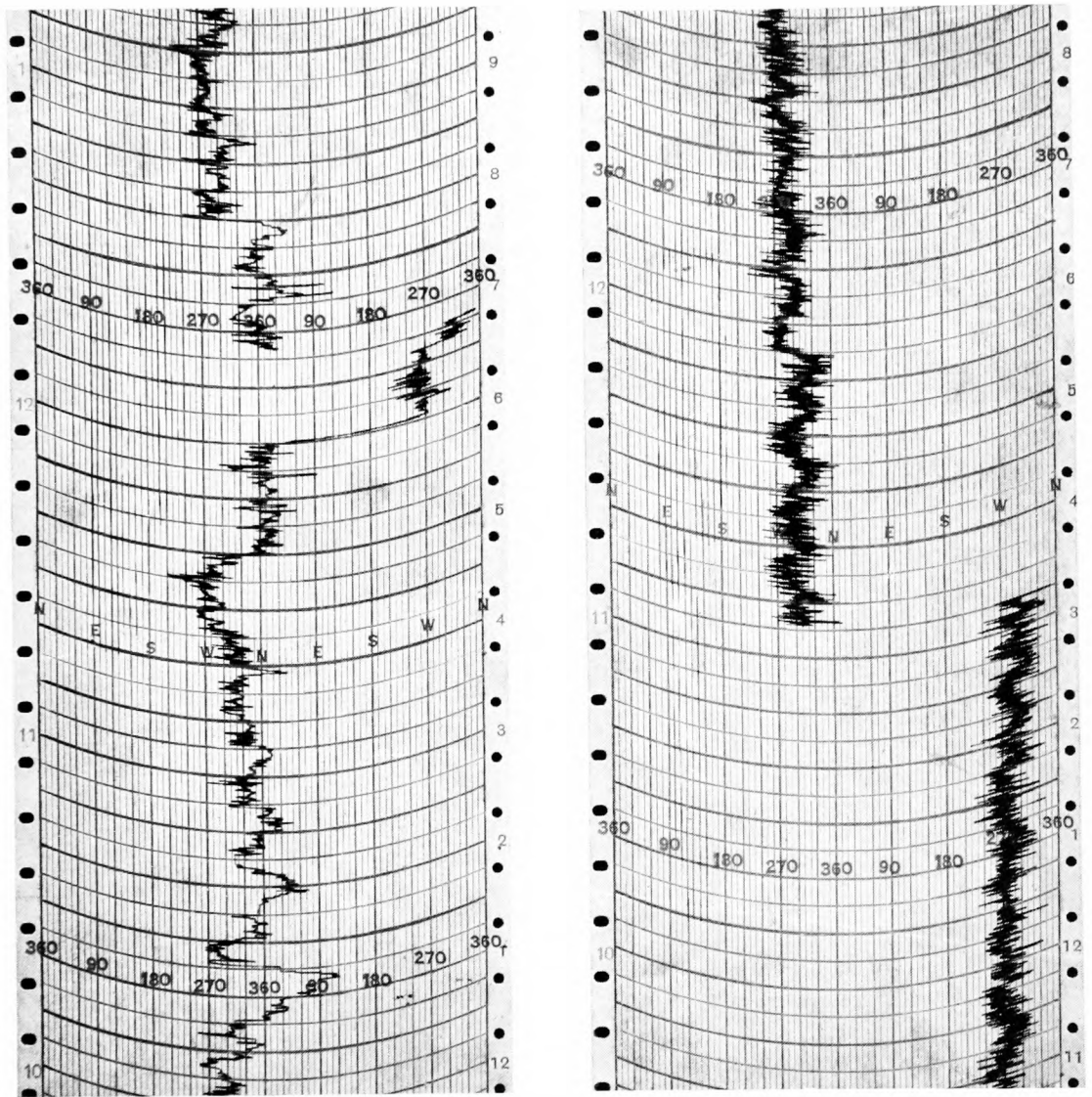


FIG. 6—SPECIMEN CHARTS FROM THE WIND-DIRECTION RECORDER

The speed of the charts was 3 in./hr. (left-hand scales); the left-hand chart was recorded with a wind speed of 2-6 kt., the right-hand chart with a wind speed of 8-20 kt. Re-centring took place at about 1217 on the left-hand chart and 1106 on the right-hand chart.

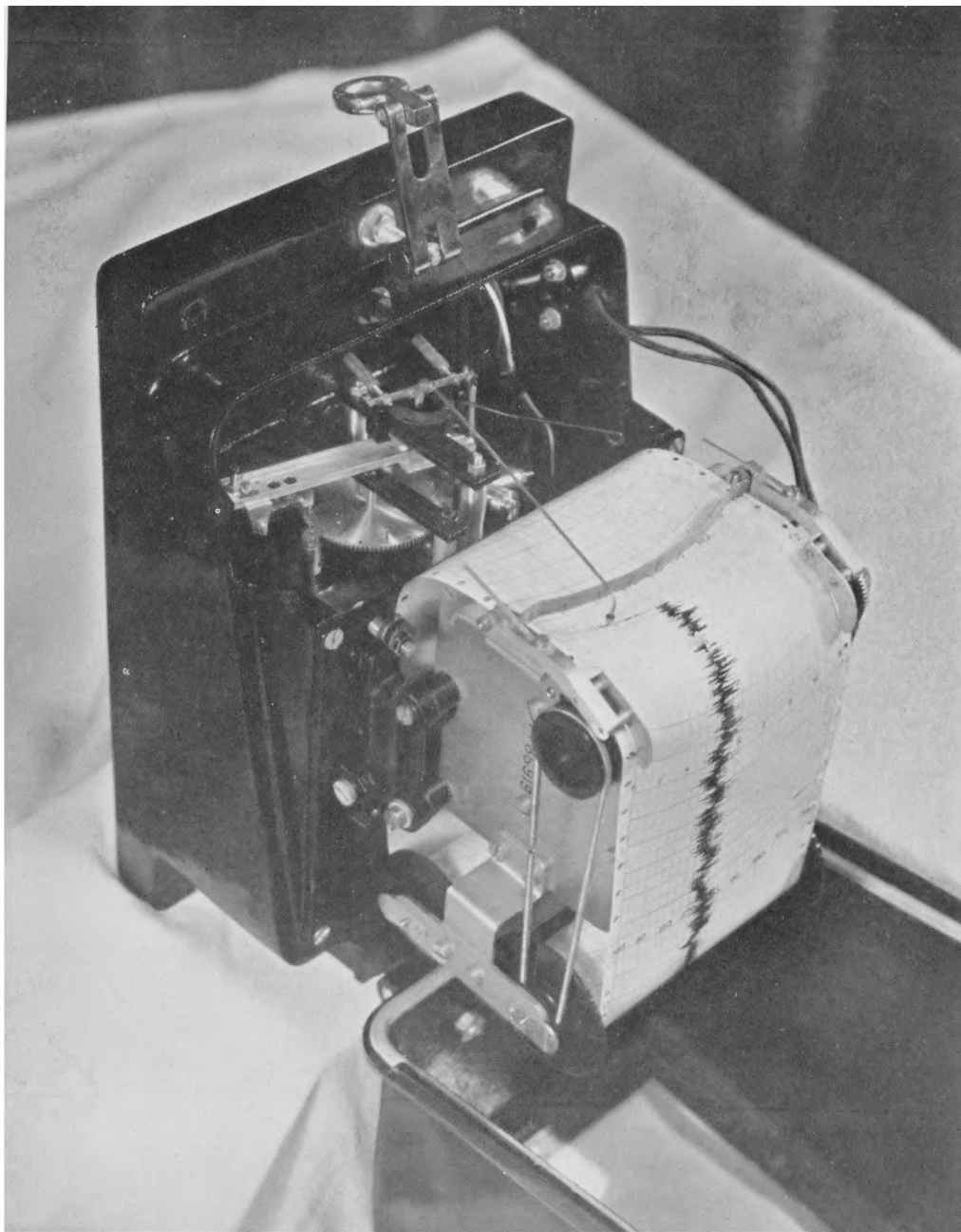


FIG. 7—SMALLER-SIZE WIND-DIRECTION RECORDER



As will be seen from the specimen chart (Fig. 3) the graduations are nearly linear above 10 kt. The anemometer cups start to revolve at 3.5 kt. and the record is of no value below 5 kt.

No trouble has been experienced with these recorders during trials; the only attention given is to top up the ink-well once a week and fit new charts when needed. The chart mechanisms used are synchronous motor driven but the makers can supply spring-driven mechanisms at a slightly higher cost.

The six recorders used for the Severn Bridge wind measurements over several years suffered only three occasions of chart motor failure, and two of change of calibration of the recorder; this was found to be due to faulty rectifiers, and when these were changed to another type as now used no further trouble occurred.

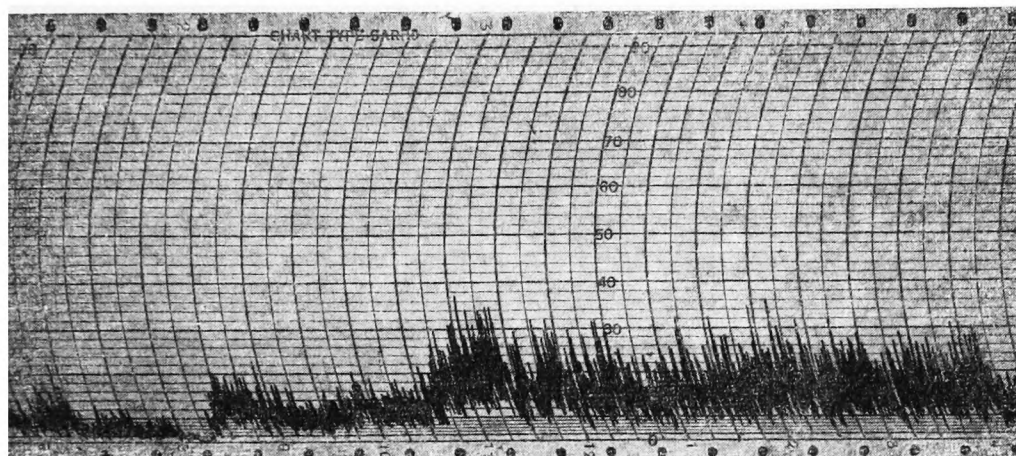


FIG. 3—SPECIMEN ANEMOGRAM FROM THE QUICK-RESPONSE RECORDER

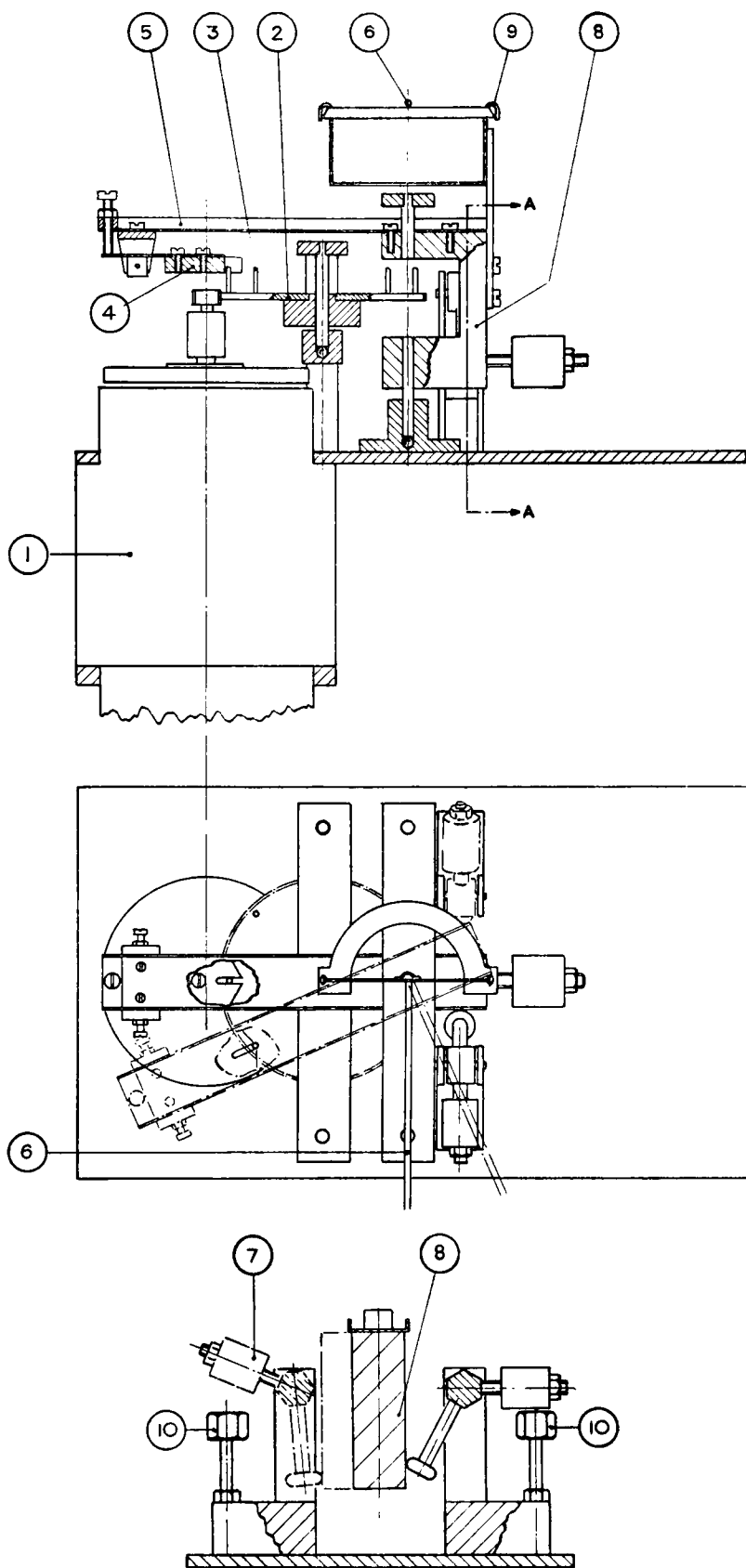
Chart speed 1 in./hr. (bottom scale)

**Wind direction.**—For remote transmission of wind direction from the vane to the recorder, 2 in. magflip motors, type E2, are used. These operate from 50V. a.c. obtained from mains by a transformer, and form a synchronous link.

At present there is no standard Meteorological Office wind vane embodying 2 in. magflips, but they are commercially obtainable incorporating a mounting for the generator anemometer above the wind vane and magflip, so that only one support is needed for both instruments.

The wind-direction recorder is of the single-pen type developed in the Meteorological Office. In its original form it was shown at the Physical Society's Exhibition in April 1951 and was briefly described<sup>2</sup> in the *Meteorological Magazine*, July 1951.

In its present form it is shown diagrammatically in Fig. 4. The receiving magflip (1) is geared down 1 : 8 to a gear wheel (2) which carries eight evenly spaced pins (3). One of these pins engages with a slot in a specially shaped block (4) pivoted to a moving arm (5) which also carries the recording pen (6) by means of the stirrup (9). The axes of the gear wheel and moving arm are not coincident, and are so placed that when the gear wheel moves 45° from a central position, the slotted block disengages from the pin and is returned by a centring device (7) to the adjacent pin near to the central position. In the



Section at AA

FIG. 4—LAY-OUT OF THE WIND-DIRECTION RECORDER



original design, the centring device was a torsion spring; this proved inconsistent in its performance, and was replaced by two pivoted and weighted levers (7) which are set so as to bring the part of the pen arm (8) on which they press to a central position by means of the adjusting screws (10). This system has proved very reliable. The movement of the arm from the central to the disengaged position corresponds to  $360^\circ$  of vane movement, and also to the movement of the pen from the centre of the chart to one or other edge.

The chart is marked with a range of  $720^\circ$  in direction; when the pen gets to either edge of the chart, the pin disengages from the slot, the centring device returns the pen through  $360^\circ$  (chart marking) to near the centre of the chart, and the slotted block engages with the pin nearest to the central position. The recorder is shown in Fig. 5.

There is a slight risk that when the arm is moving back to the centre the block may jump over, or stop short of, the central pin without engaging with it, thereby giving an incorrect record. In practice over several months trial re-centring has taken place many times and the block has only twice failed to engage. Specimen charts showing the appearance of the trace when re-centring occurs are shown in Fig. 6. In these charts the time scale is 3 in./hr. The centring device is adjustable but once set requires no further adjustment.

To reduce further the risk of wrong recording, users may be told that if at any time they see the pen near the edge of the chart they should move the block by hand to the central pin.

The chart mechanism and inking system are the same as those used in the wind-speed recorder.

There is a theoretical objection to the geometry of the system: as the pins on the gear wheel have a finite thickness, if recording takes place when the pin is on the point of emerging from the slot, the movements of the block and therefore of the pen do not exactly agree with those of the pin. In practice if this occurs, the block is always either released, or goes back fully on to the pin, and no wrong readings persist.

A later modification has been to reduce the size of the mechanism to allow it to go inside the same kind of case as the wind-speed recorder. This recorder, shown in Fig. 7, works perfectly satisfactorily.

Wind-speed recorders of the type described have been used for some years in the Falkland Islands and at Cardington and have given satisfactory service. The latest design has been undergoing trials at Harrow and has given no trouble.

Twelve complete instruments are now on order for operational trials; in these, the speed and direction recorders are to be combined in one case, with the speed and direction pens recording on the same (double-width) chart.

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### METEOROLOGICAL OFFICE DISCUSSION

#### **Electronics applied to meteorological instrumentation**

The discussion on Monday, January 17, 1955 held at the Royal Society of Arts, was opened by Mr. R. Almond of the Instruments Division of the Meteorological Office.

He stated that the greatest contribution of electronics to meteorological instrumentation had been in the investigation of the upper atmosphere, and that this field of work would be the only one considered. The main emphasis would be placed on the various electronic methods of measuring upper air temperature, pressure and humidity, upper winds and cloud height. Application of electronics to these and other meteorological instrument problems was increasing steadily, and as new techniques became established by research and the application of new materials, more and more of these problems would be solved.

Omitting the work on sferics, the free balloon meteorograph was the first upper air instrument to become electronic, taking the now familiar name radio-sonde. This introduced a new era for the forecaster in which upper air information became available on an all-weather basis with reception-time delay comparable with surface observations. From the first radio-sonde of Idrac and Bureau in 1927 have sprung the many systems now in use. In general the electronic requirements of the average radio-sonde have remained fairly simple, but improvements in electro-mechanical techniques, meteorological measuring elements, general components, and battery power supplies, have produced much more stable and sensitive instruments. Miniturization of components and reduction of power consumption of the newer valves have reduced size and weight considerably. As higher working frequencies enabled directional aerial systems to be employed in ground reception equipment, wind measurement from a single station became possible.

Very accurate radio and radar theodolite systems, combined with normal pressure, temperature and humidity sounding, are the latest development. These are made possible by the application of microwave techniques. Servo-mechanism development has made the following of airborne transmitters and passive microwave targets automatic, and also added this feature to the recording of information at the ground station.

The radar technique enables the transmission of megawatts of peak pulse power in pulses with as small a duration as  $\frac{1}{2}$   $\mu$ sec. and receivers can detect micromicrowatts of back-scattered power. This has led to the very important application of radar to the detection of storm and general precipitation areas, and the measurement of vertical cloud structure.

Airborne units are subjected to wide variations of temperature, pressure and humidity, and special care is necessary to eliminate unwanted circuit responses to those changes, which must only be measured by the appropriate meteorological units. New low-density foamed plastic materials forming heat insulating containers will greatly reduce this problem.

Consideration of various types of upper air instrument systems will illustrate the practical application of electronics in this field. Commencing with radio-sonde systems, four basic types are in use: (a) variable audio frequency, (b) variable radio frequency, (c) chronometric, (d) code.

*Type (a) Variable audio frequency.*—This has been adopted by the United Kingdom, America and Holland. The present British routine instrument is the Meteorological Office Mk IIB radio-sonde. The audio-frequency range is from 700–1,000 c./sec., and this variation is produced in a Hartley-type oscillator by varying the air gap of its mumetal-cored inductor. Three such inductors controlled by meteorological elements are connected in turn into the oscillator circuit by means of a windmill-operated switch. These elements are bimetal, aneroid capsule, and goldbeater's skin, and provide the necessary inductor air-gap variation for temperature, pressure and humidity respectively. The audio oscillator is compensated for both temperature and

voltage changes, and its output is fed through a buffer stage to amplitude modulate the transmitter carrier. The radio frequency is set within the range 27.5–28.0 Mc./sec. and the transmitter output is about 30 mW. Ground equipment consists of a communication receiver, an oscilloscope, a precision variable-audio-frequency oscillator, and a 1,000 c./sec. frequency standard. Transmitted modulation frequencies are measured by the Lissajou-figure technique and can be converted into the appropriate meteorological data.

The two main American radio-sondes in use at the present time operate on carrier frequencies of 400 and 1,685 Mc./sec. Audio-frequency modulation is controlled by varying the grid resistor of a blocking oscillator and lies within the range 3–200 c./sec. A thermistor and hygroscopic film give the required resistance variation for temperature and humidity measurement. Pressure is signalled at fixed audio-frequency high and low reference levels, and the pressure aneroid capsule operates a light contact selector switch which controls the signalling sequence.

The new Dutch radio-sonde uses three audio-frequency oscillators, whose outputs are mixed in a reactance tube which frequency modulates a carrier in the 27.5–28.0 Mc./sec. radio-sonde band. At the ground station a frequency-modulation receiver delivers the complex output signal to three band pass filters which separate the audio-frequency components. The three simultaneously available signals can be read off directly on frequency meters, and are automatically registered with time separation by a rapid response recorder. Thermistors are used for pressure and temperature measurement and goldbeater's skin for humidity. Pressure is measured hypsometrically, the thermistor giving the boiling point of the working liquid which is a Freon.

The British lightweight radio-sonde, for temperature measurement only, employs a fixed inductor in the audio-frequency oscillator in conjunction with a variable capacitor. The inductor employs a pot-type core of a new ferrite composition, whilst the capacitor is a silvered thin-walled cylindrical type, whose ceramic dielectric is barium strontium titanate. The capacity varies by a factor of four over the working temperature range, giving an audio-frequency variation from 3,000 to 7,000 c./sec. Ground equipment is similar to that used for the British Mk IIB sonde, and the instrument can be carried by a 100-gm. balloon.

*Type (b) Variable-radio frequency.*—This has been adopted by Finland, Japan, and in the past by Germany.

The Finnish radio-sonde designed by Vaisälä, varies capacity mechanically by means of bimetal, aneroid and hair for temperature, pressure and humidity measurement. The three elements are connected separately into the radio-frequency circuit along with two fixed reference capacitors by a five-way windmill-driven switch. By referring the three meteorological variables to the reference signals, errors due to permanent frequency drifts in the main circuit are eliminated. At the ground station the receiver tuning condenser is mechanically coupled to a recorder.

*Type (c) Chronometric.*—This has been adopted by Canada, Switzerland, France, Germany, India, and was at one stage used during development work on a British radio-sonde theodolite system.

For all these sondes the transmitter carrier is interrupted or shifted by reference and meteorological signals. The time intervals between such discontinuities are proportional to the meteorological variables, and are either measured in terms of the actual spacing between recorded reference and meteorological signals, or in terms of the number of pulses of a fixed frequency which occur between signals. The scanning element can be in the form of a rotating single-turn helix (German, Indian), flat spiral (Canadian), or radius arm (French and Swiss). The scanner drive is provided by electric motor for the Canadian and French instruments, and clockwork motor for the Swiss, Indian and German instruments.

*Type (d) Code.*—This system is used in the Russian Moltchanoff sonde, in several past and the latest German radio-sonde, and in the American drop-sonde used by weather reconnaissance aircraft. Electronically these sondes only involve the suppression or shifting of a radio-frequency carrier by standard morse or other code modulation. The latest German instrument uses a number code 00–99, and this can be repeated approximately five times to give a sub-division of 500 parts over the working range of measurement. The code symbols are printed by an anodic process on a grooved partial aluminium cylinder. Ground equipment for coded radio-sondes is simply a communication receiver.

The importance of upper wind data has led to the development of radio-sonde and radar-sonde theodolite systems. The important factor here is a high carrier frequency which enables the production of an aerial system with a very narrow beam width.

The American 400 Mc./sec. wind-measuring equipment depends on the electronic switching of sections of a stacked dipole aerial array. Manual aerial control enables matching of elevation and azimuth signals on a cathode-ray tube, the appropriate angles being read directly at one-minute intervals. The signals are provided by the 400 Mc./sec. radio-sonde from which height information is obtained to complete wind-computation data.

The latest American 1,685 Mc./sec. wind-measuring equipment is fully automatic as regards target following, and the printing of azimuth and elevation angles. A paraboloidal aerial is used and conical beam scanning gives the necessary target-position information to the auto-follow circuits which keep the aerial aligned on the target, this being a 1,685 Mc./sec. radio-sonde. Again height information from the radio-sonde completes the wind-data requirement.

The new British radar-sonde theodolite system carries automatism a step further by measuring target range and also computing height, wind speed and direction as well as recording temperature, pressure and humidity in a form easily convertible to meteorological values. A transponder system is employed in which the radar-sonde receives 2  $\mu$ sec. pulses on 152.5 Mc./sec., and re-transmits them on 2,850 Mc./sec. The meteorological units initiate the triggering of a second pulse from the airborne transmitter with a time delay dependent on the meteorological quantity being measured. This delay is measured in pulses by the ground equipment.

Standard gun-laying radar equipments are used in conjunction with passive targets attached to balloon trains, with or without radio-sondes, for upper wind determination. These equipments provide manually or automatically all the wind-measuring data required.

Radar equipment with an 8-mm. operating wave-length has been shown capable of detecting cloud bases and tops, but is unsatisfactory for the measurement of bases below 1,000 ft.

Optical radar is the basis of an experimental pulsed-light cloud-base meter capable of base measurement day or night over an average range 0–12,000 ft. Paraboloidal mirrors of 20 in. diameter, 25 ft. apart, and aligned with optical axes in the vertical, are used for beaming the transmitted  $\frac{1}{2}$   $\mu$ sec. light pulse and collecting its back-scattered component. The amplified received pulse is displayed on a calibrated time base and its commencement position gives the height of the cloud base.

In conclusion we can consider possible future developments. A standard radio-sonde against which all others could be compared is very desirable, and if the sonic sonde were perfected, it would at least settle radio-sonde temperature-measuring accuracy. Balloon performance should be improved to enable the attainment of 100,000 ft. regularly, and 150,000 ft. on special occasions. A simple humidity element with response time and accuracy unaffected by ambient temperature is a pressing requirement, whilst a multi-purpose ground radar set would make the application of this important new technique a more economic proposition. In general, electronics will be called upon more and more to measure, transmit, present and compute meteorological data.

*Mr. Clark* in opening the general discussion considered the new problems arising out of the increased speed of modern aircraft. In these conditions it is necessary to make meteorological measurements automatically. The two main problems are automatic following and accurate measurement of an electrical quantity. An example is the frost-point temperature determination. An automatic instrument has been developed for this type of measurement in which a thin platinum film is maintained at the frost-point temperature by opposed heating and cooling. This is achieved by a photo-electric-cell signal, dependent on the degree of frost deposit controlling the output of an amplifier which supplies heating power to the metal film. Continuously opposed to this heating

is the cooling of a copper rod, electrically but not heat insulated from the metal film, the main body of the rod standing in liquid nitrogen in a Dewar vessel. Two voltages proportional to the voltage and current across the film, are divided to give its resistance. As this resistance is dependent on temperature, a calibration for film temperature is possible. Another example is the electrical-resistance thermometer for which a self-balancing bridge based on the Callendar and Griffiths type has been developed. This follows the resistance changes by means of a binary scale relay-counting mechanism operated by the bridge out-of-balance current. The binary number at balance represents the required thermometer resistance. Changes of temperature over a range of  $100^{\circ}\text{C}.$  can be measured to  $0.1^{\circ}\text{C}.$  at a following speed of  $1^{\circ}\text{C./sec.}$  Space required for the present model is only  $0.5\text{ ft.}^3$

*Dr. Dell* mentioned the enormously enhanced accuracy of the new radar theodolite installed at Crawley. Measurements of very fine wind structure were now possible, the equipment even detecting the swinging of a wind-measuring transponder rig about a fixed apex. In considering cloud-height meters, certain new phosphors show promise of application for modulated light sources at frequencies of about  $10\text{ Mc./sec.}$

*Mr. Bibby* described a daylight cloud searchlight being developed in the Instruments Division. Its beam is modulated at  $340\text{ c./sec.}$  by a rotating shutter, and continuously sweeps between the horizontal and vertical. Some hundreds of feet away is a photo-electric detecting unit, pointing vertically. When the modulated searchlight beam illuminates the cloud base within the receiver beam, an audible signal is produced, and the searchlight elevation angle transmitted to the receiver point by a servo system can be noted at this instant. By triangulation the cloud height is determined. Though in its present form it will only detect cloud up to  $2,000\text{--}3,000\text{ ft.}$  its chief advantage seems to lie in its adaptability to continuous autographic recording at a distant observing office.

*Mr. Needham* referred to the field trials of the pulsed-light meter at Northolt, giving the effective instrument range as  $0\text{--}9,000\text{ ft.}$ , though cloud echoes had been obtained several times from higher levels up to  $15,000\text{ ft.}$  Improvements were suggested to ensure greater efficiency and convenience of operation. This method of cloud-height determination has distinct advantages over methods in current use despite certain limitations. No difficulties are experienced in receiving good returns from cloud in moderate precipitation, including snow. Further development will make the instrument a valuable day and night observing aid; forecasters and those connected with the operation of aircraft stand to benefit from the enhanced observing accuracy. The full usefulness of the instrument will not be known until the present research work is completed.

*Dr. Scrase* inquired if a radio-linked anemometer and wind-recorder system would in the long run be cheaper than a ground cabled system.

*Cmdr Frankcom* suggested that the pulsed-light system might be a useful addition to a weather ship's instruments, but thought better wind-measuring equipment was a more pressing requirement.

*Mr. Durward* mentioned the need for a remote cloud-height indicating apparatus; *Mr. Almond*, in reply, suggested that an automatic strobing technique applied to the pulsed-light meter would make remote recording a possibility. At this point *Mr. Almond* showed a series of slides depicting cloud-echo

photographs from a wide range of cloud types obtained with the pulsed-light meter.

*Mr. Parry* wondered if the cloud top could be measured with the pulsed-light meter; *Mr. Almond* suggested that there were certain cloud types which might yield both base and top information.

*Mr. Harley* suggested the difficulty of giving a true definition of cloud base. He welcomed the news of the American cloud-base and top meter, but had previously heard its value was somewhat limited.

*Mr. Harper* stated that the cloud-base and top meter only yielded satisfactory results with large-droplet clouds.

*Mr. Murgatroyd*, referring to *Mr. Clark's* statement, suggested that instrumentation was becoming too complex and accuracy of reading too great. This applied to the radar-sonde theodolite system which was the only one requiring ground and airborne transmitters. *Mr. Clark* regretted the complexity but claimed that it was unavoidable, whilst *Mr. Almond* stated that two transmitters were necessary for range determination with any transponder system, and that this determination would lead to more accurate wind data at all ranges and heights than obtainable with systems using radio-sonde heights in wind computations.

*Mr. Sawyer* saw no foreseeable use in the near future for a fully automatic computation system in actual weather forecasting. Only simplified atmospheric models could be adapted to this technique, and these only employed a very small quantity of the available upper air information.

*The Director*, in closing, remarked that the discussion had dealt mainly with the secondary communication techniques, and not with the primary measuring elements for pressure, temperature, etc. There was a need to look carefully into the accuracy of the available elements and to investigate all possible new alternatives.

## ROYAL METEOROLOGICAL SOCIETY

Before the meeting began on January 19, *Sir Charles Normand*, on behalf of the Society, congratulated the President, *Dr. O. G. Sutton*, on the award to him of a knighthood, announced in the New Year's Honours List. The Society then proceeded to a discussion on air flow over mountains, which was opened by a summary of the following paper:—

*Corby, G. A.—The air flow over mountains\**

*Mr. Corby* began by outlining the observational evidence of wind flow in the neighbourhood of mountains, particularly that of stationary lee waves. Evidence came mainly from the study of orographic clouds and from the reports of pilots, particularly glider pilots; and it seemed clear that stationary lee waves were more pronounced in stable conditions—in unstable air the flow was disorganized and turbulent—with wave-lengths of the order of a few miles. The amplitude of the waves increased upwards and then decreased at higher levels, and the air flow was rather smooth; vertical components as large as 2,500 ft./min. had been observed.

*Mr. Corby* then discussed briefly the theoretical work of *P. Queney* and *R. S. Scorer* who attempted to find mathematical expressions for wave motion over hill ridges. *Queney's* solution only gave a train of waves for hill widths of the order of 100 Km.—whereas *Scorer's*, being confined to smaller-scale phenomena in which it was possible to ignore the Coriolis factor, did give a train of waves under certain conditions of wind profile and stability. *Scorer's* simplified equation is

$$\frac{\partial^2 \psi}{\partial z^2} + \left( \frac{g\beta}{U^2} - \frac{1}{U} \frac{\partial^2 U}{\partial z^2} - k^2 \right) \psi = 0,$$

where  $\beta$  is the coefficient of stability depending on potential temperature and its gradient with height,  $U$  is the horizontal wind velocity and  $k$  is the wave number; and *Scorer* showed that wave trains were possible in the lee of a ridge if the parameter

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\**Quart. J. R. met. Soc., London*, 80, 1954, p. 491.

$$l^2 = \frac{g\beta}{U^2} - \frac{1}{U} \frac{\partial^2 U}{\partial z^2}$$

increased with height. Using several distributions of  $l^2$  likely to be found in nature, Scorer had demonstrated the theoretical existence of waves very similar to those actually observed, i.e. with forward wind shear through a stable layer.

A contribution by Dr. Förrchtgott of Prague was read by Mr. A. H. Yates. Dr. Förrchtgott was an experienced glider pilot himself, and he had been able, with the help of the observations from a team of other glider pilots and ground observations, to present a reliable model of what was observed. With no inversion, rotatory movement, sometimes with a rotating cloud, could be observed under the peaks of the lee waves near the surface; at higher levels lenticular cloud was observed. With an inversion, a standing eddy occurred immediately to the lee of a ridge, which had the effect of enlarging the size of the hill and therefore the wave-length of the observed waves. The rotating clouds and the lenticular clouds were also observed to move very slowly with the wind but after a time to return rapidly to their original positions against the wind. Dr. Förrchtgott had also devised a scheme whereby glider pilots could perform an adequate upper air sounding above standing waves; additional precautions were necessary because, owing to adiabatic changes, the temperature is warmer than elsewhere at the same level in a trough of the wave and colder at a crest.

In the general discussion that followed Mr. Wallington described a particular glider ascent in a standing wave over Camphill, Derbyshire, and showed how he had applied Scorer's theories to estimate the waves caused by each of the hills and valleys in the neighbourhood. Combining them all he had obtained an estimate of the wind flow which was within 20 per cent. of that actually observed. Prof. Gordon Manley confirmed the existence of Förrchtgott's rotating clouds by reference to the Helm Bar produced in the lee of Cross Fell. Dr. Scorer gave some illustrations of how a standing wave can "change" the profile of a ridge so that the amplitudes of the lee waves are lessened although the wave-lengths are increased; he also showed how katabatic winds can accentuate lee waves and how a standing eddy can form on the flat top of a hill—this last was illustrated by a photograph of two wind socks flying in different directions at the same time. Mr. Rosenbrock, who was interested in windmill generation of electricity, described how an increase of 40–50 per cent. in wind strength could be gained by siting the windmill on the top of a ridge; theoretically the top of an isolated hill was not so good but there was little difference in practice because the isolated hill could take advantage of higher-level winds. Mr. Townsend, a forester, reported how most trees were blown down near the middle of hill and ridge slopes rather than near the top or bottom; but the evidence was not reliable because of the variability of trees and because they were likely to be smaller near the top of a hill.

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At a meeting of the Society, held on January 26, 1955, Prof. P. A. Sheppard in the Chair, the following paper was read:—

*Rosby, C.-G.—Chemical composition of precipitation as a function of atmospheric circulation patterns*

Beginning in 1948, the monthly accumulations of precipitation at a network of 25 stations in Sweden were analysed for the concentration of the following ions: sodium (Na), potassium (K), calcium (Ca), ammonia (NH<sub>3</sub>), nitrogen (N), nitric oxide (NO<sub>3</sub>) and chlorine (Cl). From July 1951 the precipitation samples were analysed in addition for sulphur (S) and magnesium (Mg), and samples of the air at a number of the stations were also analysed for the different constituents. Since November 1954 the network has been increased to 41 stations extending to the other countries of Scandinavia.

Prof. Rosby discussed maps showing isopleths of the concentration of the different ions. The variation in the ratio of Cl : Na concentration with different circulation types was then illustrated; notable was the decrease from west to east with a strong westerly type and the high values of the ratio in a south-easterly type. A particularly interesting month was December 1953 when the air samples showed a marked maximum of Cl concentration in a south-easterly type, but the polar continental air mass, which produced northerly winds over Sweden, gave negligibly small amounts of Cl in precipitation.

Analysis of the annual totals, over the period of 4–5 yr. for the Na deposit (characteristic of maritime influence) and the S deposit (characteristic of continental influence) for three stations in western, central and southern Sweden, suggested a trend for increasing continental influence during this period. The mean circulation pattern for the year 1949 showed a definite westerly type over Sweden which was associated with high Na and low Cl concentration; on the other hand, 1952 showed an irregular pattern with no marked flow from any direction, and was associated with smaller Na values. The last map showed what Prof. Rosby considered to be the typical Cl concentration—the map indicated low concentrations over eastern Sweden and high values over central Russia.

Prof. Rosby said that this was in the nature of a preliminary report, but he considered the results were important enough to deserve further study and, he hoped, active research in other countries.

In the discussion speakers, whose work was connected with atmospheric-pollution research, referred to the useful data from a network of stations in this country, and co-operation was also promised by research workers in cloud physics.

## INSTITUTE OF NAVIGATION

### Accuracy of dead reckoning in the air

On Friday December 17, 1954, a paper on the "Accuracy of dead reckoning in the air" was read by Mr. C. S. Durst before the Institute of Navigation.

The purpose of the paper was to assess the magnitude of errors due to various causes in flying from one position to another, and also to show how these errors could be statistically combined, so producing the probable error in a dead-reckoning position when various navigational procedures are followed. The errors considered were those due to time keeping, to airspeed, to compass and to windage. In addition the effect of inaccurate position fixing was also taken into account.

The main emphasis was placed on errors due to windage, and tables were given showing the standard errors likely to arise from 24-hr. forecasts on routes of various lengths at various heights. In contrast the navigator having "found" a wind either by flying on three courses (at 60° to each other) or by measuring the drift of his aircraft between two successive fixes, may then use this found wind as a forecast for the next leg of his flight. The standard errors in such a procedure were calculated and exhibited.

Some typical examples were worked out to show how navigational and windage errors accumulated, (i) when an aircraft is flying over the ocean to intercept a convoy, (ii) when planning the necessary separation of contiguous air tracks at the same level, (iii) when planning homing equipment for an undeveloped route, and finally (iv) to answer the question when it is better to use a found wind than a forecast wind and *vice versa*.

In the course of a general discussion which followed, Wg Cmdr Anderson emphasized that one of the most accurate ways of obtaining found winds was by a three-drift method and that then the errors were very small.

Mr. J. B. Parker was anxious that casual errors in compass readings should be included as well as semi-systematic ones and that the navigator should have the errors presented as 50 per cent. circles of error. He stated that the total errors in dead reckoning appeared to be very considerably greater than the navigator was accustomed to expect.

Mr. H. E. Smith (British Overseas Airways Corporation) urged that every effort should be made to avoid the necessity of dead-reckoning navigation, rather than that the navigator be given more work in the air.

In winding up the meeting the Chairman, Sir Ralph Cochrane, also emphasized the ideal that dead reckoning should be abandoned and some black box should give the navigator his true position at any given moment.

## LETTERS TO THE EDITOR

### Glazed frost at Bwlchgwyn

After the memorable glazed frost of January 1940 I reported to the *Meteorological Magazine* the details of its occurrence at Bwlchgwyn\*, and during the intervening fifteen years I have often wondered what exactly was the nature of the precipitation. A simpler case has recently occurred, insignificant compared with the 1940 phenomenon, yet I think it appropriate to describe it as it is the best case at Bwlchgwyn since that date; and glazed frost, in contrast to rime deposit, is rare even on the mountains.

On January 15, 1955, steady snowfall began at 0700 with a temperature of 24–25°F., and with the approach of a warm front this turned to drizzle at midday with a slow rise of surface temperature which, however, still remained well below freezing point. In a fresh SE. wind the drizzle turned to rain and coated everything—twigs, posts, wires, rushes, heather, and also the snow surface—with a coating of clear ice which reached  $\frac{1}{4}$  in. thickness at the time of maximum development around sunset. The horizontal bars of wooden gates,

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\* *Met. Mag.*, London, 75, 1940, p. 23.



but not metal wires, displayed icicles up to 3 in. long. The Stevenson screen at the Bwlchgwyn station (1,267 ft.) had its door completely frozen up with the deposit, and it took the best part of an hour to free all the instruments of it. On climbing, one broke through the ice crust, and ice plates, driven by the wind, tinkled their way down the mountain side perhaps for hundreds of yards. Lumps of snow adhering to the wool of the sheep were ice coated, and also tinkled as the animals moved. The pleasant sounds, produced by no other natural phenomenon, were impressive, and I particularly noted the sound of ice-laden rushes, bent down by the ice, rubbing in the wind on the ice layer on the snow.

At 1505 there was a brief period of heavy rain—quite ordinary rain which bore no evidence of supercooling. Immediately after this the low cloud broke, revealing an altostratus layer, becoming ruddy at sunset, and one was presented with the extraordinary spectacle of being surrounded everywhere by ice, with an air temperature of 30°, and a soft grey sky typical of a tropical maritime air stream on a mild December day. Of course, a few hundred feet higher up, that is just what was happening.

The glaze was appreciable at 1,000 ft., and the intensity increased rapidly with altitude up to 1,300 ft. After sunset there was a brief thaw, which was sufficient to melt the ice deposit before the ensuing snowfall.

S. E. ASHMORE

11 Percy Road, Wrexham, North Wales, January 23, 1955

**Estimating temperature extremes**

I was greatly interested in Mr. Lawrence's paper on "Estimation of the probabilities of given extreme minimum temperatures" in the *Meteorological Magazine* for January, as I have been working on possible extreme temperatures in the Wirral. His proposed frequency distribution seemed to be rather arduous to compute, so to compare its results with other distributions, I re-worked the Cambridge data in the Appendix using the normal frequency distribution and the same distribution adjusted for skewness, by the method given by Brooks and Carruthers\*. This latter I have found the most suitable in the Wirral work. The skewness coefficient  $\gamma_1$  was  $-0.28$ . The resultant probabilities, together with Lawrence's figures are given in Table I:—

TABLE I—EXPECTATION ONCE IN  $t$  YEARS

	Values of $t$					
	1.58	5	10	25	50	100
			<i>degrees Fahrenheit</i>			
$\sigma_1/\sigma_2 = 1.12$ ...	31.9	28.2	26.5	24.7	23.5	22.6
$\sigma_1/\sigma_2 = 1.15$ ...	31.8	28.2	26.5	24.9	23.8	23.0
Normal ...	31.6	28.0	26.6	25.2	24.2	23.4
Adjusted normal ...	31.8	28.0	26.5	24.9	23.8	22.8

Bearing in mind that the distribution is based on only 30 readings taken to the nearest 1°F. (standard error of observation 0.29°F.) of an element which may, or may not, be subject to secular change, it is clear that there is little to choose for accuracy between the four series. This being the case, the normal distribution wins the test on the grounds of simplicity of computation.

\* BROOKS, C. E. P. and CARRUTHERS, N.; Handbook of statistical methods in meteorology. London, 1953, p. 114.

It may be argued that Cambridge is a bad example to take as it is nearly normal, but it is the only one with which Lawrence provides us, and other cases would need to be examined as they arose for evidence of skewness.

G. REYNOLDS

5 Raeburn Avenue, West Kirby, Cheshire, January 31, 1955

## NOTES AND NEWS

### Record of an unusually high rate of rainfall

By fitting a strip-chart mechanism, in place of the usual clock and drum, to a tilting-siphon rain recorder a much more open time scale may be secured. With this open scale details of variations of rainfall intensity which cannot be seen on the standard chart become apparent. Fig. 1 shows part of a trace obtained at Harrow on November 22, 1954, during the passage of a cold front, the last of a complex frontal system. The feature of interest is the abrupt change in intensity at 1724 from about 2 mm./hr. to over 100 mm./hr. (4 in./hr.). Unluckily, siphoning occurred during this intense rain; all we can say is that it persisted for at least 45 sec. and for not more than 75 sec. During the following 3 min. the intensity was about 20 mm./hr., and it is noticeable that the trace during this period is less smooth than either before or after.

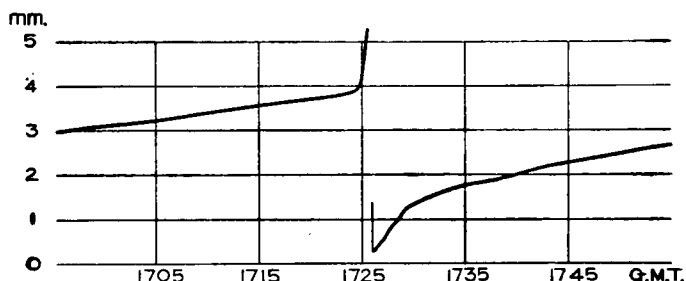


FIG. 1—RAINFALL RECORD, HARROW,  
NOVEMBER 22, 1954

Information about intense falls is of interest to many people, but the information is of limited value unless something is known about how large an area is at any one instant experiencing the heavy rain. It is planned to establish over an area of four square miles at Cardington, a close network of open-scale rain recorders with accurately synchronized clocks. A study of these open-scale synchronous records should lead to a much better understanding than we have at present of the structure of precipitating clouds.

R. FRITH

## REVIEW

*Snow crystals: natural and artificial.* By U. Nakaya. 10¼ in. × 7¾ in., pp. xiv + 510, *Illus.*, Harvard University Press (London: Geoffrey Cumberlege), 1954. Price: 80s. net.

It is not often that the research subject of the professional scientist is equally worthy of study for the sake of its beauty. In this respect the author of this book is to be congratulated, not only on his own good fortune but also for the aesthetic appeal of the 1,400 microphotographs of snow crystals which adorn this volume. Comparison with Bentley's collection of photographs is inevitable.

For some the pictorial appeal of Bentley's white photographs on their black background will be greater than that of the present photographs, for which some oblique illumination was used in order to emphasize the topography of the crystal surfaces. The different photographic technique employed by the present author is indicative of the greater emphasis on scientific research. In this connexion it should be mentioned that every photograph is accompanied by an indication of the magnification.

This book gives an account of 12 years' research by Prof. Nakaya and his collaborators. The first half deals with natural snow crystals observed at Sapporo and on Mount Tokachi in Japan. Chapter 1—the longest chapter in this part of the book—describes in detail and with many illustrations the various types of snow crystal found. Although most of the plates show regular crystals the author emphasizes that irregular or malformed crystals are just as frequent. Chapter 2 classifies the snow crystals observed by the author and gives an indication of the frequency of occurrence of the various types and of their dimensions. The third and last chapter of this part deals with the physical properties of snow crystals—the form, mass, and terminal velocity of individual crystals, the relationship between these parameters and the electrical charge on individual crystals.

The second part of the book deals with artificial snow. After a short chapter on artificial frost crystals formed on a solid surface, Chapter 5 describes the technique for the production of artificial snow crystals. These crystals were developed from "germs" which formed upon a filament of silk or of rabbit hair suspended in a chamber in which the temperature and humidity could be controlled. The humidity was controlled by the use of a dish of heated water in the base of the chamber, and the author uses the water temperature as a measure of the humidity. The importance of the rate of growth in determining the form of the crystal is stressed by the author. Some crystals were grown in less than an hour, others required more than 24 hr. A feature of this chapter is the wealth of experimental detail. Chapter 6—the longest in the book—is devoted to a description of the many different kinds of crystal the author has made in the laboratory and of the conditions in which they were made. It is profusely illustrated. Chapter 7 contains a number of pairs of photographs of similar crystals—one natural and one artificial—covering a variety of crystal types. For many of these pairs the text contains a detailed description of the physical conditions in which the artificial crystal was developed. Finally there is a short chapter on recent research.

Most of the contents of the book have been published in thirteen separate papers (but, presumably, not most of the plates) and the book itself has the style rather of a scientific paper than a textbook.

The painstaking work of the author and his associates and the careful preparation of the manuscript have been matched by the work of the publisher. The reviewer believes that any one who is interested in this field of research will consider the book good value for money. A Japanese edition of this book was destroyed while in the press by bombing during the war. The fact that publication of this English edition was made possible by assistance from both Hokkaido University and various American authorities is a happy reminder of the international nature of scientific research.

A. C. BEST

## HONOURS

Dr. J. M. Stagg, C.B., O.B.E., Principal Deputy Director, Meteorological Office, has been awarded a Gauss-Weber medal by the Academy of Science, Göttingen, "for his researches in geomagnetism especially his discussion of the Fort Rae Polar Year (1932-3) data and the investigations arising therefrom, so furthering the aims which Gauss and Weber envisaged when they set up the Magnetic Union in 1831".

Dr. Stagg received the medal on February 19, 1955 at a ceremony in the Union Hall, Göttingen, arranged by the University and the Academy of Science, Göttingen, to commemorate the hundredth anniversary of the death of Carl Frederick Gauss. The five other recipients of the medal were continental scientists distinguished in the fields in which Gauss and his contemporary Weber had made fundamental contributions: astronomy, astrophysics, mathematics and communications. Sir Geoffrey Taylor represented the Royal Society at the ceremony; the main ovation in honour of Gauss and Weber was made by Dr. Richard Courant of New York.

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It was announced in the London Gazette of March 1, 1955 that Mr. B. D. Hunt, Scientific Assistant at Bovingdon, has been awarded the Polar Medal for good services as a member of the Falkland Islands Dependencies Survey in Antarctic expeditions during the years 1949-54. Mr. Hunt served as Meteorological Assistant at Hope Bay in 1952.

## METEOROLOGICAL OFFICE NEWS

**Retirement.**—Mr. A. G. W. Howard, Experimental Officer, retired on January 31, 1955, after 49 years' service. He joined the Office in September 1905 and served in the Forecast Division until 1917, when he was transferred to the Marine Division. From 1923 to 1945 he served in the Climatological Branch, and whilst the Branch was at Stroud during the Second World War Mr. Howard took an active part in Civil Defence work. From 1945 until his retirement he served at Kew Observatory.

**Academic success.**—We offer our congratulations to Mr. R. C. Smith, Scientific Officer, who has been admitted to the degree of Ph.D. in Meteorology in the University of London.

## WEATHER OF FEBRUARY 1955

Pressure was again much above normal north-west of the British Isles, an anticyclone (1022 mb. or above) over Greenland being more prominent than the Atlantic high (represented by 1017 mb. at Madeira) on the mean map. Pressure was lowest (1005 mb.) in the middle Baltic and near the Norwegian weather station M. Anomalies ranged from +14 mb. over west Greenland to -13 mb. over central Europe.

Mean temperature was below normal over northern Europe (greatest anomaly -4°C. in Denmark and at Stornoway) and over Iceland and Greenland. The Mediterranean and the southern half of Europe was warmer than usual, anomalies of +3°C. occurring in central Italy and +4°C. in Tripolitania.

There was excessive rainfall, reaching two to three times the normal amount in a band across central Europe from Brittany to the lower Danube basin. Under half the normal amounts of equivalent rainfall were measured in east Greenland, south Iceland and in parts of the central and eastern Mediterranean.

In the British Isles it was rather mild for the first week especially in the south, but for the rest of the month it was cold with temperature everywhere below the average and with considerable snowfall at times. A notable feature of the month was the extremely low temperature recorded at some places. There was more than average sunshine nearly everywhere except during the last

week in England and Wales, but during this week there was more than twice the average for the month in parts of Scotland.

During the first few days pressure was low to the north-west of the country and depressions from the Atlantic moved eastward across Wales and the southern half of England bringing considerable rain to the south-west; parts of Devon and Cornwall had more than  $2\frac{1}{2}$  in. of rain during the first week, but there were no large falls elsewhere. Weather was mild with sunny periods for a time, but cold northerly winds, accompanied by slight snow showers spread over Scotland and parts of northern England during the latter part of the week; nevertheless, at many places on the south coast, temperature rose to  $57^{\circ}\text{F}$ . on the 7th. A marked change took place at the beginning of the second week when a ridge of high pressure developed south-eastwards from an anticyclone over Greenland, and during the 8th and 9th cold air accompanied by local thunder spread south over the whole country causing temperatures to fall as much as  $5\text{--}10^{\circ}\text{F}$ . Generally sunny weather followed but with snow showers, and these were frequent and often prolonged in north and east Scotland and over much of eastern England. Temperatures continued to fall progressively lower till by the end of the third week they were rising little above freezing point during the day. There were extensive outbreaks of snow on the 14th, and it lay from 1 to 3 in. deep on many roads in the east Midlands and up to 6 in. deep in parts of Lincolnshire that afternoon. On the 17th, a polar depression, accompanied by local thunder, moved south in the northerly stream and by the evening snow lay up to 6 in. deep in many parts of north-east England and the Midlands. The strong northerly winds, reaching gale force at times, caused serious snow-drifts in Scotland, and many farms and villages were isolated and had to be supplied by air. The winds moderated on the 18th as a weak low-pressure system settled over the country, and that night there were heavy falls of snow in Scotland, reported to be the most severe of the century. Among the greater depths of undrifted snow reported were  $23\frac{1}{2}$  in. at Glenmore, Inverness-shire, 18 in. at Glenrossal, Sutherland, and 12 in. at Glenshee, Perth, at Drummuir, Banffshire, and at Buxton, Derbyshire. Substantial falls occurred in Lancashire and Norfolk also; drifts up to 5 ft. were reported from Blackpool and Wells-on-Sea, Norfolk, was isolated by drifts. In five days during this period the Royal Air Force dropped 38 tons of hay to cattle marooned by the snow in Scotland. Very low temperatures were experienced as a consequence of the decrease in gradient and snow-cover; Northolt registered a ground temperature of  $-3^{\circ}\text{F}$ . and Kew  $2^{\circ}\text{F}$ ., this latter the lowest there for 30 yr., on the morning of the 20th. A temporary invasion of warmer air gave further rain and snow in the south-west, accompanied by thunderstorms in the western English Channel, but even colder weather followed over Scotland, and at Braemar in the Grampians screen temperature fell to  $-13^{\circ}\text{F}$ . on the morning of the 23rd, the lowest in Great Britain since 1895. Throughout the last week of the month easterly winds prevailed over most of the country with low pressure over the Bay of Biscay and slow-moving fronts lying along the English Channel. Southern England had frequent outbreaks of rain or snow, and in particular there were substantial falls in the south-west on the 23rd; snow fell continuously from 0400 to 2000 and most roads in Cornwall were snowbound. From time to time the snow spread as far north as Scotland, but mostly western Scotland, Northern Ireland and north-west England had bright cold weather, particularly in the Hebrides where Stornoway's sunshine reached the record total of 96 hr. during the month, the previous highest for February there being 91 hr. in 1886. Holyhead had 113 hr., its previous highest being 108 hr. in 1930. On the morning of the 27th screen temperature fell to  $20^{\circ}\text{F}$ . or below in many places in the north but the lowest screen temperature for this month in England and Wales was  $-1^{\circ}\text{F}$ . at Houghall, Durham, on the 20th. Rain from the Atlantic was by now affecting Northern Ireland and western Scotland, and on the last day of the month milder weather with a good deal of rain spread across Ireland and much of Scotland accompanied by southerly gales with mean wind speeds 40–50 kt. The rain was exceptionally heavy in west Scotland. Among the heaviest falls reported in 24 hr. on the 28th were 5.30 in. at Ardrishaig, Argyllshire, 5.75 in. at Inverailort, Inverness-shire, and 5.04 in. at Glenbranter, Argyllshire. The 28th however was very sunny over east and south-east England with over 9 hr. sunshine in many places, and although temperatures in the morning had been as low as  $15\text{--}20^{\circ}\text{F}$ . below freezing point in many places, they rose to  $35\text{--}40^{\circ}\text{F}$ . in the afternoon.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	$^{\circ}\text{F}$ .	$^{\circ}\text{F}$ .	$^{\circ}\text{F}$ .	%		%
England and Wales ...	59	—1	—4.9	102	+2	122
Scotland ...	55	—13	—5.9	87	0	142
Northern Ireland ...	55	4	—6.1	120	0	117

# RAINFALL OF FEBRUARY 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	1.61	96	<i>Glam.</i>	Cardiff, Penylan ...	1.96	67
<i>Kent</i>	Dover ...	2.10	109	<i>Pemb.</i>	Tenby ...	2.64	91
<i>"</i>	Edenbridge, Falconhurst	2.15	97	<i>Radnor</i>	Tyrmynydd ...	3.80	72
<i>Sussex</i>	Compton, Compton Ho.	2.40	91	<i>Mont.</i>	Lake Vyrnwy ...	3.26	71
<i>"</i>	Worthing, Beach Ho. Pk.	1.92	97	<i>Mer.</i>	Blaenau Festiniog ...	4.70	57
<i>Hants.</i>	St. Catherine's L'thouse	1.98	98	<i>"</i>	Aberdovey ...	2.05	69
<i>"</i>	Southampton (East Pk.)	2.05	89	<i>Carn.</i>	Llandudno ...	1.80	92
<i>"</i>	South Farnborough ...	1.50	80	<i>Angl.</i>	Llanerchymedd ...	2.57	102
<i>Herts.</i>	Harpenden, Rothamsted	2.24	117	<i>I. Man</i>	Douglas, Borough Cem.	4.00	125
<i>Bucks.</i>	Slough, Upton ...	1.52	99	<i>Wigtown</i>	Newton Stewart ...	3.22	86
<i>Oxford</i>	Oxford, Radcliffe ...	1.42	87	<i>Dumf.</i>	Dumfries, Crichton R.I.	2.00	61
<i>N'hants.</i>	Wellingboro' Swanspool	1.65	102	<i>"</i>	Eskdalemuir Obsy. ...	3.41	69
<i>Essex</i>	Southend, W. W. ...	1.29	95	<i>Roxb.</i>	Crailling... ...	2.23	121
<i>"</i>	Felixstowe ...	1.88	149	<i>Peebles</i>	Stobo Castle ...	1.92	70
<i>Suffolk</i>	Lowestoft Sec. School ...	1.75	125	<i>Berwick</i>	Marchmont House ...	2.60	125
<i>"</i>	Bury St. Ed., Westley H.	2.05	137	<i>E. Loth.</i>	North Berwick Gas Wks.	1.52	97
<i>Norfolk</i>	Sandringham Ho. Gdns.	2.62	160	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	1.43	86
<i>Wilts.</i>	Aldbourn ...	1.69	74	<i>Lanark</i>	Hamilton W. W., T'nhill	2.64	91
<i>Dorset</i>	Creech Grange... ..	2.33	82	<i>Ayr</i>	Colmonell, Knockdolian	...	...
<i>"</i>	Beaminstor, East St. ...	3.04	100	<i>"</i>	Glen Afton, Ayr San. ...	2.11	48
<i>Devon</i>	Teignmouth, Den Gdns.	2.61	98	<i>Renfrew</i>	Greenock, Prospect Hill	3.92	74
<i>"</i>	Ilfracombe ...	3.20	116	<i>Bute</i>	Rothsay, Ardenraig ...	3.03	76
<i>"</i>	Princetown ...	5.96	79	<i>Argyll</i>	Morven, Drimnin ...	4.81	91
<i>Cornwall</i>	Bude, School House ...	2.67	107	<i>"</i>	Poltalloch ...	3.63	84
<i>"</i>	Penzance ...	5.16	154	<i>"</i>	Inveraray Castle ...	2.96	44
<i>"</i>	St. Austell ...	5.11	133	<i>"</i>	Islay, Eallabus ...	3.70	88
<i>"</i>	Scilly, Tresco Abbey ...	5.18	186	<i>"</i>	Tiree ...	3.02	88
<i>Somerset</i>	Taunton ...	2.73	131	<i>Kinross</i>	Loch Leven Sluice ...	3.61	128
<i>Glos.</i>	Cirencester ...	1.65	73	<i>Fife</i>	Leuchars Airfield ...	1.80	103
<i>Salop</i>	Church Stretton ...	2.32	99	<i>Perth</i>	Loch Dhu ...	4.79	64
<i>"</i>	Shrewsbury, Monkmere	1.69	108	<i>"</i>	Crieff, Strathearn Hyd.	1.59	45
<i>Worcs.</i>	Malvern, Free Library...	1.71	95	<i>"</i>	Pitlochry, Fincastle ...	2.19	74
<i>Warwick</i>	Birmingham, Edgbaston	2.11	113	<i>Angus</i>	Montrose, Sunnyside ...	2.57	140
<i>Leics.</i>	Thornton Reservoir ...	1.95	117	<i>Aberd.</i>	Braemar ...	3.65	128
<i>Lincs.</i>	Boston, Skirbeck ...	2.86	196	<i>"</i>	Dyce, Craibstone ...	2.82	123
<i>"</i>	Skegness, Marine Gdns.	2.21	144	<i>"</i>	New Deer School House	2.96	139
<i>Notts.</i>	Mansfield, Carr Bank ...	2.19	113	<i>Moray</i>	Gordon Castle ...	2.00	104
<i>Derby</i>	Buxton, Terrace Slopes	4.65	124	<i>Nairn</i>	Nairn, Achareidh ...	1.92	119
<i>Ches.</i>	Bidston Observatory ...	1.84	109	<i>Inverness</i>	Loch Ness, Garthbeg ...	...	...
<i>"</i>	Manchester, Ringway...	1.59	83	<i>"</i>	Glenquoich ...	5.49	53
<i>Lancs.</i>	Stonyhurst College ...	1.72	51	<i>"</i>	Fort William, Teviot ...	4.24	57
<i>"</i>	Squires Gate ...	2.34	110	<i>"</i>	Skye, Broadford ...	3.77	58
<i>Yorks.</i>	Wakefield, Clarence Pk.	2.75	161	<i>"</i>	Skye, Duntuilin ...	3.88	84
<i>"</i>	Hull, Pearson Park ...	2.07	125	<i>R. &amp; C.</i>	Tain, Mayfield... ..	2.39	104
<i>"</i>	Felixkirk, Mt. St. John...	2.26	134	<i>"</i>	Inverbroom, Glackour...	4.07	80
<i>"</i>	York Museum ...	1.71	113	<i>"</i>	Achnashellach ...	5.17	75
<i>"</i>	Scarborough ...	1.87	111	<i>Suth.</i>	Lochinver, Bank Ho. ...	3.36	84
<i>"</i>	Middlesbrough... ..	1.63	125	<i>Caith.</i>	Wick Airfield ...	3.13	138
<i>"</i>	Baldersdale, Hury Res.	1.59	54	<i>Shetland</i>	Lerwick Observatory ...	3.02	96
<i>Norl'd.</i>	Newcastle, Leazes Pk....	2.74	179	<i>Ferm.</i>	Crom Castle ...	3.46	118
<i>"</i>	Bellingham, High Green	3.23	127	<i>Armagh</i>	Armagh Observatory ...	3.55	160
<i>"</i>	Lilburn Tower Gdns. ...	3.45	173	<i>Down</i>	Seaforde ...	3.58	117
<i>Cumb.</i>	Geltsdale ...	2.10	81	<i>Antrim</i>	Aldergrove Airfield ...	3.24	134
<i>"</i>	Keswick, High Hill ...	1.69	34	<i>"</i>	Ballymena, Harryville...	3.83	118
<i>"</i>	Ravenglass, The Grove	1.02	33	<i>L'derry</i>	Garvaghy, Moneydig ...	4.07	130
<i>Mon.</i>	A'gavenny, Plâs Derwen	2.38	68	<i>"</i>	Londonderry, Creggan	3.26	102
<i>Glam.</i>	Ystalyfera, Wern House	3.34	64	<i>Tyrone</i>	Omagh, Edenfel ...	2.92	98

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## THE SNOW OF JANUARY AND FEBRUARY 1955

By R. E. BOOTH

The first two months of 1955 were notable for widespread and heavy snowstorms, the worst in the British Isles since 1947, which in many areas completely dislocated normal activities. The cold weather during January lasted about three weeks, but was separated into two clearly defined spells by a brief mild period about the 10th of the month. Easterly winds prevailed during the first spell and the snowfall during this period was mainly in the southern part of the country, but during the second spell winds were predominantly from a northerly direction and the northern part of the country was the more seriously affected by snow. The end of January and the first few days of February were comparatively mild, but during the second week of February polar air swept south over the country. This was a prelude to a prolonged spell of cold weather and severe snowstorms which lasted almost to the end of the month. These storms were worst in the northern part of the country at first, but during the last week of the month when the wind veered to an easterly point, the heaviest snowfalls were further south.

The closing months of 1954 were unusually mild so that the arrival on New Year's Day of cold weather associated with an easterly air stream which swept over the country from southern Russia was all the more striking. There were a few light snow showers, mainly in eastern coastal regions, for the first day or two, but on the 4th an occlusion associated with a depression in the western approaches moved slowly north-eastwards across our southern districts. Slight snow was reported at Plymouth and St. Eval at midnight; by 0600 snow had reached a line extending from Bristol to Portsmouth with moderate falls in places, and by 1800 it was snowing hard at Birmingham and Mildenhall but had ceased in London. Strong easterly winds, reaching gale force at times, caused considerable drifting especially in Devon and Cornwall where roads were reported to be blocked with drifts from 6 to 12 ft. deep, but in the extreme south of Cornwall the snow turned to rain in the late evening; the rain was heavy locally with occasional thunder. A map of the depth of undrifted snow, compiled from observations taken at 0900 on the 5th, shows that the area with more than 1 in. of snow lying was confined almost entirely to England and Wales south of a line from Mersey across the Peak to the Wash. Most stations recorded 2-4 in. and the largest area with as much as 6 in. was in east Kent. West London also had a fall of 6 in. which was the largest fall since 1947. Although there were further falls of snow during the day, a thaw soon followed and there was little snow remaining on the ground by the 8th.

An influx of polar air with northerly winds on the 10th, brought a sharp fall of temperature and renewed snow showers to Scotland and the north of England, but in the south the change was preceded by widespread rain, which later turned to snow. A vigorous depression, accompanied by gale-force winds, approached our south-western districts from the west during the 13th. Snow began in Cornwall during the morning and by 1800 was falling steadily over most of the southern half of England and Wales, and thereafter continued throughout the night. In the north, and particularly in Scotland, there were frequent and heavy snowstorms; two passenger trains on their way to Wick were snowbound, and in Caithness and Sutherland nearly every road was blocked by drifts several feet deep. The following morning 12 in. of level snow were reported from north Scotland, while snow lay to a depth of 4–8 in. over a wide area in the southern counties and 9–12 in. locally in Somerset and south Wales; nearly all parts of the country had some snow cover.

Another depression crossed southern England during the 16th with widespread snow on its northern side, and there were frequent snowstorms in Scotland in the strong northerly winds after its passage. At Rotherham, Yorkshire, rain turned to snow shortly after midnight and continued with only a break of half an hour for  $17\frac{1}{2}$  hr., while at Southport on the same day  $3\frac{1}{2}$  in. of snow fell in less than an hour. Caithness and Sutherland were the worst affected counties in Scotland, where there had been appreciable snowfalls almost daily since the invasion of the polar air on the 10th. In Sutherland the accumulated depth of undrifted snow increased from 10 to 24 in. at Elphin from the 16th to 18th, while at Glenrossal, the depth increased by 12 in. (to 18 in.) during the same period. Owing to the strong northerly winds nearly every road in the north of Scotland was blocked by drifts many feet deep; some drifts as much as 30 ft. deep were reported. The island of Orkney was paralysed on the 13th by the worst snowstorm for many years, described by some as the “worst in living memory”; every road on the island was blocked by drifts up to 7 ft. deep. Shetland too was in a similar plight; here the drifting was so bad that snow ploughs often proved useless.

A map of snow depths at 0900 on the 17th shows that level snow was lying to a depth of more than 12 in. over practically the whole of Caithness and Sutherland, and to a depth of more than 6 in. in Inverness-shire and northwards, in Northumberland, Durham, the North and West Ridings of Yorkshire, south Lancashire and north Wales.

Conditions in the north of Scotland became so bad that “Operation Snow-drop” was arranged for the relief of snowbound areas. The Admiralty sent five helicopters and a frigate to Wick, where the Royal Air Force had previously set up a centre from which they could call on a special fleet of aircraft based at Kinloss to undertake emergency flights as the occasion arose. In addition, the aircraft carrier *Glory* was anchored in Erriboll Bay, north Sutherland, to refuel the helicopters before they carried out their missions. The operation, the first of its kind, was begun on January 18, and was mainly concerned with dropping food and medical supplies to marooned farmers and villagers, and hay to cattle. The helicopters often landed on the snow at points where distress signals were displayed, so that in many cases personal contact could be made. Doctors were occasionally taken to medical cases, and some patients were flown out of the affected area to hospital. The Kinloss fixed-wing aircraft were used for dropping cattle fodder. In the upper photograph facing p. 137, which shows helicopters



being loaded up with food at Wick during the operation, it will be seen that the engines were kept running for a quick turn-round. The area to which relief was afforded included parts of Ross and Cromarty and Inverness-shire as well as Caithness and Sutherland. So much public interest was aroused by the operation that 153 press reporters visited Wick on the first day.

Mild air from the south-west brought a thaw to most of the country on the 21st, but "Snowdrop" was continued till the 23rd. Most of the ground was clear of snow by the 25th.

Maximum depths of undrifted snow reported during the month included 14 in. at Elphin on the 19th and 20 in. at Glenrossal on the 18th (both in Sutherland); 14 in. at Glackour on the 18th-19th (Ross and Cromarty), 18 in. at Fersit on the 18th and 15 in. at Achnagoichan on the 18th-21st (both in Inverness-shire).

The wintry conditions returned on February 8 and 9 as polar air spread south over the whole country heralding the longest and most severe spell of the season. Temperature fell sharply 5-10°F. and the showers in the northerly air stream turned to snow. Thereafter, winds reaching gale force at times continued to blow from a northerly or north-easterly direction for about 12 days, and the accompanying snowstorms over north and east Scotland and eastern England became more and more frequent and prolonged as the cold weather continued. Minor troughs moved southwards in the air stream, locally increasing the snowfall; a more pronounced trough on the 16th gave a fall of 2 in. at Buxton (making a total depth there of 6 in.) and frequent snow showers in the London area during the afternoon. The following day a polar-air depression, embedded in the stream, moved south accompanied by heavy snowfalls and northerly gales in most northern districts; later in the day the Midlands and East Anglia were also affected.

The experience of Mr. Hay, meteorological assistant at Grimsetter, Orkney, is of interest as it shows the kind of conditions experienced fairly widely in the extreme north of Scotland during this period. During the early hours of the 17th, the northerly gale then blowing became severe and the frequent showers became continuous snow. Power lines at Grimsetter failed, as they did over most of the island, under the weight of snow and wind. Transport to the airfield had become impossible owing to snow drifts quite early, and the relief observer, who attempted to make the journey by foot during the morning had to turn back. Mr. Hay, who had been doing hourly observations all the previous night, had planned to walk to the nearest farmhouse for a meal, but bad weather and the deep snow prevented him from doing so. He began his second night duty by the light of a single paraffin lamp, having had no sleep the night before and with no food. His only link with the outside world was the G.P.O. line which fortunately held, so he was able to send observations till he was relieved at 1100 the following day, after a continuous watch of 40 hr. Unfortunately Mr. Hay had a similar experience at the end of the month when a southerly gale and severe drifting of the snow prevented relief from reaching him at the office for 36 hr. A photograph showing ice and snow on telegraph wires near the meteorological office at Grimsetter is reproduced facing p. 137.

During the 18th and 19th, as the strong northerly winds in Scotland moderated, a complex shallow depression formed over the country with a small centre off north-east Scotland and another over Norfolk. There were heavy

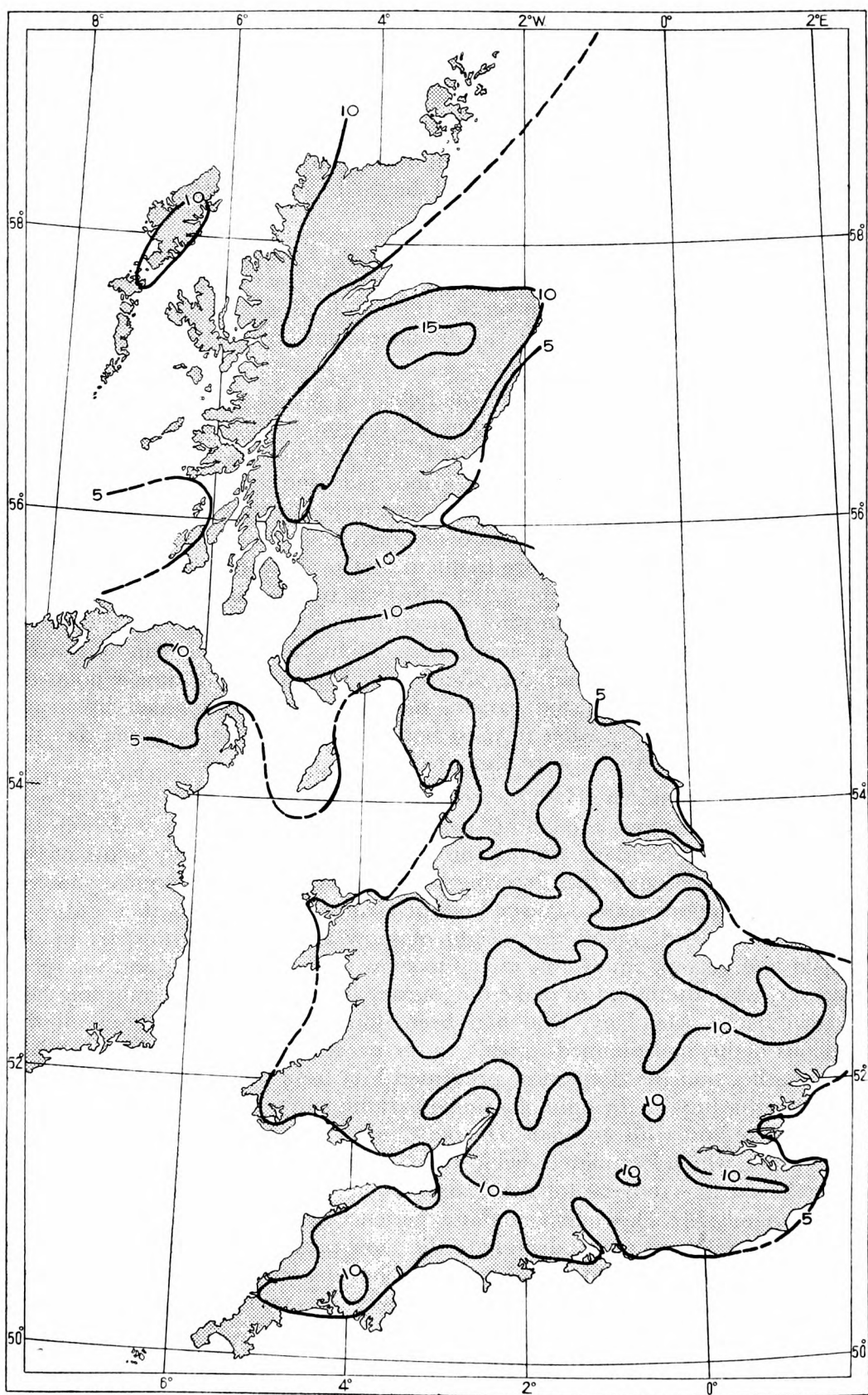


FIG. 1—NUMBER OF DAYS OF SNOW FALLING, JANUARY 1955

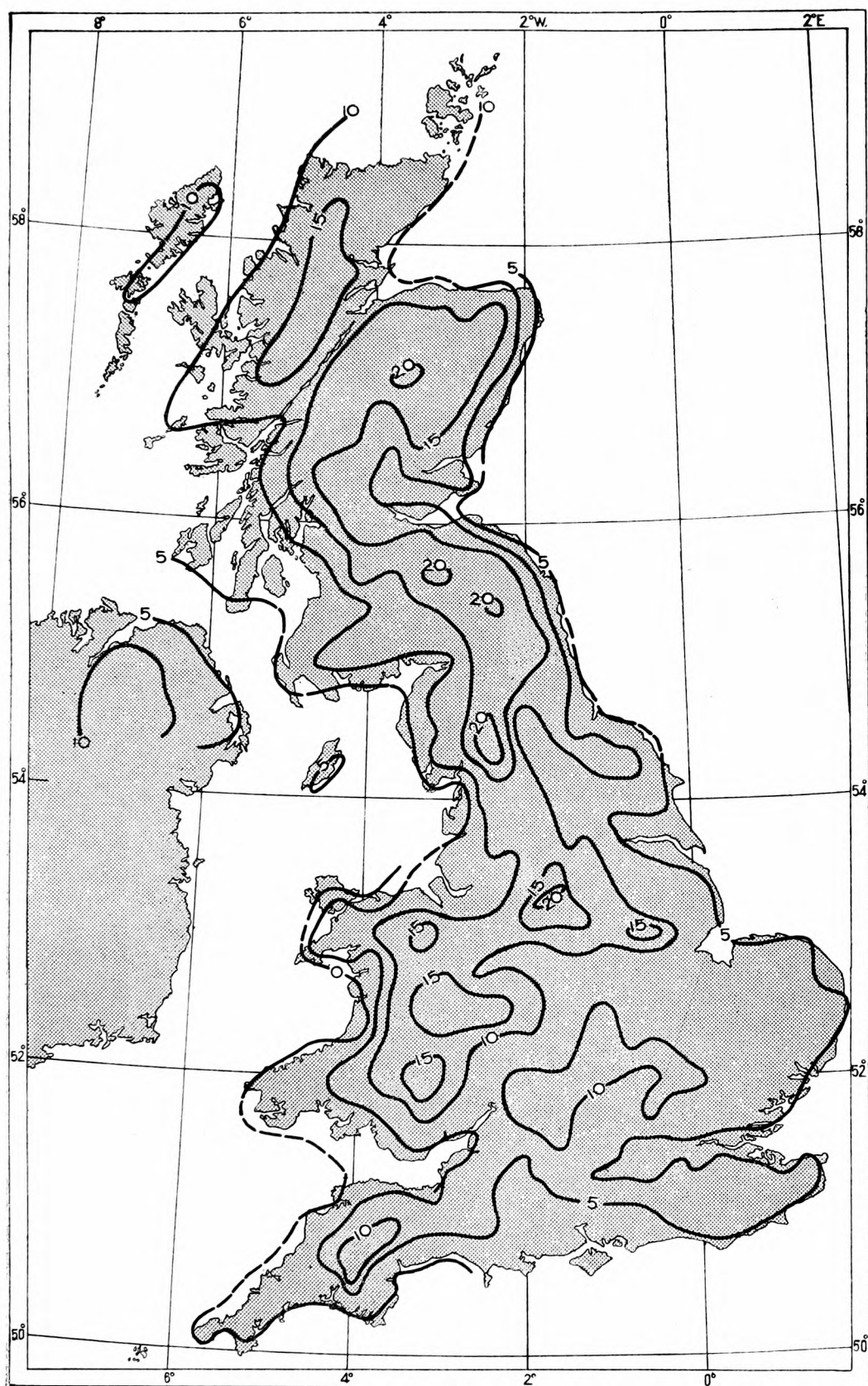


FIG. 2—NUMBER OF DAYS OF SNOW LYING, JANUARY 1955

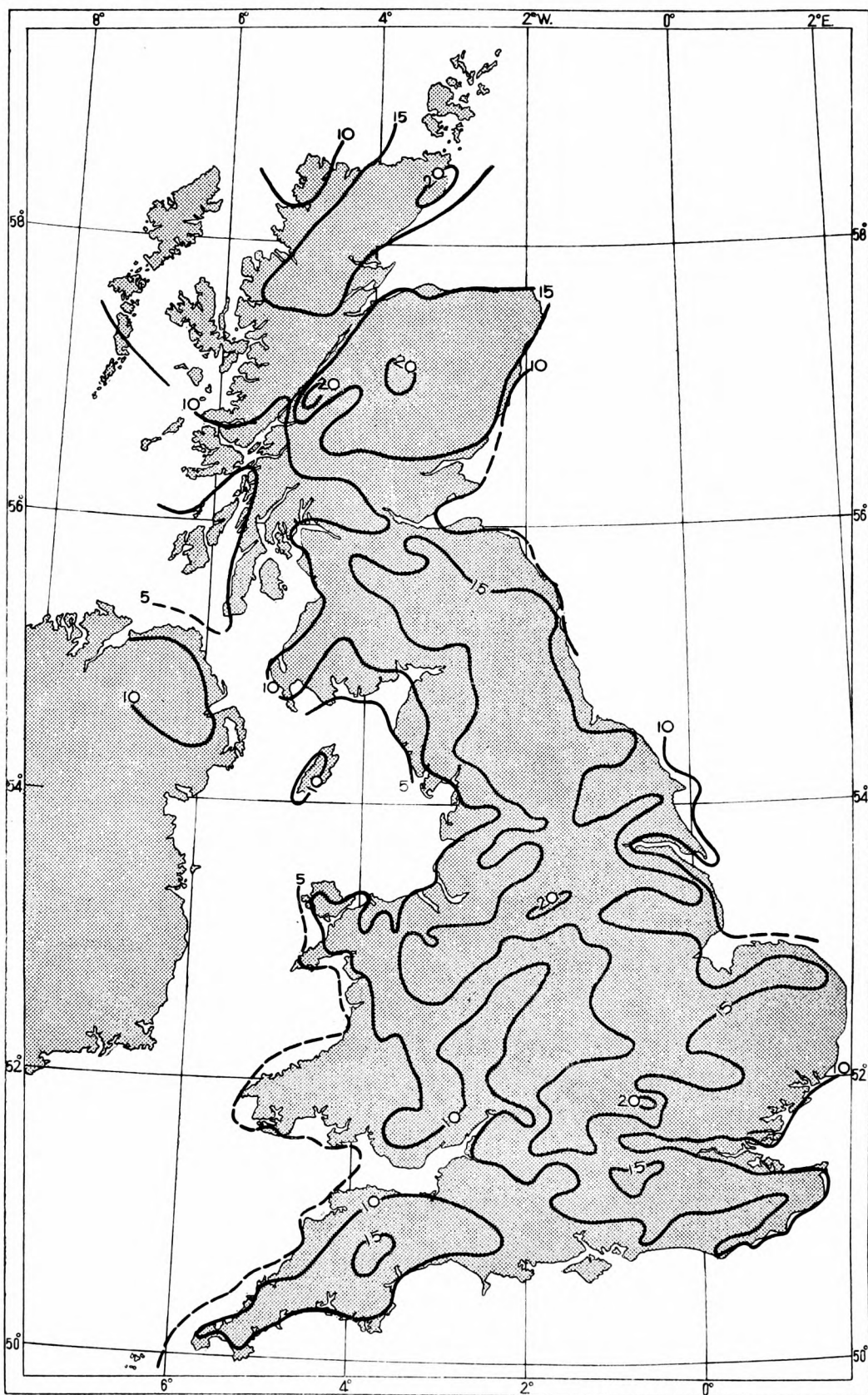


FIG. 3—NUMBER OF DAYS OF SNOW FALLING, FEBRUARY 1955



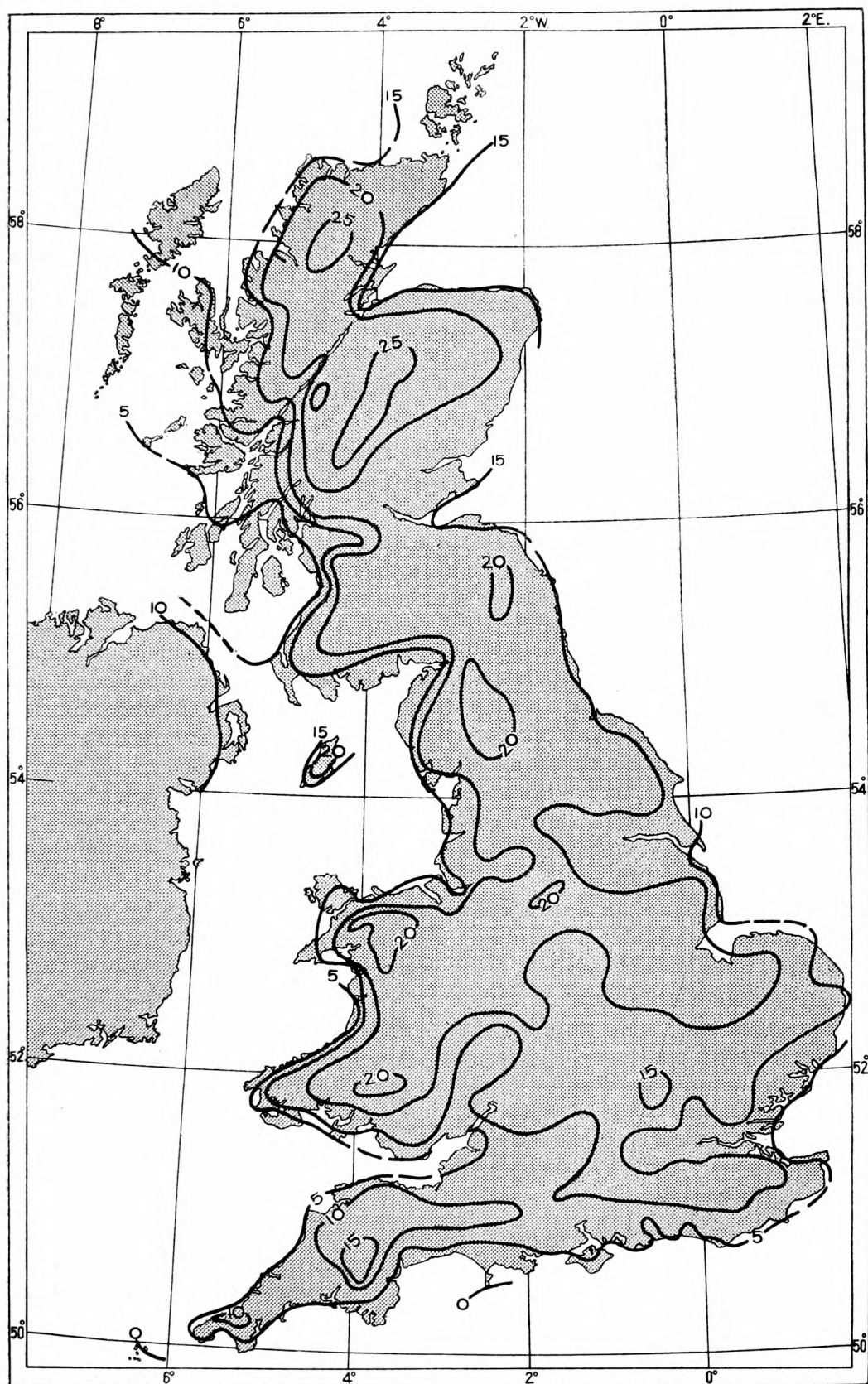


FIG. 4—NUMBER OF DAYS OF SNOW LYING, FEBRUARY 1955

snowstorms over Scotland (described locally as "the most severe of the century"), off the Lancashire coast and in Norfolk; drifts of 5 ft. were reported from Blackpool while Wells-on-Sea was temporarily isolated by drifts. Conditions were so bad in Scotland that the Royal Air Force recommenced "Operation Snowdrop", on similar lines to that flown in January, for the relief of snowbound communities. The operation continued for 11 days until the end of the month, and during this period aircraft from Kinloss flew 182 sorties, dropping 267 lb. of food and 105 tons of cattle fodder; Royal Naval helicopters from Wick flew 25 medical sorties and dropped  $6\frac{1}{2}$  tons of food and hay; 163 sheep were rescued from drifts by helicopter. The photographs taken on February 18, facing p. 152, show the meteorological office enclosure at Wick with a snowplough on the perimeter track, and an amusing picture taken a little further to the left which gives a graphic indication of the depth of the snow near the anemometer mast (the guys of which can be seen in both pictures) on the same day.

The accumulated depth of undrifted snow measured at 0900 on the 20th was 26 in. at Elphin, 18 in. at Glenrossal (both in Sutherland), 24 in. at Glenmore, 22 in. at Braemar (both in Inverness-shire), 24 in. at Glenlivet and 18 in. at Drummuir (both in Banffshire).

Throughout the last week of February winds were mainly easterly with low pressure over the Bay of Biscay and slow-moving fronts lying along the English Channel. Southern England had severe outbreaks of snow during this period, and on the 23rd the west country had violent snowstorms probably the worst since 1947. Snow fell continuously from 0400 to 2000 accompanied by a gale with gusts up to 60 kt. Nearly every road in Cornwall was snowbound and hundreds of motor vehicles had to be abandoned; drifts up to 5 ft. were reported on Bodmin Moor. The two photographs facing p. 153 are of snow drifts at the Filter Works of the North Cornwall Joint Water Board at 890 ft. with drifts 6-7 ft. Throughout the following day snow fell almost continuously in Wales, the Midlands and East Anglia, with prolonged periods of snow in southern England. Reports from Derbyshire told of serious drifting during the night with drifts of 10 ft. near Ashbourne.

From the 20th to the 24th undrifted snow increased in depth by 7-9 in. in Northumberland and Cumberland, 6-8 in. in Nottinghamshire, Durham, Derbyshire and north Wales. In north Wales there were local increases of 18 in. at Bwlch Tunnel and 16 in. at Mount Pleasant (both in Flintshire).

The maximum depth attained by undrifted snow during the month was between 2 and 3 ft. over a wide area. Among the greatest depths reported were: Drummuir (Banffshire) 36 in. on the 21st; Bwlch Tunnel (Flintshire) 30 in. on the 25th-28th; Glenlivet (Banffshire) 28 in. on the 22nd-23rd; Elphin (Sutherland) 26 in. on the 20th-27th; Glenmore (Inverness-shire) 26 in. on the 22nd; Braemar (Inverness-shire) 24 in. on the 22nd; Derry Lodge (Aberdeen-shire) 21 in. on the 24th; Buxton (Derbyshire) 20 in. on the 25th-28th.

Figs. 1 and 2 show the number of days of snow falling and the number of days of snow lying respectively during January, with isopleths drawn for multiples of five days. Snow fell on at least one day everywhere including the Scilly Islands, and on more than 10 days of the month over a considerable part of the country; and lay on the ground more than 20 days in parts of the Grampians, the Pennines and the Peak District (see Fig. 2). Fig. 3 shows that snow fell for 20 days or more during February in the Grampians, the Peak District



*Reproduced by courtesy of J. McDonald, Wick*

**SNOW DRIFT COVERING A CROFT, MID CLYTH, CAITHNESS**



*Reproduced by courtesy of W. C. Glander*

HELICOPTERS BEING LOADED AT WICK WITH FOOD FOR  
“OPERATION SNOWDROP”



*Reproduced by courtesy of J. C. Lennie*

ICE FORMATION ON TELEPHONE WIRES NEAR THE METEOROLOGICAL  
OFFICE AT GRIMSETTER, NEAR KIRKWALL, AFTER THE SNOW OF  
FEBRUARY 17, 1955



and on the Dunstable Downs. The number of days of snow lying during February (Fig. 4) exceeded 25 on much of the higher ground in the north of Scotland, but a few stations such as Scilly and Portland Bill reported no days of snow lying.

The four maps reproduced and those mentioned earlier in the text are each based on several hundred observations.

## COMPARISON OF WIND SPEEDS MEASURED SIMULTANEOUSLY BY A DINES ANEMOGRAPH AND A ROBINSON CUP ANEMOMETER IN FLUCTUATING WINDS

By P. J. RIJKOORT

Royal Netherlands Meteorological Institute

In many papers attention has been paid to the lag of anemometers and to the errors that are caused by the fluctuation of winds in evaluating mean wind speeds from anemograms. The computations of Schrenk<sup>1</sup> on the lag errors of cup anemometers are well known. The over-estimation of the mean wind speed as indicated by cup anemometers in fluctuating winds may be considered as an established fact. The effect of wind fluctuation on the measurements of mean wind speed by anemometers of the pressure type was investigated by Noetzlin<sup>2</sup> and recently by Sanuki<sup>3</sup>. Again, over-estimation of mean wind speed measured by pressure-tube anemometers resulting from wind fluctuation must be accepted.

The question arises: how great is the over-estimation of mean wind speed under natural circumstances? The correct answer to this question cannot be given as it is impossible to obtain an exact value of mean wind speed. We must therefore confine ourselves to an investigation into the differences between the measurements of the two types of anemometers. As far as we know data demonstrating such differences have not yet been published.

**Comparison of both anemometers at De Bilt.**—We have made a comparison between the data from a Dines anemograph (Mk II) and a Robinson cup anemometer (conical cups of 10 cm. diameter, distance from middle of cup to axis 10 cm.) constructed by the Royal Netherlands Meteorological Institute. The anemometers are mounted about 40 m. above level country on the tower of the Royal Netherlands Meteorological Institute at De Bilt. The station is situated near the Utrecht-Amersfoort road and is surrounded by meadows and orchards; on the west side there are a few acres of wood (trees of 20-25 m.).

The comparison was carried out as follows:—

From the anemograms of the Dines anemograph estimates were made of the mean wind speed  $U_D$  together with the mean amplitude  $a$  for each clock hour. The determination of the wind fluctuations by means of eye reading of the mean amplitude is rather rough and has the disadvantage of being subjective, but no objective method was available. From the obtained amplitudes the “relative” fluctuation  $b(=a/U_D)$  was computed, and in this way an expression almost independent of the mean wind speed was obtained\*.

Each clock hour furnishes three data:  $U_D$  the mean wind speed from the Dines anemograph,  $b$  the mean “relative” fluctuations from the Dines anemograph,

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\* Relative fluctuation replaces the usual<sup>4</sup> mean fluctuation factor  $(U_{max} - U_{min})/U$ .

and  $c$  the number of contacts made by the Robinson cup anemometer. The material to be discussed consists of 1,274 hourly values obtained during the period February 23–May 1, 1953. Only observations from periods in which both instruments were exposed freely to the wind were used.

Regression lines were computed of the form  $U_D = a b + \beta$  indicating the relation between  $U_D$  and  $b$  for groups of  $c$  with mid-point values 3, 8, 13 . . . 58 and 68 contacts (representing the groups with 0–5, 6–10, 11–15, etc. contacts), and corresponding to wind-tunnel calibrations of 1.4, 2.3, 3.2, 4.2, 5.1, 6.1 . . . 12.2 and 14.3 m./sec.

The results are presented in Fig. 1. From this figure it is clear that there is a regular increase in the value of  $a$  with increasing  $c$ . It is obvious that there are not only differences in the measurements made by the Dines and Robinson anemographs, but that these differences change in a systematic manner. For mean wind speeds over 5 m./sec.  $U_D$  increases when  $b$  decreases; the opposite seems to hold for wind speeds under 5 m./sec. With higher wind speeds the over-estimation of the pressure-tube anemograph is greater than that of the Robinson cup anemometer; for lower wind speeds the fluctuations seem to have a greater influence on the cup anemometer. The latter effect is rather small however, and the question arises whether it is significant.

It is therefore clear that there is a fluctuation effect. It is possible, however, that this effect is partly caused by errors in the estimation by eye of the mean wind speed from the anemograms. The recording of wind structure on the diagram is rather compact. It may be that a great many low maxima are difficult to distinguish, so that the difference between lower and higher maxima is greater than that between lower and higher minima. If this is so the estimation by eye of the mean wind speed can easily be too high. The following experiment was performed in order to investigate this possibility.

During four different hours half-minute momentary readings were made of the height of the pen of the Dines anemograph. The mean of these readings was taken as the “true” mean of the Dines anemogram. Independently, estimations by eye of the mean wind speed for the same periods were made by six assistants of the Royal Netherlands Meteorological Institute. The results are given in Table I.

TABLE I—ESTIMATES OF THE MEAN WIND SPEED

Date	Mean wind speed $U$	Estimates by assistant						Fluctuation $b$
		A	B	C	D	E	F	
1954		<i>metres per second</i>						
January 15 ...	9.8	9.8	9.9	9.9	10.4	9.9	10.2	1.2
January 21 ...	3.3	3.2	3.2	3.2	3.2	3.2	3.4	0.6
January 25 ...	7.3	7.6	7.5	7.3	7.4	7.5	7.6	0.6
February 8 ...	4.7	4.6	4.5	4.7	4.5	4.7	4.9	0.2

There is indeed some indication of a subjective error. Of course it is not possible to conclude from this small amount of material how great the subjective error really is; much more material would be needed.

**Conclusion.**—The wind speed obtained from anemograms of the Dines anemograph is highly influenced by the relative fluctuation. Especially for wind speeds above 5 m./sec. and fluctuations  $b > 0.5$ , over-estimation of the mean wind speed is considerable and amounts to as much as 10 per cent. as

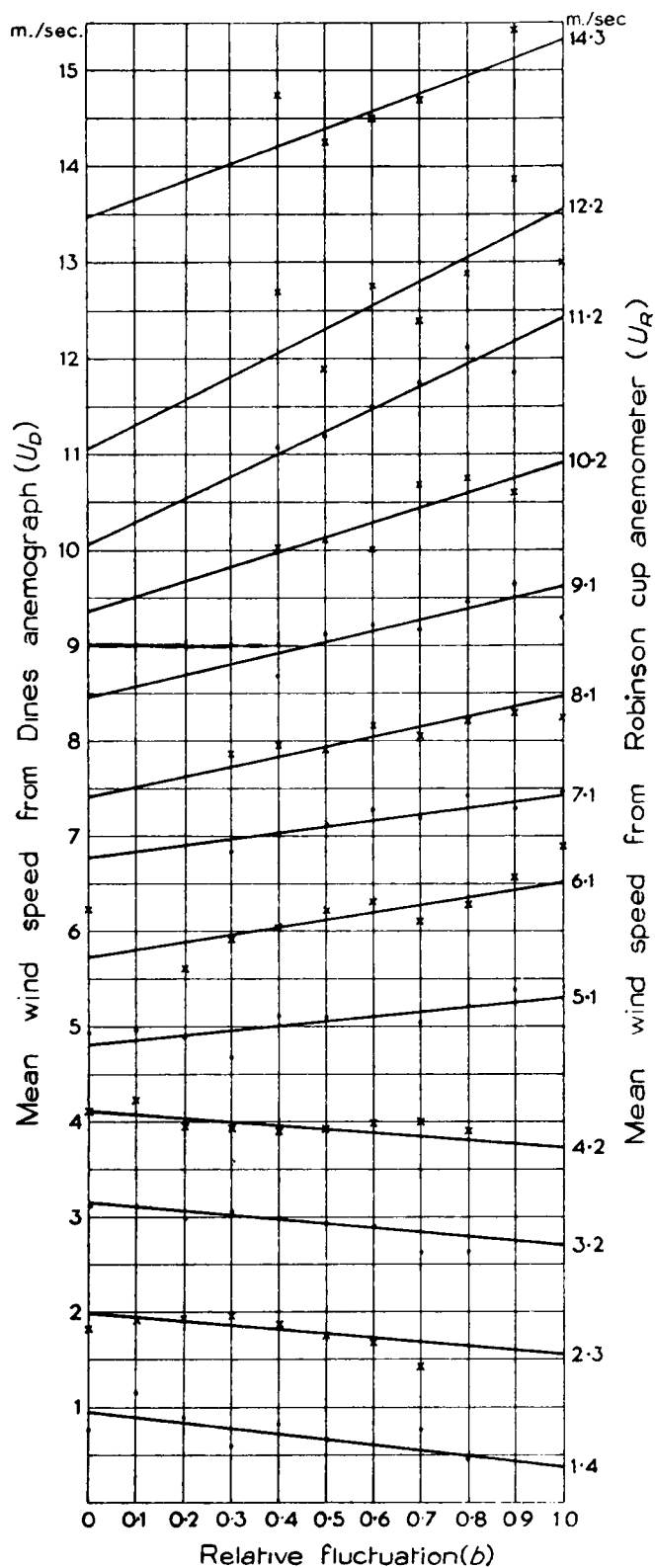


FIG. 1—REGRESSION LINES COMPUTED FOR EACH GROUP OF MEAN WIND SPEEDS, THE MID-POINT SPEED OF EACH GROUP AS MEASURED BY THE ROBINSON CUP ANEMOMETER BEING GIVEN ON THE RIGHT-HAND SIDE

compared with those indicated by a Robinson anemometer. This over-estimation is partly caused by the lag of the instrument and partly by subjective errors made when evaluating the anemograms.

Pressure-tube anemographs and Robinson cup anemometers are therefore not equivalent instruments.

The result of our comparison is another indication that the organization of a uniform network of anemometer stations is very necessary. Pressure-tube anemographs should not be used for this purpose<sup>4</sup>.

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### AVERAGE VECTOR WIND DISTRIBUTION OF THE UPPER AIR IN TEMPERATE AND TROPICAL LATITUDES

By A. F. JENKINSON, B.A.

**Summary.**—Charts have been drawn showing, for the months of January, April, July and October and for the area between the latitudes of 60°N. and 50°S., the stream-lines and isotachs of the average vector wind flow at the levels of 500, 300, 200 and 100 mb. They are based on the "surface" geostrophic vector wind with the addition of thermal vector winds in a succession of layers constructed from upper air temperature charts recently prepared in the Meteorological Office. A grid of 234 points was used, supplemented and checked by upper air wind data.

**Data.**—The basic data used were the preliminary charts, prepared in the Upper Air Climatology Branch of the Meteorological Office, of upper air temperatures over the world at the levels of 700, 500, 300, 200, 150 and 100 mb. for the months of January, April, July and October, with isotherms drawn at intervals of 2°C.

**Theory.**—The thermal wind between two pressure levels, that is the vector difference between the geostrophic winds at the upper and lower levels, is in the direction of the isotherms of the mean temperature ( $T$  plotted against  $\log p$ ) between the two levels and, for a given pair of pressure levels, proportional to the rate of increase of mean temperature at right angles to the isotherms.

In vectorial terms, the vector thermal wind  $\mathbf{V}(p_1, p_2)$  between pressure levels  $p_1$  and  $p_2$  is given by

$$\mathbf{V}(p_1, p_2) = k_{(1, 2)} \mathbf{n} \times \text{grad } T_{(1, 2)} \quad \dots \dots \dots (1)$$

where  $T$  is the absolute temperature at pressure  $p$ ,  $\text{grad } T_{(1, 2)}$  is the vector gradient of  $T_{(1, 2)}$  measured positively towards higher temperature,  $\mathbf{n}$  is the unit vertical vector,  $\times$  denotes vector multiplication,

$$T_{(1, 2)} = \int_{p_1}^{p_2} \frac{T dp}{p},$$

and the constant

$$k_{(1, 2)} = \frac{R}{gl} \log_e \left( \frac{p_1}{p_2} \right),$$

where  $l$  is the Coriolis constant for the latitude and  $R$  and  $g$  have their usual meanings.

If the average monthly temperature at various pressure levels  $p$  is plotted against  $\log p$  the curve is essentially two straight lines, one for the troposphere and one for the stratosphere, with a discontinuity of lapse rate at the tropopause.

The layers chosen for the computation of thermal vector winds were 1000–500, 500–300, 300–200, 200–150, 150–100 mb. Apart from the layer including the tropopause the average curve of  $T$  plotted against  $\log p$  differs most from a straight line in the layer 1000–500 mb.; but even in this layer the mean temperature  $T(1000, 500)$  is very nearly  $T(707)$ , the temperature at 707 mb. ( $\log 707 = \frac{1}{2}[\log 1000 + \log 500]$ ). At neighbouring places the way in which the average-temperature curve differs from a straight line is nearly identical, and the rate of change from place to place of the difference between  $T(1000, 500)$  and  $T(707)$  is of a much smaller order than the rate of change of  $T(707)$ , which is very nearly the rate of change of  $T(700)$ .

Hence, very approximately,

$$\mathbf{V}(1000, 500) = k(1000, 500) \mathbf{n} \times \text{grad } T(700) \quad \dots \dots (2)$$

That is, the thermal wind of the layer 1000–500 mb. is in the direction of the 700-mb. isotherms with magnitude proportional to the gradient of temperature between the isotherms.

For the other layers above 500 mb. not including the tropopause, the mean temperature between any two levels is nearly half the sum of the temperatures at the two levels; and the gradient of the field of mean temperature is very approximately equal to half the vector sum of the gradients of the temperature fields of the two levels.

For the layer including the tropopause, the curve of  $T$  plotted against  $\log p$  is two straight lines. Curves for neighbouring places are similar and the rate of change from place to place of the difference between  $T(1,2)$  and  $\frac{1}{2}[T(p_1) + T(p_2)]$  is very much less than the rate of change of  $\frac{1}{2}[T(p_1) + T(p_2)]$ . Hence, also for the layer including the tropopause, the gradient of the field of mean temperature is very approximately equal to half the vector sum of the gradients of the temperature fields of the two levels.

Thus the thermal wind of the layer 500–300 mb. is equal to half the sum of two vectors which are respectively directed along the isotherms of the 500-mb. and 300-mb. temperature fields and with magnitudes proportional to the gradients of temperature at those levels; and similarly for other layers.

In the notation of equation (2),

$$\left. \begin{aligned} \mathbf{V}(500, 300) &= \frac{1}{2} k(500, 300) \{ \mathbf{n} \times \text{grad } T(500) + \mathbf{n} \times \text{grad } T(300) \} \\ \dots\dots\dots \\ \mathbf{V}(150, 100) &= \frac{1}{2} k(150, 100) \{ \mathbf{n} \times \text{grad } T(150) + \mathbf{n} \times \text{grad } T(100) \} \end{aligned} \right\} \dots (3)$$

**Method.**—A fixed grid of 234 points was chosen being at the intersection of longitudes 160°W., 140°W., 120°W., ..... 180°E. with latitudes 50°S., 40°S., 35°S., 30°S., 25°S., 20°S., 20°N., 25°N., 30°N., 35°N., 40°N., 50°N., 60°N.

For each of the months January, April, July and October, at each grid point, measurements were made of the vector quantities, for the levels of 700, 500,

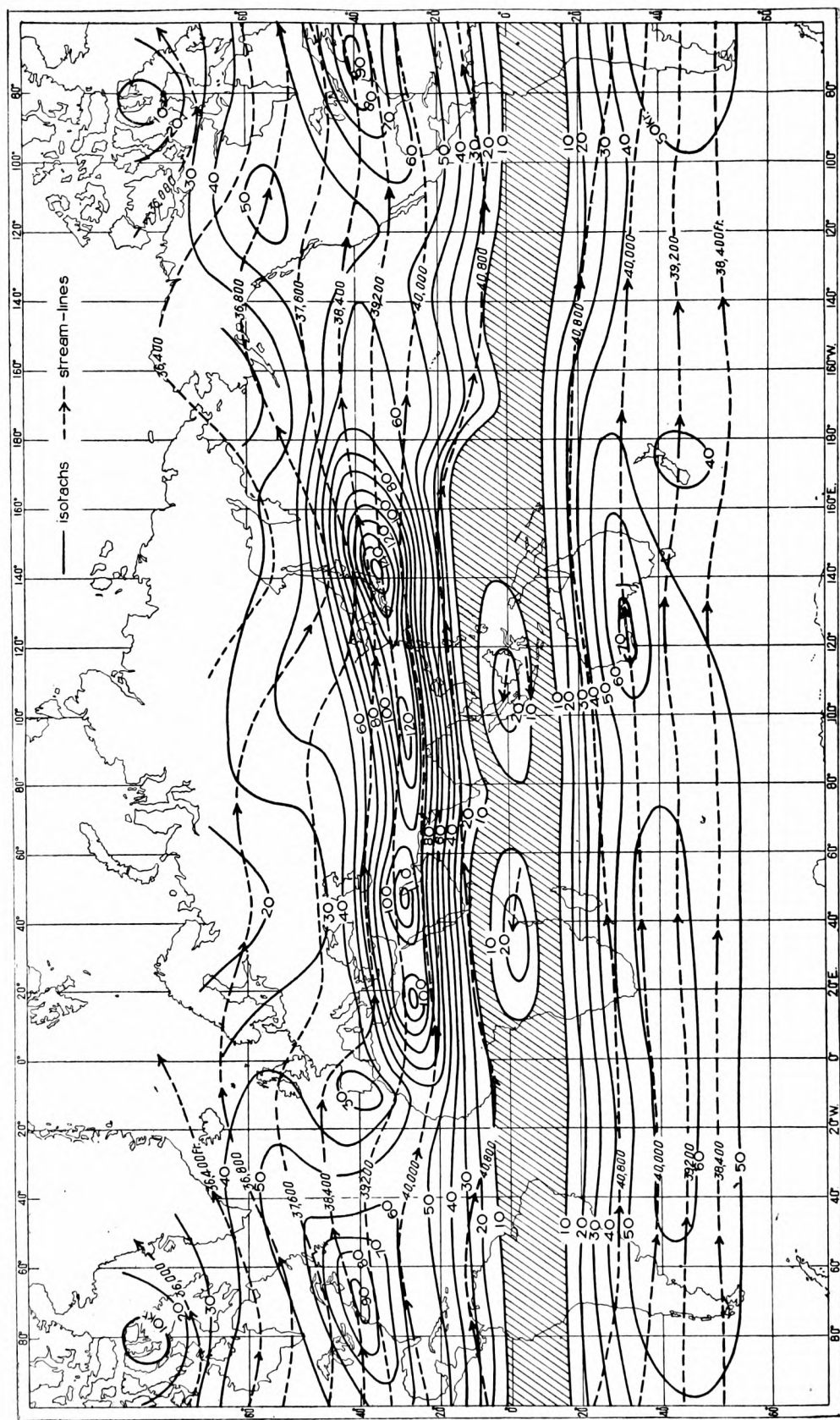


FIG. 1.—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION  
AT 200 MB. IN JANUARY

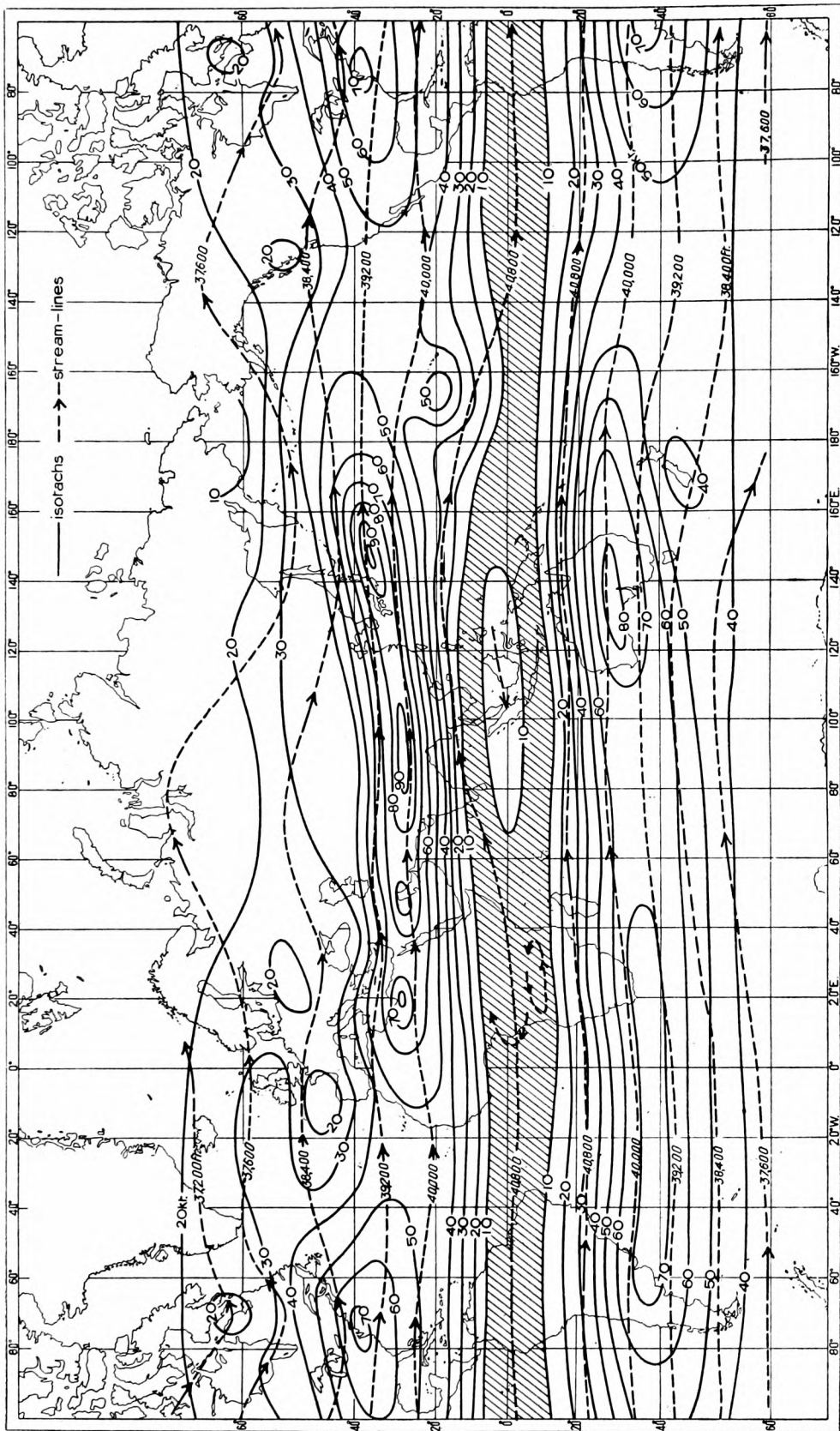
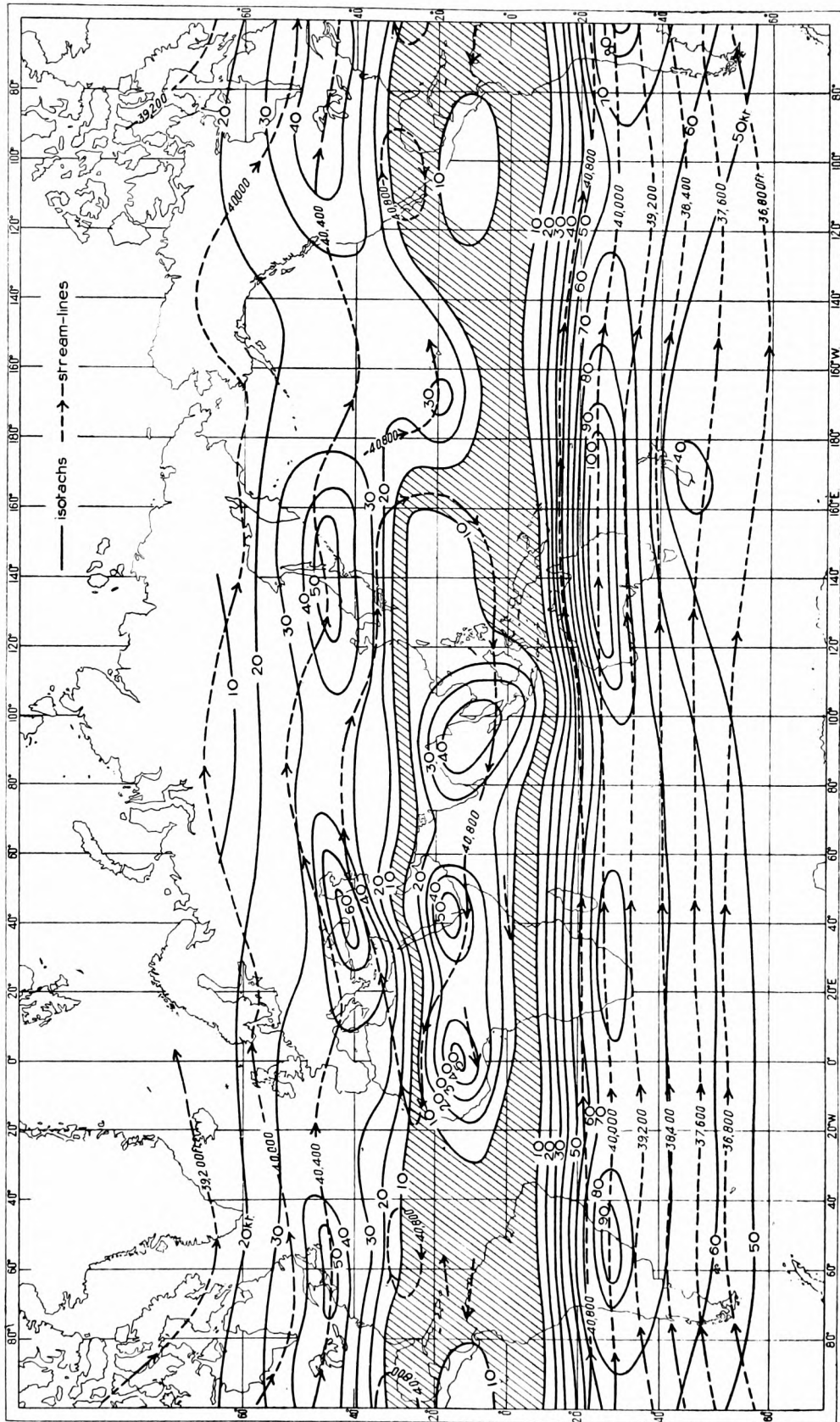
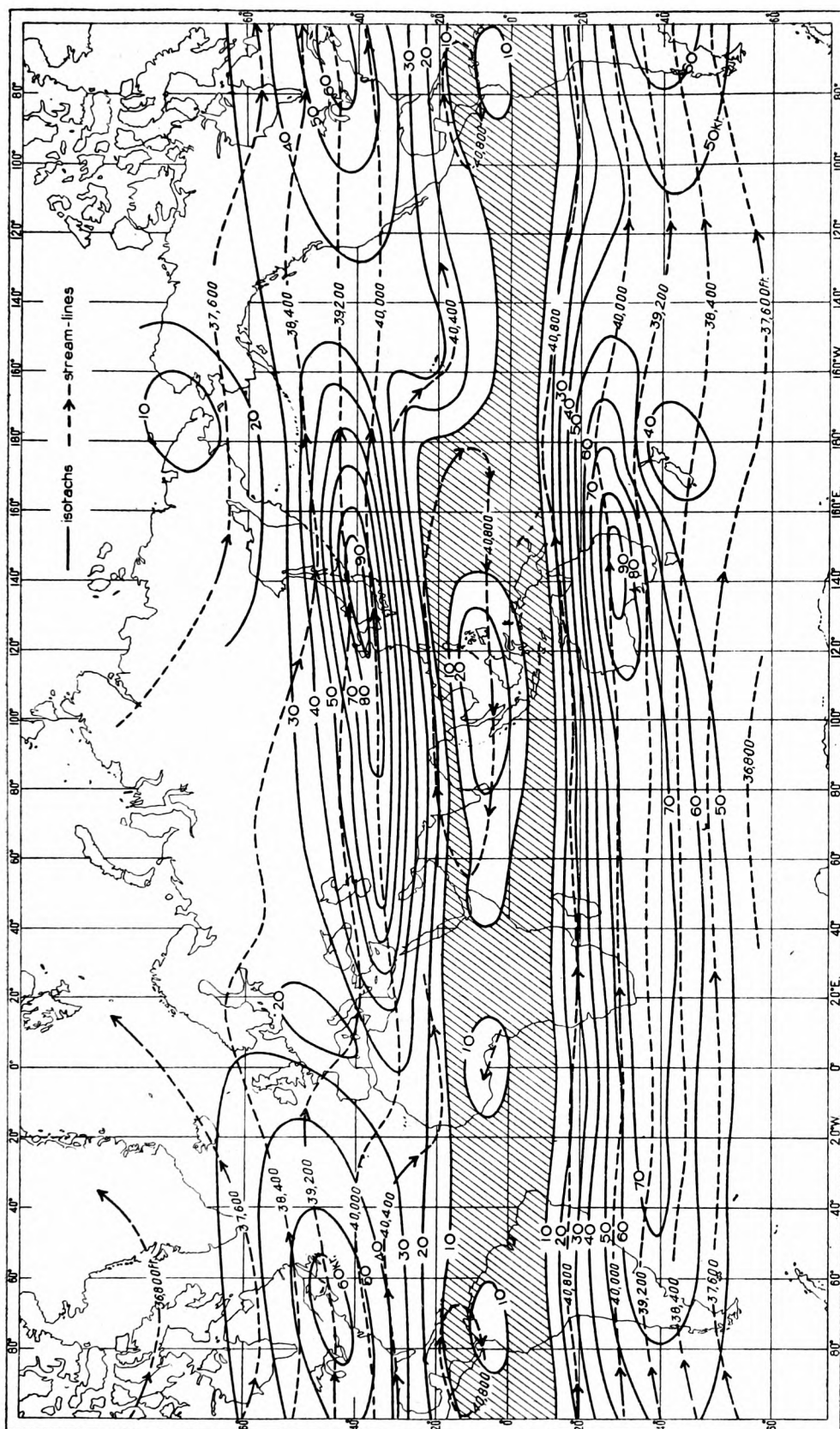


FIG. 2—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION  
AT 200 MB. IN APRIL









300, 200, 150 and 100 mb., whose directions were along the isotherms and of magnitudes equal to the gradients of the temperature field. From these, substituting the appropriate values of the constants  $k$ , the thermal winds were obtained for the layers 1000–500, 500–300, 300–200, 200–100 mb., with speeds measured to the nearest knot and directions to the nearest five degrees.

The “surface” geostrophic vector wind at each of the 234 grid points was measured from mean-sea-level pressure charts, with isobars drawn at 4-mb. intervals, prepared in the World Climatology Branch of the Meteorological Office. Over the oceans a check was obtained from the charts of average winds for five-degree squares prepared in the Marine Branch of the Meteorological Office<sup>1-4</sup>, and for some doubtful points over the continents from available manuscript data in the Meteorological Office.

The vector winds at 500, 300, 200 and 100 mb. were obtained by successive vector addition of the “surface” and thermal vector winds. The vectors were plotted on 16 Mercator charts.

Geostrophic winds were not measured in the areas between 20°N. and 20°S. To help in drawing the charts wind data were worked up for a number of stations, chiefly for 3-yr. periods between 1949 and 1952; with the help of these data and other available data it was considered that the charts could be drawn up even in the tropical regions with considerable accuracy. Lists are given in the Appendix of data worked up, data recently published or made available, and also of older material examined.

Isotachs of the average vector wind speed in knots (full lines) and stream-lines (pecked lines with direction arrows) were drawn. Most of the stream-lines were drawn as isopleths of approximate contour height in hundreds of geopotential feet. The contour heights have been entered for the benefit of possible users, but it should be understood that they are not complete in themselves. Areas in the tropics with vector resultant wind speed less than 10 kt. were shown by hatching.

Of the 16 charts which were drawn, those for the level of 200 mb. for the months of January, April, July and October are reproduced as Figs. 1–4. A limited number of charts for all levels, approximately 28 in. × 17 in., are available for purchase on application to the Director, Meteorological Office, World Climatology Branch, Headstone Drive, Harrow, Middlesex.

## Appendix

### Vector mean winds for 3-yr. period

Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.
Athens	5, 6	Albrook		Lagos	...	Caribou*	9, 10	Gibraltar	27
Hanover	7	Field	6	Bismarck	9, 10	Oklahoma*	9, 10	Benina	27
Cairo	8	Marshall		Columbia*	9, 10	St. Cloud*	9, 10	Malta	27
San Juan	9, 10	Island	6	Greensboro*	9, 10	Big Spring*	9, 10	Nicosia	27
Canton		Guam	6	Little Rock*	9, 10	Brownsville*	9, 10	Nairobi	27
Island	6	Manila	6	Oakland*	9, 10	Charleston*	9, 10	Habbaniya	27
Honolulu	6	Wake		San Antonio*	9, 10	Miami*	9, 10	Bahrain	27
Midway		Island	6	Tatoosh*	9, 10	New Orleans*	9, 10	Aden	27
Island	6	Rome	6						

\* July only.

Japanese stations<sup>11</sup>, chiefly Wakkani, Tateno and Shionomisaki were worked up for 1950–51.

### Vector mean winds recently published or made available

Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.
Larkhill	12	Singapore	13	Auckland	15	Poona	16
Lerwick	12	Hongkong	14	Nandi	15	(July 1949-50)	
						Falkland Islands	27
						Aldergrove	27

### Older material examined

Station	Ref. No.	Station	Ref. No.	Miscellaneous data	Ref. No.
Lindenberg	17	Ghanzi	21	Observations from the German expedition "Meteor"	22
Batavia	18	Cuyaba	22	Cirrus cloud observations	23
Mauritius	19	Curityba	22	Pilot-balloon data for India	24, 25
Apia	20	Santiago	22	Vector winds computed from medium and cirrus cloud observations for the United States and the Caribbean	26

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## METEOROLOGICAL OFFICE DISCUSSION

### Prebaratics—their preparation and interpretation

The discussion on February 21, 1955, was opened by Mr. P. F. Illsley who largely confined himself to the methods employed at the Central Forecasting Office at Dunstable in producing "prebaratics" (forecast surface charts) for 24 hr. ahead covering the area from about 30°N. to 70°N. and 55°W. to 35°E. The main uses of these prebaratics are to give guidance to outstations, to assist in the preparation of forecasts issued from Dunstable, especially those for the B.B.C. and Press, and to meet international commitments. In his opening statement, of which a summary follows, Mr. Illsley referred to notable contributions to the literature on prebaratics by Sutcliffe<sup>1</sup> and Douglas.

Many aids and devices, e.g. isallobaric charts, hodographs, cross-section diagrams, frontal contour charts and isentropic analysis, have been developed to assist in the analysis of current charts and in the preparation of forecast charts but only a limited number of tools can be usefully employed in one office. At Dunstable these are surface charts, 1000–500-mb. thickness charts, 500-mb. contour charts and, to a less extent, those for 700 and 300 mb., and individual tephigrams and wind ascents. Lack of information from vital areas of the Atlantic sometimes makes a reliable analysis impossible, and even with adequate information frontal analysis presents difficulties. Fronts drawn are mainly those which are associated with an appreciable gradient in the 1000–500-mb. thickness field and those which, without having any obvious effect on the thermal field, nevertheless have a well marked surface discontinuity or well defined area of precipitation associated with them.

In producing prebaratics the main principles used at Dunstable are extrapolation, the use of synoptic models and analogues, and dynamical methods based on thickness and contour charts.

Extrapolation may be used on well marked features on both surface and upper charts to give first approximations to the future positions and intensities of anticyclones, depressions, ridges, troughs, etc. A slide was shown giving the tracks followed by the major surface features during the period November 8–17, 1954. This clearly illustrated that extrapolation for a few hours ahead would have given reasonably accurate positions for the centres of the anticyclones and depressions on most occasions, but for 24 hr. ahead extrapolation would have often resulted in large errors.

The tendency of the atmosphere to behave in a particular manner in recognizable circumstances enables systems to be introduced in certain areas, or to be developed in certain ways when the required conditions are realized or expected. The best known and probably the most important "model" in our region of the globe is the development of a frontal wave into a warm-sector depression which deepens and eventually occludes when it stops deepening, slows down and turns to the left. Much help in deciding whether a particular depression will follow this sequence can be obtained from considerations of the thickness field. A model peculiar to a particular area is the cyclogenesis in the Gulf of Lions when cold air penetrates into the western Mediterranean from France, and another is the breaking away of depressions from southern Greenland. In recent years study of the upper air has resulted in the formulation of additional models as, for example, a "block" which can roughly be defined as an area where there is a marked drop in the mean westerly flow throughout the troposphere. The

prolonged blocking situation in January 1955 was illustrated by slides. The use of analogues is an extension of the use of models to a whole situation rather than a single feature. No situation is ever repeated in all details so that a complete analogue is not to be expected. However, knowledge of happenings in similar situations is valuable, and experience, so important in forecasting, is largely a matter of mental analoguing. Extremes of various kinds should be borne in mind and, to forecast an extreme, abnormal developments must be expected. A knowledge of singularities, such as those found by Lamb<sup>2</sup>, is useful background knowledge since it gives some indication of the preferred circulations at any season.

The use of thickness charts in forecasting largely stems from Sutcliffe's theory of development. This theory, with various assumptions, links development with the surface isobars and thickness distribution in the formulae

$$\text{for cyclogenesis} \quad V' \frac{\partial}{\partial s} (l + 2 \zeta_0 + \zeta') < 0$$

$$\text{for anticyclogenesis} \quad V' \frac{\partial}{\partial s} (l + 2 \zeta_0 + \zeta') > 0$$

where  $V'$  is the thermal wind,  $\partial/\partial s$  denotes change in the direction of the thermal wind,  $l$  is the Coriolis parameter  $2\omega \sin \phi$ ,  $\zeta_0$  is the vorticity of the surface wind, and  $\zeta'$  is the vorticity of the thermal wind. The 1000–500-mb. thermal wind field is usually used in applying the formula.

Complete evaluation of the thermal development over the whole of a chart is laborious, and in practice application of the Sutcliffe theory is restricted to a qualitative assessment of the development where vorticity changes in the thickness pattern are large, as near troughs and ridges, and where there is marked diffuence or confluence. The developments associated with these configurations have been discussed in various papers, the most exhaustive being that by Sutcliffe and Forsdyke<sup>3</sup>.

Another dynamical approach, that of Rossby, is also made use of in the preparation of prebarotics. Rossby, postulating a barotropic atmosphere with no vertical motion, produced a formula for the movement of a train of small-amplitude waves as follows

$$C = U - \beta \frac{L^2}{4\pi^2},$$

where  $C$  is the speed of movement of the wave train towards the east,  $U$  is the mean westerly wind speed,  $L$  is the wave-length, and  $\beta$  is the latitudinal variation of the Coriolis parameter.

Checks at Dunstable have shown that, when applied to the large-amplitude waves of roughly sinusoidal form which appear in the 500-mb. flow pattern, the formula works in a qualitative sense, but much experience and care are needed in its application. Rossby's theory requires conservation of the absolute vorticity of the flow, and even if there is not a complete wave train some idea of the future pattern can be gained assuming constant-vorticity trajectories of the air from a region with a pronounced flow.

The movement of a front is largely controlled by the winds across it in the lower levels. Experience shows that cold fronts move roughly with the speed of the geostrophic wind at right angles to them though the development of a ridge

behind a cold front may cause it to move more quickly. Warm fronts on the average move at some two thirds of the speed of the geostrophic wind at right angles to them but the ratio varies considerably. A warm front which shows little kink in the isobars will move at a speed near that of the geostrophic wind across it, while a large wind shift, a strong gradient ahead of the front and fast movement of the front all tend to produce a reduction in its speed below the geostrophic value. In extreme cases a warm front may be held stationary or its motion actually reversed while it still retains the characteristics of a warm front. The problem of occlusion largely resolves itself into forecasting the movements of the warm and cold fronts independently, and occluding the warm front to the point where the fronts cross. Fronts may be dropped on the prebaratic when frontolytic processes, especially subsidence, are expected. New ones are sometimes introduced usually in areas where substantial thermal gradients are expected to develop.

A prebaratic is most conveniently drawn on a light table with the prebaratic chart on top of the latest surface chart on which have been put the corresponding thickness lines. Before beginning the actual drawing a general study should be made of the broad-scale developments, including an assessment of the probable movements of any troughs and ridges in the 500-mb. pattern. The tracks of surface systems and upper air features should also be studied. The positions and intensities of the main surface-pressure centres, troughs and ridges are then put on the prebaratic chart using extrapolation, models and an application of development ideas. Fronts are sketched on roughly by extrapolation making allowance for expected changes in speed. A sketch of the isobars will then give a rough picture. Checks of the gradients will usually make adjustments necessary to some of the frontal positions to ensure consistency with the mean wind throughout the period. Thickness lines should then be estimated for the prebaratic time and the chart scrutinized to ensure consistency between surface and thickness features. A gridding of the surface and thickness fields to confirm that the 500-mb. pattern is in line with expectations is also advisable.

Slides were then shown illustrating developments during the period November 11-14, 1954; and the prebaratics prepared during this period, during which there was a rapid change from an unsettled westerly type of weather to an anticyclonic type over the British Isles, were discussed. It was noted that the change of type on November 13 fitted to the exact day the table of singularities given by Lamb<sup>2</sup>.

Prebaratics have obvious advantages and drawbacks. Their production ensures that the forecaster gives thought to the various processes involved and tries to form the best balance. They force the forecaster to produce a definite solution, but herein lies one of the main drawbacks in that the prebaratic may be taken too literally and conclusions drawn which are not justified. A prebaratic should always be studied in conjunction with the corresponding "General synoptic review" in which possible alternative developments may be suggested. Even if normal confidence is indicated, the probable errors of prebaratics must be borne in mind. In the vicinity of the British Isles, the average error in the positions of pressure centres on 24-hr. prebaratics is some 240 miles and of fronts about 115 miles. This indicates a probable error of several hours in the timing of the passage of a front 24 hr. ahead, and the phraseology of forecasts for the latter part of a 24-hr. period should try to reflect this uncertainty. Forecasts of thicknesses and of 500-mb. contours should be

studied in conjunction with the prebaratics. The forecast thicknesses will give some idea of the stability of the various air masses compared with their stability on the current charts. The statistical investigations by Murray<sup>4</sup> and Lamb<sup>5</sup> into the relationship of precipitation forms with thickness should be kept in mind during the winter months. In assessing the activity of fronts on a prebaratic it should be remembered that increased troughing at a front often leads to increased rainfall while the occlusion process frequently leads to greater rainfall near the point of occlusion. Winds increasing markedly with height over a warm sector are likely to spread rain well ahead of the warm front and reduce the activity of the cold front. Increased rainfall is likely near a wave or anywhere else where near-saturated air is subjected to convergence by falling pressure. Rising pressure and increasing anticyclonic curvature of the isobars will normally result in decreasing precipitation and thinning cloud. Modifications of the air masses due to cooling or heating by the underlying surface, by orographic or frontal uplift, or by subsidence should also be considered. Other factors to be borne in mind when interpreting a prebaratic are the season of the year, diurnal changes, and local effects such as sea-breezes and katabatic winds.

*Mr. F. H. Bushby* then presented the results of a computation of a 24-hr. prebaratic for 0300 on November 14, 1954, made with the aid of an electronic computer using the method described by Bushby and Hinds<sup>6</sup>. This was compared with the prebaratic for 0600 on the same day produced by orthodox methods and was clearly an improvement. Mr. Bushby pointed out that in producing the computed prebaratic the observed changes on the boundary had been used, and this point led to some discussion.

*Mr. E. Gold* commented on Mr. Illsley's clear and impartial exposition in which the shortcomings of present-day forecasting had been openly recognized. One of the older and well known forecasting "rules" which Mr. Illsley had omitted to mention is the tendency for mutual rotation of the centres of a dumb-bell-shaped depression. Mr. Gold also asked whether the term "blocking situation" was merely another name for a warm anticyclone. In reply Mr. Illsley said that the rotation of one depression round another is a special case of the more general rule that surface pressure features tend to move in the direction of the strongest flow in their circulations at low levels. A warm anticyclone certainly forms an important part of a "block", but some writers, at least, insist on a depression at a lower latitude to complete the block and the upper levels must also show marked diminution of the zonal flow.

*Mr. H. T. D. Holgate* pointed out that, on occasions, errors of several hundred miles occurred in the prebaratic positions of depression centres over the Atlantic. Such errors could have serious effects on transatlantic flights. Many differences between Dunstable and Prestwick forecasts could be traced to differences in the initial analysis caused mainly by insufficient data from the Atlantic. He asked if anything could be done to check doubtful ship reports. Mr. Illsley stated that no statistics are available on errors in prebaratics except for the vicinity of the British Isles. It is quite likely that the errors are larger in some areas, especially in the north-west Atlantic where information from ships is scanty. Everything possible is done at Dunstable to check doubtful reports. A continuous plot is kept of all British reporting ships on a wall-board and doubtful reports are referred back to the ships where possible. Many ships maintain a restricted radio watch, however.

*Mr. H. H. Lamb* considered that the singularities noticed in his own and other similar investigations are sufficiently pronounced to merit further investigation to discern the basic causes of the circulations producing the singularities.

*Dr. J. M. Stagg*, in a provocative contribution, asked whether the prebaratic is the best means of promulgating the considered views of forecasters at the Central Forecasting Office to outstations. To the man who prepares it a prebaratic is certainly useful in that it clears his mind but is there not the danger that the prebaratic is too specific? It is well known that there is a greater or less degree of uncertainty in a prebaratic, and this is taken account of by the originator when he frames his own related forecasts, but can this uncertainty be adequately represented to outstation forecasters by the present procedures even when the prebaratic is supplemented by the "General synoptic review"?

*Mr. S. P. Peters* said he would like to hear the views of outstation forecasters on the value they attached to receiving prebaratics and the accompanying "General synoptic reviews"; the construction of prebaratics is an essential process at Dunstable. There are often several possible solutions to the development problem and the prebaratic represents the one selected as the most probable. Outstation forecasters could always discuss their own ideas with the Central Forecasting Office by telephone.

*Mr. E. G. Ward* expressed the view that the Central Forecasting Office prebaratics are essential to the work of outstations. A forecaster at an average outstation has neither the time nor the facilities to produce 24-hr. prebaratics which are necessary to meet the very varied demands for forecasts made by the Services and the general public.

*Mr. P. M. Shaw* also considered that the Central Forecasting Office prebaratics were essential to outstations. He inquired about the use of the Sutcliffe theory in forecasting, and suggested that, in effect, a limited number of models, deduced somewhat empirically from the theory, are employed.

*Dr. R. C. Sutcliffe* recalled that long before the last war there were general ideas regarding the association of convergence and cyclogenesis, but no use was then made of three-dimensional dynamics in prediction, neither was development linked with the geometry of the surface and upper air pressure fields. Nowadays, however, these ideas are part and parcel of the forecaster's mode of thought. He agreed with Mr. Shaw that the present application of the Sutcliffe expression for development is largely qualitative in association with certain easily recognized configurations in the thickness field. For fuller use numerical methods and computational aids are necessary, and much progress is being made in these fields.

*Mr. J. S. Sawyer* was of the opinion that the almost universal adoption of prebaratics speaks for their advantages. He wondered whether isallobars could not be used more systematically in their preparation. To assist in the interpretation of prebaratics he suggested that precipitation areas should be indicated in some way.

*Mr. B. Fox-Holmes* considered that the Central Forecasting Office prebaratics are particularly valuable at outstations which are not manned continuously, and so cannot maintain a complete sequence of charts. He thought that the change from one prebaratic to the next is sometimes abrupt, and that in such circumstances some indication of the change of policy should be given earlier, say in





*Reproduced by courtesy of W. C. Glander*

VIEW FROM CONTROL TOWER OF METEOROLOGICAL ENCLOSURE, WICK,  
FEBRUARY 18, 1955

Excavation had begun inside the enclosure and a snow plough can be seen clearing the perimeter track. The depth of the drift in the foreground can be seen from the photograph below.



*Reproduced by courtesy of W. C. Glander*

SHOWING THE DEPTH OF THE DRIFT SNOW AT WICK, FEBRUARY 18, 1955

The guy lines on the right of the photograph extend from the anemometer pole and can also be seen in the top photograph.



*Reproduced by courtesy of H. J. E. Hoskin*

LOOKING AT THE GATES FROM INSIDE THE FILTER WORKS



*Reproduced by courtesy of H. J. E. Hoskin*

DRIFT INSIDE THE FILTER WORKS

DRIFTS UP TO 7 FT. DEEP AT THE FILTER WORKS OF THE NORTH  
CORNWALL JOINT WATER BOARD AT LOWERMOOR, NEAR CAMELFORD

the "Supplementary general synoptic review". Mr. Illsley replied that any clear-cut indications that a prebaratic was going wrong would be so notified to the outstations, but one had to be sure that the line being followed was incorrect before making any radical alteration. An amended forecast which goes wrong is always liable to greater criticism, especially if the original forecast turns out to be correct after all.

*The Director*, in summing up, spoke of the comparisons that had been made during the discussion between "conventional" and "numerical" forecasts, and remarked that no forecaster could be more conventional than the computing machine. For success with numerical forecasting it would be necessary to obtain some forecast of the boundary conditions, perhaps by orthodox prebaratic methods.

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1. SUTCLIFFE, R. C.; Principles of synoptic weather forecasting. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 291.
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4. MURRAY, R.; Rain and snow in relation to the 1000-700-mb. and 1000-500-mb. thicknesses and the freezing level. *Met. Mag., London*, **81**, 1952, p. 5.
5. LAMB, H. H.; Two-way relationships between the snow or ice limit and 1000-500-mb. thicknesses in the overlying atmosphere. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 172.
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### METEOROLOGICAL RESEARCH COMMITTEE

The 68th meeting of the Meteorological Research Committee was held on November 25, 1954. The Committee reviewed the progress which had been made on the more important research problems since the previous meeting and Dr. Scrase gave an account of the work being done under his control in developing meteorological instruments.

The 33rd meeting of the Synoptic and Dynamical Sub-Committee was held on December 9, 1954. The Sub-Committee discussed at length the provision of an electronic computer for Meteorological Office use and concluded that the time was now ripe for an intense effort in numerical forecasting using such a machine. A paper by Mr. J. G. Moore<sup>1</sup> on the average pressure and temperature of the tropopause was then considered. Two papers dealing with corrections which might be applied to radio-sonde temperatures were discussed. The first by Dr. F. J. Scrase<sup>2</sup> considered radiation and lag corrections and the second by Mr. D. H. Johnson<sup>3</sup> dealt with corrections which might be applied to take account of diurnal and interdiurnal variations.

The 31st meeting of the Physical Sub-Committee was held on December 16, 1954. There was some discussion on methods of measuring the stress of wind on water arising out of correspondence with the Ministry of Agriculture and Fisheries. The Sub-Committee then considered a paper by Dr. D. G. James<sup>4</sup> which dealt with observations of the fine-scale structure of the lowest 5,000 ft. of the atmosphere made from an aircraft of the Meteorological Research Flight. The observations referred primarily to days when convection was likely to

occur. A further paper<sup>5</sup> relating to observations made by the Meteorological Research Flight discussed humidity measurements at heights up to 50,000 ft. over southern England. A paper<sup>6</sup> from Kew Observatory on the estimation of the reflection and absorption of solar radiation by a cloudless atmosphere was also considered.

#### ABSTRACTS

1. MOORE, J. G.; Average pressure and temperature of the tropopause. *Met. Res. Pap., London*, No. 874, S.C. II/176, 1954.

Using all available radio-sonde data, obtained by various methods, average pressures and temperatures at the tropopause (or 2 tropopauses) are plotted on Mercator world charts and polar charts for January, April, July and October, and isopleths drawn. Between latitudes 35° and 45°N., two tropopauses were found on 10–95 per cent. of occasions. The charts are discussed.

2. SCRASE, F. J.; The application of radiation and lag corrections to radio-sonde temperatures. *Met. Res. Pap., London*, No. 889, S.C. I/95, 1954.

Errors of a radio-sonde due to radiation (short and long waves) and corrections for solar altitude and lag are evaluated and set out in tables.

3. JOHNSON, D. H.; Diurnal and interdiurnal variations of the measured heights of pressure surfaces. *Met. Res. Pap., London*, No. 888, S.C. I/94, S.C. II/179, 1954.

Observed diurnal variations of 700, 500, 300, 200 and 100 mb. heights were computed for Malta and Nicosia (0300–1500–0300) and for Larkhill and Lerwick (0300–0900–1500–2100–0300). These are compared with radiation errors read from new graphs for Meteorological Office radio-sondes at solar altitudes 70° to –5° up to 20 Km. The observed and computed variations are mostly similar; differences are attributed to neglect of sky radiation. Smoothed “observed” curves are drawn for use in correcting 0600 and 1200 synoptic height tendencies for diurnal variation.

4. JAMES, D. G.; Fine-scale characteristics of the lowest 5,000 ft. of the atmosphere as observed from an aircraft. *Met. Res. Pap., London*, No. 875, S.C. III/172, 1954.

Flights were made on convective days between about 500 and 5,000 ft. to measure details of gustiness and bumpiness and fluctuations of temperature and dew point. The ultra-rapid instruments are described and the results tabulated in detail. Over land three layers were found: up to 800–1,200 ft., chaotic; from this layer to 200–300 ft. below cloud base, less frequent and better defined fluctuations; sub-cloud layer, increased stability. Over sea these layers are not found; bumpiness is less and there is often an inversion. It is inferred that during the morning bubbles of heated air rise from the ground and, if moist enough, form cloud. Further ascent warms and deepens the sub-cloud layer and cloud formation proceeds by bubbles from this layer, continuing long after surface temperature has passed its maximum.

5. MURGATROYD, R. J., GOLDSMITH, P. and HOLLINGS, W. E. H.; An interim report on measurements of humidity from aircraft to heights of about 50,000 ft. over southern England. *Met. Res. Pap., London*, No. 877, S.C. III/174, 1954.

Regular observations with the Dobson-Brewer pressurized hygrometer in a Canberra up to 50,000 ft. over southern England are described. Observations at 5,000–50,000 ft. are tabulated and discussed for 21 flights. At the tropopause the frost point ranged from –65° to –96°F. lower for high than low tropopause. About 50,000 ft. (100 mb. above tropopause) values cluster round –120°F. (relative humidity over ice at –60°F. 0.7 per cent.). There may be a “humidity tropopause” a few thousand feet above temperature tropopause.

6. BLACKWELL, M. J., ELDRIDGE, R. H. and ROBINSON, G. D.; Estimation of the reflection and absorption of solar radiation by a cloudless atmosphere from recordings at the ground, with results for Kew Observatory. *Met. Res. Pap., London*, No. 894, S.C. III/178, 1954.

Records on cloudless occasions at Kew in 1947–51 of total, direct and diffuse radiation (total and two spectral regions) and illumination on a horizontal surface are discussed, including effect of London smoke with E. winds. Attenuation of radiation by Rayleigh scattering and “Fowle” (particulate) scattering and by water absorption, and diffuse radiation, are computed by several methods for a model atmosphere. Results are compared with those given by the extra-terrestrial distribution of solar radiation proposed by Nicolet and known attenuation of an unpolluted atmosphere. The results are consistent if the measured illumination is reduced by 5 per cent. Absorption is estimated as rather less than 10 per cent. with another 10 per cent. for “grey” multiple scattering. Albedo of cloudless atmosphere (total and various wave-lengths) is plotted against sine of solar altitude.

## ROYAL METEOROLOGICAL SOCIETY

### Meteorology in a large water engineering project

At a meeting of the Royal Meteorological Society on Wednesday, February 16, 1955, with the President, Sir Graham Sutton, in the Chair, Dr. E. B. Kraus gave a talk on meteorology in a large water engineering project.

Dr. Kraus has been the meteorological officer attached to the Snowy Mountains Hydro-Electric Authority, Cooma, New South Wales, and he described, partly with the aid of a film of the construction work in progress, the plan to build a large reservoir on the eastern side of the Snowy Mountains and drain the water through a tunnel to the western side where it was needed for irrigation. During flood time the flow of water in the tunnel was to be from west to east, thus filling the reservoir; during drought the flow was to be from east to west. The fall of water was to be used for hydro-electric power, and it was this that made the scheme commercially possible.

Meteorological advice was necessary to make the best use of the rainfall, for out of an average annual rainfall of 16 in. the total run-off was only  $1\frac{1}{2}$  in. The annual rainfall at the peak of the Snowy Mountains (Mount Kosciuszko) was about 150 in. A large reservoir could only be placed on the eastern side of the mountains where, unfortunately, because of föhn effects the evaporation was greatest; subsidiary feeder reservoirs were available at higher levels but their storage capacity was insufficient for commercial use.

The meteorological aid could be summarized under the headings of expected yield from the reservoir, protection against floods, duration of droughts, effect on soil conservation, observations, forecasting and miscellaneous matters. The dearth of previous observations made it difficult to estimate the normal rainfall yield and very difficult to estimate the maximum storm yield. Various methods had been tried including the "transplanting" of storms, observed in detail in similar climatic areas, to the Snowy Mountains area; the spring yield was estimated by means of a snow survey correlated with stream gauges during the spring run-off, but this would need at least ten years of observations. New stations had been set up, including 14 climatological, 150 rainfall and 98 storage stations; these last often consisted merely of an ordinary milk can chained in position. Such forecasting as was requested during the constructional period was comparatively easy, since all that was required was the likelihood of rain, and it had been observed that every front crossing the Australian continent gave rain on reaching the Snowy Mountains. When the project was fully operational—from 1960 onwards—much more detail would be required, in particular the rainfall amounts during the next 48 hr., for the demand for power would be greatest if it could be supplied in accurately predicted amounts.

Dr. Penman asked for details of the effect of tree destruction on the soil and the amount of water available for irrigation (this was conserved in lower reservoirs on the western side). Dr. Glasspoole asked about compensation water; there was little difficulty in the Australian scheme because the whole area was nationally owned and only used under leases for grazing. Mr. Craddock asked about the marked decrease in seasonal rainfall at the turn of the century; Mr. Gold thought it might be due to faulty measurement, but Dr. Kraus assured him that the same decrease occurred simultaneously in many parts of the world between 30°N. and 30°S. Furthermore the period used for normal averages in Australia, 1911–40, was chosen because of the loss of records in the first decade of the century when many farmers went bankrupt; 1902–48 was used for stream-gauges. Mr. Ludlam asked what progress there was on large-scale treatment of water surfaces with a film of cetyl alcohol to prevent evaporation; Dr. Kraus replied that Deacon and Priestley had developed a method of renewing the film from anchored floats over a disturbed sizeable water surface but it was still experimental.

## LETTERS TO THE EDITOR

### Confluence and diffluence

The term confluence is widely used in synoptic meteorology to imply a flowing together without necessarily implying "convergence" as defined in hydrodynamics. The distinction is very important, and corresponding with "divergence" I have been guilty in certain papers of writing "diffluence" and of pronouncing it with a long i.

My attention has been drawn to this error and as the word is a handy one which is being rather widely adopted I would like to commend the correct form for future use.

R. C. SUTCLIFFE

*March 22, 1955*

### Precipitation with clear sky

In the typescript *Meteorological Magazines* for 1944 and 1945 there was considerable discussion of this phenomenon, and a conclusion which emerged was that, at a place like Wrexham lying to the east of the mountains, low cloud can lie over the mountains in a strong W. wind and precipitate fine rain which comes to earth some miles to eastward. The cloud is invisible from where the observation is made and it does not itself advance down into the lowlands owing to adiabatic warming. However, observations in Wrexham in February 1955 seem to show that other processes must operate at times. On February 5 there was a period of light rain from 2130 to 2230 G.M.T. The cloud then suffered a complete and rapid dispersal, and from 2235 to 2255 light rain continued to fall from the cloudless sky. Not a trace of cloud could be seen and the stars were as bright as they can be with a nearly full moon, and it was calm at the surface. The rain was not heavy enough to be registered on the autographic rain-gauge, but was sufficient to wet clothing.

Again, on February 15 at 0920 there was a light fall of snow in the absence of low cloud and with 4 oktas of hazy cirrus only. The dry bulb was 32°F. and the wind NNW. 6 kt. The rest of the day was fine; a little low cloud occurred about an hour later, but even then there was only thin high stratocumulus above.

One or two other similar cases have been reported in the *Meteorological Magazine*\*.

S. E. ASHMORE

11 Percy Road, Wrexham, February 20, 1955

### NOTES AND NEWS

#### Heavy rainfall at Changi, Singapore

During a rainy spell which affected Singapore on December 8–11, 1954 the rainfall amounts at the airfields on the island for the standard 24-hr. period ending at 0730 local time (0000 G.M.T.) on December 10 were as follows:—

	in.
Changi (at eastern end of Singapore Island) ... ..	9·29
Seletar (on north coast, 7½ miles west-north-west of Changi) ...	7·58
Kallang (on south coast, 9 miles south-west of Changi) ...	9·06
Tengah (inland, near west of island, 19 miles west of Changi) ...	7·09

However, this is not the whole story; for in the 24-hr. period ending 2230 local time on December 9, a total fall of 12·90 in. was measured at Changi. The rate of fall during this period is given in the three-hourly records below:—

Local time	Rainfall in.	Local time	Rainfall in.
2230–0130	0·48	1030–1330	1·65
0130–0430	1·93	1330–1630	3·22
0430–0730	1·42	1630–1930	1·53
0730–1030	2·10	1930–2230	0·57

The rate of fall is not exceptional for Singapore, as on many occasions this rate is greatly exceeded in thunderstorms (e.g. 4·28 in. fell in a thunderstorm

\* DINES, J. S.; Drizzle falling from a clear sky. *Met. Mag., London*, 70, 1935, p. 16.

ASHMORE, S. E.; Drizzle falling from a clear sky. *Met. Mag., London*, 70, 1935, p. 116.

at Changi between 1430 and 1530 local time on April 20, 1953\*). However, the persistence of the heavy rainfall can be assessed when the actual fall is compared with the average rainfall for December—just over 10 in. The maximum intensity of rainfall occurred on December 9 when 0.4 in. fell in 9 min., i.e. at a rate of 2.67 in./hr.

The rainfall at Changi for the standard period ending 0730 local time on the 10th—9.29 in.—is the highest 24-hr. fall since records were begun here in 1947. The previous highest was 6.66 in. in January 1947. Also, it approaches the highest 24-hr. fall ever recorded in Singapore which was 9.62 in. in December 1892.

The weather was associated with a surge in the NE. monsoon which, it is thought, was converging aloft over Singapore Island and south Malaya with Indian Ocean westerlies, the latter having been strengthened by a depression in the Bay of Bengal. But as most of the upper air information in this area is derived from pilot-balloon ascents, it will be realized that during the rain spell little or no data were available. Unfortunately, too, the Singapore radar-wind equipment was unserviceable most of the month.

It is notable that during the period there was no report of thunder from any station in Singapore or south Malaya. The cloud structure, as reported by aircrews and by inference from the Singapore radio-sonde ascents, was 8 oktas nimbostratus continuous from about 5,000 ft. to over 30,000 ft. with stratocumulus and stratus below.

Besides the spell December 8–11, the rainfall generally throughout the month was abnormally heavy, and the previous highest 24-hr. rainfall at Changi—6.66 in. in January 1949—was exceeded again when a fall of 7.29 in. was measured in the 24-hr. period ending 0730 local time, December 17.

The total rainfall measured at Changi during December was 35.91 in. which is more than double the previous highest December rainfall, 17.17 in. in 1947. It is also much higher than the greatest December rainfall ever measured in Singapore which was 22.01 in. in 1942. And, as far as can be ascertained, the rainfall at Changi in December 1954 is the highest fall ever recorded for any month in Singapore, the previous highest being 32.3 in. in January 1893.

When one considers that the fall of 12.9 in. in 24 hr. is more than the average six-month fall in London and that the month's rainfall of 35.9 in. is approximately the average fall over eighteen months in London, the reader may be able to imagine just how much rain did fall at Changi during December 1954.

F. BOTHWELL

### **Meteorological Office album of historical photographs**

An ornamental album containing photographs of historical interest related to the Meteorological Office, and suitable for exhibition, is being prepared in collaboration with Her Majesty's Stationery Office. The photographs are mostly of international meteorological conferences and other important meetings. The album has spare leaves to facilitate the addition of photographs to the collection. Any readers knowing of photographs which might be suitable for adding to the album are invited to communicate with the Editor.

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\* PALMER, W. G.; Heavy storm at Changi. *Met. Mag., London*, **82**, 1953, p. 341.

## NEWS IN BRIEF

Information has been received from Stockholm that Dr. Anders Ångström retired from the post of Director-in-Chief, Meteorological and Hydrological Institute of Sweden on December 31, 1954. Dr. Ångström is succeeded by Dr. Alf Nyberg.

### METEOROLOGICAL OFFICE NEWS

**Academic successes.**—*University degrees.*—We offer our congratulations to Mr. G. B. Tucker, Scientific Officer, who has been admitted to the degree of Ph.D. in Meteorology in the University of London, and to Mr. J. MacDowall, Scientific Officer, who has been admitted to the degree of M.A. in the University of Cambridge.

*Fellowship.*—Mr. D. H. McIntosh, Senior Scientific Officer, has been elected a Fellow of the Royal Society of Edinburgh.

*General Certificate of Education.*—Information has reached us that Mr. J. H. Rawlinson, Scientific Assistant, has passed the General Certificate of Education at the Advanced Level in Pure Mathematics.

**Ocean weather ships.**—The following extracts from reports by the Meteorological-Officers-in-Charge aboard two ocean weather ships emphasize the contrast in weather which can be experienced in the North Atlantic.

*o.w.s. Weather Recorder.*—Voyage 57 (December 7–January 3, 1955) at station I.

A white Christmas indeed! But white with spray and spume for gale force winds and storms were the notable features of this voyage. Gales were recorded on 15 days and reached storm force on 6 occasions.

*o.w.s. Weather Explorer.*—Voyage 57 (December 24–January 22, 1955) at station A.

Apart from a severe gale on the outward passage the weather was very good indeed. In fact, no one can recall a better voyage at any season. The wind rarely exceeded force six and we enjoyed quiet anticyclonic weather for almost the entire trip.

**Sports activities.**—The Air Ministry Chess Championship of 1955 has been won by Mr. P. B. Sarson; second was Dr. J. Pepper. Of the nine contests held since 1946 the Meteorological Office has provided the winner six times and the runner-up six times.

### WEATHER OF MARCH 1955

The pressure pattern departed widely from normal over most of the Atlantic and Europe, on account of the frequency and persistence of blocking anticyclones; the highest monthly mean pressure in this sector was 1020–1021 mb. over Ireland and the Hebrides. The subtropical anticyclone was represented by a 1020 mb. centre near the Bahamas. Pressure was relatively low in three areas—1004–1005 mb. off Labrador, 1006 mb. off north Norway and 1010 mb. between the Azores and Spain. In other parts of the hemisphere the patterns seem to have been closer to normal. Pressure had been notably high all winter over north Greenland and the Canadian archipelago, but whereas this was abnormal in December, January and February it is usual in March; the March 1955 pressure values were close to normal in these northern areas, but a southward extension of the anticyclone, which was noticeable in the second half of the month, produced the maximum pressure anomaly of +14 mb. in Iceland.

The temperature and rainfall patterns over Europe reflected the anomalies in the pressure and wind distribution. Prevalent northerly and easterly winds brought below-normal temperature all over Europe, culminating in departures of  $-4^{\circ}\text{C}$ . in central Europe and locally in England. Rainfall exceeded twice the average over the mountains of north Norway and locally in Denmark, the eastern Alps, Sardinia, southern Italy and the Balkans.



In the British Isles the weather during the first two weeks was anticyclonic, with wintry showers and long sunny periods. High pressure in the neighbourhood of Greenland maintained a cold arctic air stream over the major part of the country for about another week, until an influx of maritime air from the south-west, from the 23rd to the 26th brought a change to mild wet weather. During the remainder of the month, as an anticyclone moved southwards from Iceland, a polar air stream was re-established over the country with a return to fine cold weather.

During the first three days of the month an anticyclone centred over Germany maintained a cold easterly air stream with dry sunny weather over the southern part of the country, but in the north-west and north the passage of an active trough on the 1st was associated with fresh to strong south-westerly winds and considerable rain in Ireland, Wales and Scotland; heavy rain coupled with melting snows caused widespread floods in the Renfrewshire-Clyde area. Areas of fog, dense in the north-east, formed in the moister air behind the trough during the early hours of the 2nd and 3rd, but otherwise the weather was fine though rather cold. By the 4th, an anticyclone of over 1040 mb. had crossed the Atlantic and settled west of Ireland, and fresh northerly winds associated with the system brought frequent snow showers to eastern England. These showers were particularly prolonged in East Anglia and Kent on the 6th where snow lay in places up to a depth of 6 in. On the same day there was a general veer of wind to north-easterly, and slight snow showers spread westward across the whole country. There was a return to fine cold weather on the 10th, as an anticyclone developed over the British Isles, until a temporary incursion of maritime air from the north-west during the 14th and 15th brought day temperatures to their seasonal normal for the first time this month; 54°F. was registered in a few places. Rain and drizzle occurred in Scotland, but some places in the extreme south continued to enjoy more than 10 hr. of sunshine daily. High pressure developed over Greenland on the 16th and for nearly a week afterwards the British Isles was under the influence of an associated northerly air stream of arctic origin. Showers of sleet or snow occurred in all areas, and temperatures everywhere again fell below normal. Bournemouth (Hurn) recorded a grass minimum temperature of 10°F. during the early hours of the 18th and again on the 20th, Kew recorded 12°F. on the grass on the 20th and 21st. A polar depression crossed Scotland on the 20th, and during that evening and the following day parts of southern Scotland and the Lake District had heavy falls of snow, depths of undrifted snow from 6 to 9 in. being reported. A pronounced change occurred on the 22nd when warm moist air spread from the south-west as far north as the Scottish border. A small but vigorous depression moved up the Irish Sea and across northern England on the 23rd, accompanied by gales in the south-west and locally heavy rain. A gust of 85 kt. was reported from Cornwall, and there was considerable damage to shipping in the path of the gales; the Norwegian ship *Venus* was blown on to the rocks in Plymouth Sound, and there were reports of several other vessels breaking adrift. The following day another though less vigorous depression followed a similar track, again with outbreaks of heavy rain, but this too turned east towards the North Sea before reaching Scotland. A big contrast of temperature was thus established between the south of England where temperatures were generally about 60°F. (63°F. was reached at Kew and London Airport and 66°F. on the Air Ministry roof, Kingsway, on the 25th) and Scotland where the temperature was still generally below 40°F. In 48 hr. during the passage of these two depressions  $\frac{3}{4}$  in. of rain fell in many places in Wales, northern England and southern Scotland, but still heavier falls were measured on the 25th and 26th when thunderstorms and thundery rain broke out over a wide area in England and Wales. In the 24 hr. up to the evening of the 26th many places had more than 1 in. while there were falls of 2 in. or more in parts of south Wales and the Midlands. It was reported to have been the wettest week in Birmingham since November 1951. The four days of abnormally wet weather resulted in serious floods in the Midlands; the River Severn was reported to be 6 ft. above its normal level at Worcester on the 27th. On the 26th an anticyclone began to move southwards from Iceland and brighter colder weather with northerly winds spread over the whole country by the 27th. The closing days of the month were dry and sunny with some stations in the west reporting more than 11½ hr. of sunshine on the 31st. In spite of the number of sunny days, with sunshine totals 50 per cent. above normal in parts of south-west England and Wales, it was a cold month for most of the country. Birmingham and Ross-on-Wye had their coldest March since 1916 and Kew since 1917.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	65	10	—4·9	83	—5	134
Scotland ...	57	9	—3·0	50	—5	116
Northern Ireland ...	57	18	—3·9	36	—11	139

# RAINFALL OF MARCH 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	1·14	62	<i>Glam.</i>	Cardiff, Penylan ...	1·41	45
<i>Kent</i>	Dover ...	2·06	99	<i>Pemb.</i>	Tenby ...	3·42	110
<i>„</i>	Edenbridge, Falconhurst ...	1·50	60	<i>Radnor</i>	Tyrmynydd ...	4·49	84
<i>Sussex</i>	Compton, Compton Ho. ...	1·66	60	<i>Mont.</i>	Lake Vyrnwy ...	3·54	79
<i>„</i>	Worthing, Beach Ho. Pk. ...	0·92	48	<i>Mer.</i>	Blaenau Festiniog ...	2·55	30
<i>Hants.</i>	St. Catherine's L'thouse ...	1·04	53	<i>„</i>	Aberdovey ...	2·48	74
<i>„</i>	Southampton (East Pk.) ...	1·18	52	<i>Carn.</i>	Llandudno ...	1·48	73
<i>„</i>	South Farnborough ...	0·96	48	<i>Angl.</i>	Llanerchymedd ...	1·86	63
<i>Herts.</i>	Harpenden, Rothamstead ...	1·34	65	<i>I. Man</i>	Douglas, Borough Cem. ...	2·47	83
<i>Bucks.</i>	Slough, Upton ...	0·99	56	<i>Wigtown</i>	Newton Stewart ...	2·21	64
<i>Oxford</i>	Oxford, Radcliffe ...	1·43	87	<i>Dumf.</i>	Dumfries, Crichton R.I. ...	2·10	70
<i>N'hants.</i>	Wellingboro' Swanspool ...	2·18	122	<i>Roxb.</i>	Eskdalemuir Obsy. ...	3·42	70
<i>Essex</i>	Southend, W. W. ...	1·03	67	<i>Peebles</i>	Crailing ...	1·23	57
<i>„</i>	Felixstowe ...	1·45	97	<i>Berwick</i>	Stobo Castle ...	1·64	57
<i>Suffolk</i>	Lowestoft Sec. School ...	1·54	96	<i>E. Loth.</i>	Marchmont House ...	1·62	61
<i>„</i>	Bury St. Ed., Westley H. ...	1·67	88	<i>Mid'l'n.</i>	North Berwick Gas Wks. ...	1·24	67
<i>Norfolk</i>	Sandringham Ho. Gdns. ...	2·07	109	<i>Lanark</i>	Edinburgh, Blackf'd. H. ...	1·51	77
<i>Wilts.</i>	Aldbourne ...	1·66	70	<i>Ayr</i>	Hamilton W. W., T'nhill ...	1·90	68
<i>Dorset</i>	Creech Grange ...	1·36	48	<i>Renfrew</i>	Colmonell, Knockdolian ...	...	...
<i>Devon</i>	Beaminster, East St. ...	1·63	56	<i>Bute</i>	Glen Afton, Ayr San. ...	1·81	43
<i>„</i>	Teignmouth, Den Gdns. ...	2·13	82	<i>Argyll</i>	Greenock, Prospect Hill ...	2·11	45
<i>„</i>	Ilfracombe ...	1·39	48	<i>„</i>	Rothsay, Ardenraig ...	1·47	41
<i>„</i>	Princetown ...	3·31	48	<i>„</i>	Morven, Drimnin ...	1·32	27
<i>Cornwall</i>	Bude, School House ...	1·03	42	<i>„</i>	Poltalloch ...	...	...
<i>„</i>	Penzance ...	1·95	61	<i>„</i>	Inveraray Castle ...	1·51	24
<i>„</i>	St. Austell ...	1·44	42	<i>„</i>	Islay, Eallabus ...	...	...
<i>„</i>	Scilly, Tresco Abbey ...	2·19	84	<i>„</i>	Tiree ...	0·88	26
<i>Somerset</i>	Taunton ...	1·14	55	<i>Kinross</i>	Loch Leven Sluice ...	2·31	77
<i>Glos.</i>	Cirencester ...	1·72	74	<i>Fife</i>	Leuchars Airfield ...	1·58	81
<i>Salop</i>	Church Stretton ...	3·58	149	<i>Perth</i>	Loch Dhu ...	2·60	39
<i>„</i>	Shrewsbury, Monkmore ...	2·57	154	<i>„</i>	Crieff, Strathearn Hyd. ...	2·17	68
<i>Worcs.</i>	Malvern, Free Library ...	2·36	122	<i>„</i>	Pitlochry, Fincastle ...	0·62	22
<i>Warwick</i>	Birmingham, Edgbaston ...	3·45	164	<i>Angus</i>	Montrose, Sunnyside ...	1·56	75
<i>Leics.</i>	Thornton Reservoir ...	2·75	149	<i>Aberd.</i>	Braemar ...	2·03	68
<i>Lincs.</i>	Boston, Skirbeck ...	2·05	131	<i>„</i>	Dyce, Craibstone ...	1·78	67
<i>„</i>	Skegness, Marine Gdns. ...	2·24	135	<i>„</i>	New Deer School House ...	2·11	82
<i>Notts.</i>	Mansfield, Carr Bank ...	2·99	143	<i>Moray</i>	Gordon Castle ...	1·44	62
<i>Derby</i>	Buxton, Terrace Slopes ...	3·68	89	<i>Nairn</i>	Nairn, Achareidh ...	0·79	43
<i>Ches.</i>	Bidston Observatory ...	1·78	94	<i>Inverness</i>	Loch Ness, Garthbeg ...	...	...
<i>„</i>	Manchester, Ringway ...	1·82	83	<i>„</i>	Glenquoich ...	2·21	23
<i>Lancs.</i>	Stonyhurst College ...	1·49	40	<i>„</i>	Fort William, Teviot ...	1·00	15
<i>Yorks.</i>	Squires Gate ...	1·37	61	<i>„</i>	Skye, Broadford ...	1·87	31
<i>„</i>	Wakefield, Clarence Pk. ...	2·29	127	<i>„</i>	Skye, Duntuilim ...	1·80	41
<i>„</i>	Hull, Pearson Park ...	2·37	130	<i>R. &amp; C.</i>	Tain, Mayfield ...	1·26	56
<i>„</i>	Felixkirk, Mt. St. John ...	2·03	103	<i>„</i>	Inverbroom, Glackour ...	1·98	40
<i>„</i>	York Museum ...	1·93	115	<i>Suth.</i>	Achnashellach ...	2·31	34
<i>„</i>	Scarborough ...	2·15	119	<i>Caith.</i>	Lochinver, Bank Ho. ...	1·28	34
<i>„</i>	Middlesbrough ...	1·18	75	<i>Shetland</i>	Wick Airfield ...	1·64	72
<i>„</i>	Baldersdale, Hury Res. ...	1·99	69	<i>Ferm.</i>	Lerwick Observatory ...	1·56	49
<i>Norl'd.</i>	Newcastle, Leazes Pk. ...	1·91	93	<i>Armagh</i>	Crom Castle ...	0·78	25
<i>„</i>	Bellingham, High Green ...	1·75	60	<i>Down</i>	Armagh Observatory ...	1·08	46
<i>„</i>	Lilburn Tower Gdns. ...	1·77	67	<i>Antrim</i>	Seaforde ...	1·73	59
<i>Cumb.</i>	Geltsdale ...	0·95	34	<i>„</i>	Aldergrove Airfield ...	0·87	35
<i>„</i>	Keswick, High Hill ...	1·38	31	<i>L'derry</i>	Ballymena, Harryville ...	0·75	24
<i>„</i>	Ravenglass, The Grove ...	2·29	74	<i>„</i>	Garvagh, Moneydig ...	0·81	26
<i>Mon.</i>	A'gavenny, Plás Derwen ...	3·13	94	<i>Tyrone</i>	Londonderry, Creggan ...	1·36	42
<i>Glam.</i>	Ystalyfera, Wern House ...	3·86	72		Omagh, Edenfel ...	1·03	32

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METEOROLOGICAL OFFICE

# THE METEOROLOGICAL MAGAZINE

***Meteorological Office Centenary***  
***1855 - 1955***

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Message from the  
**Secretary of State for Air**

This year marks the centenary of the State Meteorological Service. Not many scientific institutions can claim so long a history. During the past one hundred years, the Meteorological Office has built up a great tradition of service to the public, and its many notable contributions to knowledge have markedly increased the scientific and material progress of the civilized world.

Half-way through its life the development of the art of flight began greatly to increase the importance of its work. The science of meteorology has played as great a part in the history of aviation as did that of astronomy in the navigation of the seas.

Thus it was natural that in 1920 the Office should become part of the responsibilities of the Secretary of State for Air. Since that date a close and cordial association has grown up between the Meteorological Office and the Air Ministry. Throughout this period, in peace and in war, it has rendered most valuable service to the Royal Air Force and to British aviation.

While the Meteorological Office will always be closely associated with aviation, it serves many other institutions, national and private. Its name is familiar to every household in the country; its forecasts are studied daily by many millions, and are soon to be a part of the public telephone service. On the occasion of this centenary, I congratulate most warmly all members of the staff, past and present, on creating and maintaining a great tradition of public service.

## FOREWORD

By THE DIRECTOR OF THE METEOROLOGICAL OFFICE

A century, although an artificial division of time, is a significant period in the history of any human organization, and centenaries afford useful opportunities to pause and look around. What we see in the record of the first hundred years of the Meteorological Office gives cause for legitimate pride. In 1855, when Admiral FitzRoy began his duties as Director, it was difficult to disentangle fact from folklore in the study of weather, and meteorology hardly existed as a science. In the years that followed, crude observation has slowly given way to exact measurement all over the globe, and our knowledge of the atmosphere now extends to regions that once were completely inaccessible. The Meteorological Office has always taken a leading part in this work. Progress in the main problem of our science, that of forecasting weather over significant periods, has not been as rapid or as sure, but this causes less surprise today than it would have in the nineteenth century. We are now in a better position to appreciate the formidable nature of the problem, perhaps the most stubborn in the whole of physical science, and a proper appreciation of the difficulties and an inkling of how they arise are an essential first step towards their resolution.

It is a far cry from the nineteenth century, with official interest in meteorology represented by a handful of staff in a small London Office, to the modern weather service with its headquarters, outstations, observatories, weather ships and research flights. Aviation and telecommunications have greatly extended the range and power of operational meteorology, but at the cost of an increasing complexity of organization. The paucity of university support for meteorology has compelled the Meteorological Office to build up its own research division, to the great profit of all concerned. Our activities now touch almost every aspect of national life, and one looks back with nostalgic wonder to the days when Shaw could write a "Manual of meteorology" that truly comprehended the science of the atmosphere in his day.

A governmental organization has little opportunity to tell its story, except on occasions like the present. Perhaps because of the nature of their work, professional meteorologists tend to be isolated from their fellow scientists. But this characteristic, now becoming much less pronounced, has had its compensations. "Once a meteorologist, always a meteorologist" may not be altogether desirable in a public service, but it has helped to create the unique spirit of fellowship that is characteristic of the Office. Of the heritage of the past, this is perhaps the most valued feature which we hope to carry into the next hundred years.

## SHORT HISTORY OF THE METEOROLOGICAL OFFICE

By G. A. BULL, B.Sc.

The Meteorological Office was founded early in 1855 as the Meteorological Department of the Board of Trade and a distinguished sailor, Admiral FitzRoy, was appointed Superintendent. The title was changed to Meteorological Office in 1863.

The Department was founded, following the recommendations of an international conference held in 1853, to collect meteorological and sea-current observations for the benefit of shipping, and this work has remained an important part of the duties of the Office ever since. Observations made voluntarily by large numbers of British and foreign ships over the past hundred years have provided the basic data for the climatology of the oceans of the world.

Weather changes over an area had been studied from observations made at about the same time at a number of widely scattered stations for many years before 1860, in which year FitzRoy, encouraged by the British Association and in collaboration with Le Verrier of Paris, began the collection of observations by telegram and the organization of a forecasting service. Storm warnings were sent to ports from February 1861, and forecasts were issued to the Press from July 1861. Fuller details are given on p. 167.

FitzRoy died in 1865, and in 1866 the publication of forecasts and the issue of gale warnings were stopped on the recommendation of a Royal Society Committee which considered current scientific basic knowledge of weather inadequate for forecasting. At the end of 1866 the Office was transferred from the Board of Trade to the control of a Committee of the Royal Society, and R. H. Scott, who was to remain chief of the Office under more than one title for 33 years, was appointed Director. The Committee gave very close attention to the improvement of knowledge of the connexions between weather changes and the movements and developments of the depressions and anticyclones shown on the weather maps. Seven observatories equipped with continuously recording instruments measuring wind, pressure, temperature and rainfall were established, largely under the inspiration of Sir Francis Galton, and the records of these instruments carefully studied in relation to the movements of depressions. In the course of this work the fact that sharp changes in wind direction, pressure and temperature can occur together was recognized, but the existence of fronts extending a great distance across country was not realized. The traces for the individual elements given by these continuously recording instruments were published one above the other for immediate comparison of their variations. Following this study confidence in forecasting was regained, and the publication of forecasts was resumed in 1879. Storm warnings had been resumed soon after 1866 in response to popular request. In the first instance this was done by notifying ports of the existence of a gale observation and leaving the harbour authorities to draw their own conclusions, but by 1876 the full warning service was in operation.

The need for international standardization of methods of making and reporting observations was realized at this time, and the Director attended the first international conference for the purpose held at Leipzig in 1872. The next such conference was held in Vienna in 1873, and since then international collaboration in meteorology has been continuous with conferences at frequent intervals.

In 1877 there was an administrative change in the placing of the Office under the control of a Meteorological Council, whose members were paid by the Government and of which R. H. Scott became Secretary. Research in meteorology was largely entrusted by the Council to university and other outside workers. In this way Napier Shaw, later to become one of the most eminent of meteorologists, came into meteorological work by undertaking research on the measurement of humidity. The destruction of the Tay Bridge in a gale in 1879 led to the investigation of wind structure and the invention by W. H. Dines of an anemometer to measure wind gusts.

Dr. Napier Shaw was appointed Secretary of the Council in succession to R. H. Scott in 1900. The Meteorological Council, following the recommendations of a Treasury Committee, ceased to exist in 1905, and the Office was placed under the control of a new Committee financed by a grant-in-aid from the Treasury. Shaw became Chairman of the Committee (which included representatives of the Navy, Mercantile Marine and Ministry of Agriculture and Fisheries) and Director of the Office.

Soon after his appointment as Secretary of the Meteorological Council Shaw began to recruit highly trained physicists to the staff. The first of these was R. G. K. Lempfert whose first work was an investigation into London fogs for the London County Council. With Lempfert, Shaw investigated the air movements in depressions, a work which began with tracing the flow of air which brought dust from north Africa to give the "red rain" of February 21 and 22, 1903. In 1906 this led to the great work "Life history of surface air currents" which gave the first general picture of air movements in depressions. Shaw also worked on the relation between weather and crop yields. Another notable Office research of the first ten years of the twentieth century was E. Gold's demonstration of the close degree with which wind speed at 2,000–3,000 ft. agrees with the theoretical value calculated from the distance between the isobars.

About 1910 the meteorological needs of aviation were beginning to make themselves felt. J. S. Dines investigated wind structure for the Advisory Committee for Aeronautics, and the first outstation to give meteorological advice to aircraft pilots was opened at South Farnborough in 1912.

In the international field Shaw became in 1907 President of the International Meteorological Committee. Experience in forecasting grew rapidly under Shaw's guidance, and was embodied in his book "Forecasting weather" published in 1911. Until 1910 forecasts were limited to a period of 24 hours, but in that year "further outlooks" of weather prospects for a longer period were added whenever the forecaster thought one justified.

A major function of the Meteorological Office is to be the "public memory of the weather", that is to collect, process and publish climatological data for the British Isles, and to furnish advice for the economic life of the nation on the basis of that "memory". This side of its work was strengthened in 1912 by the taking over from the Royal Meteorological Society of the collection of the climatological observations made in England by private observers. The supervision and distribution to the Press of the observations of sunshine and weather made at Health Resorts were also undertaken in the same year. The corresponding climatological work in Scotland was not taken over from the Scottish Meteorological Society until 1920. Information was collected on world climate also,

and is used in answering many inquiries from British industrial and commercial organizations with interests overseas.

The work of the Office in general geophysics increased in 1910 by the transfer from the National Physical Laboratory of control of the observatories at Kew and Eskdalemuir, which made observations and research in terrestrial magnetism and seismology as well as meteorology. The Superintendent of the Eskdalemuir Observatory, L. F. Richardson, worked out in the next six years his revolutionary ideas on weather forecasting by numerical solution of the basic dynamical formulae of atmospheric motion, ideas that had to wait over 30 years for the invention of electronic calculating machines to bring them within the bounds of practical possibility.

The outbreak of war in 1914 led to a great increase in the work of the Office. Forecasts for the public had eventually to be stopped, but the supply of forecasts to the Services continually increased. The Office supplied trained staff to the meteorological services of the Forces in the field. Above all, the needs of aviation led to a great demand for information on the upper atmosphere.

Sir Napier Shaw was appointed in 1918 Scientific Adviser to H.M. Government on Meteorology for the duration of the war, and his administrative duties were performed by Colonel H. G. Lyons. The fruit of this appointment was the publication in 1919 of a large work on wind structure to form a volume of a planned "Manual of meteorology".

By the end of the war there were four meteorological services, the Meteorological Office and three others serving respectively the Army, Navy and Royal Air Force. The Cabinet decided in 1919 to absorb the three younger services into the Office, make the Office responsible for meeting all the meteorological needs of the nation, and attach it to the Air Ministry as the Department making most use of its services. A Meteorological Committee, composed of representatives of all Departments concerned and of the Royal Society, was established to control general policy.

An important addition to the work of giving advice based on past observations was made in 1919 when the British Rainfall Organization, which collects rainfall observations and advises water supply authorities, was taken over.

Sir Napier Shaw retired in 1920 and was succeeded by Dr. G. C. Simpson, later Sir George Simpson.

Radio first came into use in meteorology before 1914 for collecting weather reports from ships. This made it possible for ships' observations to be used by the daily forecasting service. For the British Isles the reports made voluntarily by "selected" ships have become invaluable for forecasting since they constitute almost the only source of information from the North Atlantic from which most of our weather comes. After the war the international exchange of weather reports by radio began, and by 1920 the broadcasting of forecasts for shipping in the Atlantic was in operation. The first forecast broadcast to the general public by the B.B.C. was transmitted on November 14, 1922.

During the following years the work of the Office continuously increased in volume and complexity, notably because of the needs of civil and military aviation. Meteorological offices were established at many aerodromes. The first overseas office was formed at Malta in 1922; others in Egypt and Iraq followed later. A special division met the needs from 1925 to 1930 of the

experimental work with airships. The Admiralty, however, in 1937 took over from the Office full control of the weather service for the Royal Navy.

In international work the Office was particularly prominent in the devising of new codes for transmitting weather observations to meet the increasing amount of detail needed by forecasters for the application of the new techniques of air-mass and frontal analysis. E. Gold was Chairman for 28 years of the international commission responsible for this work.

Sir George Simpson retired in 1938 and was succeeded by Dr. N. K. Johnson, later Sir Nelson Johnson.

Shortly before the outbreak of war in 1939 the method was developed of obtaining upper air observations by the radio transmission of readings of air pressure, temperature and humidity from a small instrument, the radio-sonde, carried by a free balloon. From these readings and observations of the bearings of the incoming radio signals from the balloon as it rose and drifted with the wind the upper winds also could be measured. This system enabling upper air observations to be obtained very rapidly in all weather and above cloud was to prove of the utmost importance during the war.

During the Second World War 1939–45 the demands on the Office for operational forecasts and for guidance in planning future operations were enormous. The staff gradually increased about tenfold to a maximum of some 6,000 towards the end of the war. The “target for the night” in the bomber offensive was selected by the Commander in Chief of Bomber Command in the light of the advice of his Chief Meteorological Officer following routine discussions between the senior meteorological officers at the Bomber Groups and the senior forecaster at Dunstable. Meteorological advice was vital in taking the decision to invade Normandy in 1944. Meteorological reconnaissance flights to take observations over the sea and enemy territory were organized, and the location of distant thunderstorms by observing at three stations the directions of arrival of the atmospheric clouds produced by the storms was brought into operational use. New techniques for use in the forecasting of the much more abundant upper air information were devised.

Early in 1939 an Assistant Director was appointed to supervise research work in the Office, and in 1942 the Meteorological Research Committee of the Air Ministry was formed with an eminent scientific membership. In 1942 a Meteorological Research Flight was formed to make observations for research into such problems as ice accretion on aircraft, aircraft condensation trails, and the atmospheric water-vapour content.

Research has developed in many directions. A Deputy Director of Research and Assistant Directors of research in forecasting, instrument development, general physical meteorology and for special investigations were appointed in 1948 and an Assistant Director for climatological research in 1954. There is space for references to only a few of the problems dealt with. In forecasting research much has been done on the use of upper air observations in general forecasting, and in forecasting wind for aircraft flying at ever increasing heights. Trials of numerical forecasting with electronic calculating machinery have shown much promise. New methods of observation such as the tracking of balloons to great distances by radar for the measurement of upper winds and the use of radar for cloud investigations have been brought into use. The Meteorological Research Flight has, amongst other matters, investigated the detailed structure of the water and ice in clouds.



Since the end of the war progress in the supply of meteorological information for the life of the nation has been continuous. A great organization for civil aviation, to provide meteorological information for day-to-day operation, has been built up and a special branch has been established to study and summarize upper air temperature, humidity and wind over the whole world. Another special branch has been established to study and meet the meteorological needs of agriculture.

The international scheme for ocean weather ships, under which the United Kingdom maintains four ships staffed and equipped by the Meteorological Office at fixed stations in the North Atlantic to make both surface and upper air observations and provide navigational guidance to aircraft and air-sea rescue facilities, came into operation in 1947. Responsibility for the observation at four fixed stations is now shared with France and the Netherlands.

The B.B.C. Television Service began to show forecasts prepared by the Office in 1950; from January 1954 the television forecasts have been presented by a forecaster of the Meteorological Office.

In international meteorology the Director, Sir Nelson Johnson, was President of the International Meteorological Organization during the eventful period 1946–51 in which the Organization was transformed into the World Meteorological Organization as a specialized agency of the United Nations.

Sir Nelson Johnson retired from the Directorship in 1953 and was succeeded by Dr. O. G. Sutton, later Sir Graham Sutton.

During its century the Office has built up one of the largest meteorological libraries in the world. It has published hundreds of books and reports of researches. The *Daily Weather Report* has been published since 1869. The *Quarterly Weather Report*, *Monthly Weather Report* and *Weekly Weather Report* of summarized data must also be mentioned. Charts of marine meteorology have been produced in fulfilment of the original purpose of the Office. Of the research publications the most important are *Geophysical Memoirs*, 93 of which have been published since they were instituted in 1912. Textbooks range from the first “Barometer manual for seamen” by FitzRoy to the recent “Meteorology for aviators” and “Handbook of statistical methods in meteorology”. Periodicals include the annual *British Rainfall* and the monthly *Meteorological Magazine* which came to the Office with the British Rainfall Organization in 1919, and the *Marine Observer* published quarterly since 1924.

By the end of 1954 the Office organization had grown under the Director and Principal Deputy Director to three Deputy Directorates—one for Research, one for Forecasting and Public Services, and one for Services covering the needs of the Army and military and civil aviation, twelve Divisions under Assistant Directors, and 25 Branches with a total staff of about 3,000.

## **FITZROY AND WEATHER FORECASTS**

By SIR GEORGE SIMPSON, F.R.S.

Reprinted, by permission, from “The development of weather forecasting” in *The nineteenth century and after*, London, 1911, 1927, p. 557.

It is a remarkable fact that it was only in the middle of the nineteenth century, just when steam was about to make ocean navigation independent of the winds and largely independent of the weather, that maritime nations realized the

necessity of knowing the prevailing winds and ocean currents in all parts of the world in order to make safe and rapid voyages. Largely as the result of the work of Lieutenant Maury, of the United States Navy, an international conference met in Brussels in 1853 to organize an intensive study of marine meteorology in order to obtain the data so urgently required for navigation. The British Government was represented at the conference, and in the following year it was decided that the Board of Trade should establish an office for the discussion of the observations which it was proposed to make. Before doing so, however, the Board of Trade very wisely decided to consult the Royal Society "as to what are the great desiderata in meteorology", not only on the sea, but also on the land. The reply of the Royal Society is a model of what such replies should be; it stated in simple language the problems to be solved and suggested the lines along which they could be attacked.

The Meteorological Department of the Board of Trade was formed with Admiral FitzRoy, who had commanded the *Beagle* when Charles Darwin made his voyage, at its head, and the letter of the Royal Society became the instructions under which it commenced its labours. It is fascinating to a meteorologist to read what the Royal Society had to say about meteorology 73 years ago, when meteorology, as a separate science to be fostered by Government, was about to be born; but it is what the letter does not say which is the most significant. From beginning to end there is not a word about what has now come to be called weather forecasting, nor is there the slightest indication that the drafters of the letter even considered the possibility of foretelling the weather.

FitzRoy commenced his work of collecting, tabulating, and discussing observations from the sea at his new office in Parliament Street in 1854, and all went smoothly for a number of years. But in 1859 an event occurred which slowly but surely changed the whole of his attitude to meteorology, gave the English language if not a new word, at least a new phrase "weather forecast", and laid the foundations of what has become a very important branch of applied science.

In 1859 the British Association held its annual meeting at Aberdeen, and the Prince Consort was its President. The Council of the Association decided that an attempt ought to be made to make use of telegraphy to warn distant ports of the approach of storms. A resolution to this effect was communicated to the Board of Trade, who instructed Admiral FitzRoy to get into touch with the Committee of the Association dealing with the matter and to prepare a plan for an experimental trial. Two meetings were held at Buckingham Palace, when it was decided to divide Great Britain and Ireland into three "weather districts" and "to appoint a few officers (only three or four in each district) to send occasional messages according to specified readings of the instruments supplied". These messages were to be exhibited at Lloyd's and transmitted to the other co-operating stations for conspicuous posting. It is quite clear from the wording of the original resolution that no attempt to foretell the weather was contemplated; the system was simply a method by which one port could inform other ports and Lloyd's that the weather was disturbed in its neighbourhood.

Concurrently with these developments in England similar events were taking place in France, where M. Le Verrier, Senator and Director of the Imperial Observatory at Paris, had organized a daily service of telegraphic weather reports from a number of Continental stations to Paris. He wrote to Professor

19 Oct 1861

My dear Admiral

I have just come to town  
I found your instrument,  
letter, and the pamphlet.

I have placed the instrument  
in the yard of the lighthouse  
in a place I think sufficiently  
open yet where no sun  
shades. We have Hampton  
Court in a week or two.  
I should not need if it

were there.

The instrument is an  
old friend of mine and  
used to take my attention  
very much when I was younger.  
It interests I think of Galileo  
Water Barometer of Blagden and  
Hydrostatic of Arminius  
- but I do not know the pre-  
cisions or perhaps all this.  
mechanics - I could never make

out more than that it was affected  
by changes of temperature. I hope  
ple with mine or help report -  
the time being important in  
relation to the appearance of the  
crystals.

If you can refer any of the  
changes to fog or to wind -  
independent of change of temp.  
- then you may perhaps discover  
something good in the matter.

Yours  
My dear Admiral  
Yours truly  
Admiral Fitzroy  
M. Faraday

## LETTER TO ADMIRAL FITZROY FROM MICHAEL FARADAY

The instrument referred to in this letter from Michael Faraday to Admiral FitzRoy is the old-fashioned "weather glass". Its method of operation remains something of a mystery!



VICE-ADMIRAL ROBERT FITZROY, C.B., F.R.S.,  
SUPERINTENDENT OF THE METEOROLOGICAL OFFICE  
1855-65



R. H. SCOTT,  
DIRECTOR OF THE METEOROLOGICAL OFFICE  
1866-1900

Airy, the Astronomer Royal, asking for the exchange of observations, and FitzRoy, to whom the inquiry was referred, was very willing to co-operate. To effect this exchange it was necessary for FitzRoy to obtain daily instead of occasional messages from his reporting stations, and this he arranged in the summer of 1860. Le Verrier's object, as that of the British Association and probably that of FitzRoy himself at this time, was simply to issue warnings to ports when a storm was definitely known to be in existence.

In order to inform the ports when the weather was disturbed a system of visual signals consisting of cones and drums hoisted on masts in conspicuous positions was inaugurated, and the necessary apparatus was supplied to fifty ports. In February 1861 the first storm signals were hoisted at British ports on instructions from the Meteorological Office in London.

FitzRoy was very much interested in foretelling the weather, and had already drawn up "Instructions for the use of the barometer to foretell the weather". It is, therefore, not surprising that as he contemplated each day the messages from the various parts of the country he should feel in a position to say what kind of weather was to be expected in each district, for he had only to apply the same rules to the observations which he received by telegram as he applied to those made locally to obtain equally satisfactory forecasts. Prognostications of this kind began to play a part in his storm warnings, which now became intelligent anticipations instead of mere reports of existing conditions. By August 1861 FitzRoy felt so confident of his ability to indicate the probable future weather that he decided to publish in the daily Press what he called "forecasts". The choice of this word was carefully considered, for, in his own words, "Prophecies or predictions they are not; the term forecast is strictly applicable to such an *opinion* as is the result of a scientific combination and calculation, liable to be occasionally, though rarely, marred by an unexpected 'downrush' of southerly wind, or by a rapid electrical action not yet sufficiently indicated to our extremely limited sight and feeling". The word *opinion* is in italics in the original.

This development of science in the direction of the weather prophet and maker of almanacs much disturbed men of science. Le Verrier in Paris had strongly appealed to FitzRoy to go slowly, and not to run the risk of ruining the storm-reporting service by trying to predict storms before he was in a position to do so. The feelings of Fellows of the Royal Society can be as easily imagined as described; but FitzRoy, supporting himself on the obvious public demand for his forecasts and on favourable reports of the storm warnings which he received from the ports, was not to be deflected from his path. The following statement, which he quoted to show the effect of his forecasts in an address delivered before the Royal Institution in 1862, is rather amusing: "At a recent meeting of the shareholders of the Great Western Docks at Stonehaven, Plymouth, it was stated officially that the deficiency [in revenue] is to be attributed chiefly to the absence of vessels requiring the use of the graving docks for the purpose of repairing the damages occasioned by storms and casualties at sea".

FitzRoy had the encouragement of seeing his example copied all over Europe. Le Verrier in Paris organized his storm-warning service, and even started daily forecasts, but he soon dropped the latter. Storm-warning services were established in Germany, Holland and Russia, while Denmark, Sweden, Hanover, Hamburg and Oldenburg all asked to be warned by the London Office of storms which were likely to affect them.

Weather forecasting occupied more and more of FitzRoy's time, and he took his staff off their legitimate work of collecting and discussing marine observations to help in his forecast service. Less and less money was spent on instruments and other expenses connected with the marine work, while more and more was spent on telegraphing and storm warning.

It is interesting to consider the methods employed in this early period of British weather forecasting. It must be remembered that the mapping of weather information on what are now called synoptic charts was in its extreme infancy, and although FitzRoy had himself employed such charts in a rudimentary form in his investigation of the great storm which wrecked the *Royal Charter* in 1859, he did not employ them for making his daily forecasts. I have already stated that FitzRoy had drawn up a number of rules for interpreting the readings of a barometer. They were purely empirical rules without any scientific basis except that of observation. As an example, three of his forty-seven rules may be quoted:

17. If the barometer has been about its ordinary height, say near thirty inches, at the sea-level, and is steady or rising, while the thermometer falls, and dampness becomes less, north-westerly, northerly or north-easterly wind, or less wind, less rain or snow, may be expected.

18. On the contrary—if a fall takes place, with a rising thermometer and increased dampness, wind and rain may be expected from the south-eastward, southward, or south-westward.

19. In winter, a fall, with low thermometer, foretells snow.

Empirical as FitzRoy's rules are, they are wonderfully correct, and there is hardly a single one for which a scientific reason cannot now be given, although the reason was entirely unknown to FitzRoy.

Each morning reports were received by telegram from sixteen stations in the United Kingdom and from four stations on the Continent, the latter being received from Paris in exchange for the messages sent to Le Verrier. A list of the observations was made, and then by simple inspection of these returns forecasts for different parts of the country were prepared. No notes or calculations upon paper were made; the operation was conducted mentally and occupied about half an hour. As soon as the forecasts were made they were sent to the newspapers, and if storms were foretold notice was sent by telegraph to the ports to hoist the storm signals.

In April 1865 Admiral FitzRoy died, and the Board of Trade, who had evidently become uneasy regarding the changes in the Meteorological Office, considered this a good opportunity to have the whole position investigated. They again sought the help of the Royal Society, and a small committee, with Mr. Francis Galton as chairman, was set up for the purpose. The committee was shocked at the way in which the programme laid down by the Royal Society in 1855 had been neglected, and at the great accumulation of marine observations which had received little or no attention in the Office. We are not, however, concerned here with this aspect of the committee's report, but the following question and answer may appropriately be quoted:

*Question 4.* Assuming that the system of weather telegraphy is to be continued, can the mode of carrying it on and publishing the results be improved?

*Answer.* The system of weather telegraphy and of foretelling weather is not in a satisfactory state. It is not carried on by precise rules; and has not been established by a sufficient induction from facts. The storm warnings have, however, been to a certain degree successful, and are highly prized. We think that the daily forecasts ought to be discontinued, and that an endeavour should be made to improve the storm warnings, to define the principles on which they are issued, and to test those principles by accurate observations.

On receiving the report of the committee the Board of Trade realized the difficulty of a Government Department controlling a purely scientific service, and they proposed to the Royal Society that the latter should appoint a committee to take over the management of a reorganized Meteorological Office. The Royal Society agreed to this proposal only on the condition that storm warnings and weather forecasts should be dropped. The Board of Trade accepted this condition, and at the end of 1866 the management of the Meteorological Office passed into the hands of a strong committee appointed by the Royal Society.

Thus ended in apparent failure the first attempt to issue official weather forecasts in this country; but the reputation of the great admiral, the first official meteorologist, in no wise suffers. He was a true pioneer, and if he had any fault it was the praiseworthy one of refusing to be deflected from his path by the advice of more timorous men, but facing his difficulties and frequent failures without losing confidence in achieving the great task which he had set before himself. And one wonders whether his failures were so real as made out by the committee. FitzRoy knew more about the weather and the sequence of its changes than any man then living; therefore, when fortified by his daily reports, he could tell the public more than they knew, or could possibly know, of what weather to expect. Surely this was something gained and was better than passive ignorance. But the committee realized this fully, and I will let them speak on FitzRoy's behalf by quoting the last paragraph of their report:

We feel moreover that we should be doing great injustice to ourselves if we were to allow it to be supposed that we under-value either what the late Admiral FitzRoy attempted or what he effected. To his zeal and perseverance is due the credit of establishing a system of storm warnings which is already highly prized by the seafaring class; and, if a more scientific method should hereafter succeed in placing the practice of foretelling weather on a clear and certain basis, it will not be forgotten that it was Admiral FitzRoy who gave the first impulse to this branch of inquiry, who induced men of science and the public to take interest in it and who sacrificed his life to the cause.

The Meteorological Office came under its new management at the end of 1866. At once a circular was issued suspending the storm warnings, and the issue of forecasts was discontinued. Immediately there was a great popular outcry. Memorials praying for the restitution of the storm warnings were forwarded from several ports, and questions were repeatedly brought before Parliament. The Board of Trade felt their hand forced, and they requested the committee "to give some intelligence of storms in such a manner as they might think fit". The committee had to bow to the popular demand, and they agreed to issue a communication as soon as a storm or a serious atmospheric disturbance *existed* on some part of our coasts. This was simply a return to the original idea of issuing warnings which were only statements of fact and not of opinion. Still public opinion was not satisfied, and the demand for forecasts continued. The British Association at their meeting at Dundee in 1867 passed a very strong resolution praying for the restitution of the FitzRoy system. To all requests for forecasts the committee turned a deaf ear.

The Meteorological Office, however, did not let the matter rest in this *non possum* state. The daily messages from the telegraphic reporting stations were continued, and a daily weather report was published containing the observations and a general statement of the weather over the British Isles, but no forecast. Each day the observations as they were received were plotted on charts, and these were carefully studied. In the meantime Buys Ballot had enunciated the

law which goes by his name connecting wind force and direction with the distribution of barometric pressure. In this way the study of the weather by means of synoptic charts was inaugurated, and it was soon found that the weather map was a more powerful aid to systematizing and interpreting weather changes than FitzRoy's rules. It was found that the weather bore a very close relationship to the type of isobars shown on the maps. Barometric depressions as the cause of cyclonic storms had long been known; now the areas of high pressure, to which Galton gave the name of anticyclones, were recognized also as regions of very characteristic weather.

As this improved knowledge slowly accumulated the temptation to use it became irresistible. Although the very idea of issuing forecasts remained anathema to the committee, the Director of the Office, to whom "the issue of storm warnings, etc., has necessarily been confided by the committee", slowly and cautiously introduced the element of anticipation into the warnings, and from a report which he made to the committee in 1876 it is clear that he was then making great use of his daily synoptic charts in determining the development and future movement of storms. Thus again the Meteorological Office started down the slippery slope of forecasting which FitzRoy had so disastrously trodden and in exactly the same way, except that now weather maps replaced verbal rules.

In 1877 another change was made in the management of the Office. The appointment of a committee by the Royal Society to manage the Meteorological Office had always been considered to be a provisional arrangement, and at first it was suggested that it should be appointed for three years only; but, as a matter of fact, it retained control until 1877, when, owing to difficulty with the Scottish Meteorological Society, it was decided to replace the voluntary committee by a paid council. This change made no difference at first in the attitude of the Meteorological Office towards the issue of forecasts; but in 1879 the council decided that the knowledge of the sequence of weather had been so much extended by the study of synoptic charts that the issue of forecasts, which had now been discontinued for thirteen years, might be recommenced.

The complaint of the committee which investigated the work of the Meteorological Office on the death of Admiral FitzRoy had been that the system of forecasting employed by FitzRoy "is not carried on by precise rules: and has not been established by a sufficient induction from facts". To forestall a similar complaint against the new series of forecasts the council asked the Hon. Ralph Abercromby, an experienced sailor, a keen observer and an acute meteorologist, to formulate the rules employed in the official forecasts. The result was a small book published by the council under the title "Principles of forecasting by means of weather charts". It throws a sidelight on the attitude of the council to forecasting at this time that they should ask an outsider to prepare an account of the methods used in the Office, and even then that the author should state in his preface:

It must be understood that the Meteorological Council, although authorizing the publication of the work [he had already said that it had been undertaken at the request of the council], accept no responsibility for the opinions it contains, which are therefore to be regarded as those of the author alone.

In 1880 the Meteorological Office had reached the stage at which modern methods may be said to have commenced; a copious supply of observations was received daily by telegram from fifty well spread stations in the United Kingdom



and on the Continent; synoptic charts were drawn and a method with some claim to being scientific, although quite as empirical as FitzRoy's, was used to prepare the forecasts. All future advances have been developments along these lines making use of wireless, aeroplanes, radar and television, all undreamed of by FitzRoy, leading to the great organization described on other pages.

## **THE METEOROLOGICAL OFFICE AND THE FIRST WORLD WAR**

By E. GOLD, D.S.O., F.R.S.

The first outstanding impact of meteorology on military operations in the war arose from the bombing of east coast towns by Zeppelins (airships) in the spring of 1915. In those days there was no observation of upper winds in, or above, a cloud layer, and very little on other occasions. The only effective guide to the upper wind was the geostrophic wind (gradient wind as it was then called). It was clear as daylight from the synoptic charts, even reduced as they were, that the Zeppelins had been carried north and east of their target, London, by a SW. geostrophic wind of which they had no knowledge prior to, or during, their passage across the North Sea. When the Director, Dr. Shaw, brought this to the notice of the appropriate authorities, they began to think more seriously of meteorology as a factor in war.

(It was a later disaster to Zeppelins, on October 19, 1917, through failure to allow for the effect of a warm air mass to the west in turning a weak southerly wind at low levels into a strong northerly wind at very great heights, that was the occasion of my origination of the term "thermal wind".)

Almost simultaneously with the 1915 Zeppelin event, occurred the German gas attack near Ypres, in violation of the convention to which Germany was a party, prohibiting the use of gas in war. At that time a gas attack could be made only with a wind which would drift the gas released from cylinders in the direction of the enemy and do so without dispersing it too rapidly to let it reach the enemy in effective concentration. Thus the decision to retaliate naturally brought meteorology directly into the field of British offensive military operations, and the need for a meteorological service with the Army in France, obvious to the meteorologists, became clear also to the soldiers.

After the outbreak of war, July 28–August 4, 1914, the meteorological information received was limited to that from the British Isles and France, and some reports from Spain and, later, from Scandinavian countries. At first forecasts continued in the Press and the *Daily Weather Report* was issued, though subsequently issue to the public was only after a fortnight's interval, and publication of forecasts in the Press was stopped. Meteorological information for the British Expeditionary Force in France was supplied direct from the Meteorological Office in London (without any adequate reports of conditions in the area of operations in France). Now a detachment—or rather a couple of officers—was to be sent to France. They were described as the "Meteorological Field Service", which in fact they grew into, though the name was changed within a few months to Meteorological Section R.E. and abridged generally to "Meteor".

The general organization of the military meteorological services was in the charge of Maj. H. G. Lyons, R.E. acting for the Director of the Meteorological Office. The staff of the Field Service for France consisted of a meteorologist

of the rank of Captain (E. Gold), and a professional assistant of the rank of Lieutenant (A. E. M. Geddes), the latter "for upper wind observations", commissioned in the General Infantry, and stationed at General Headquarters. Technical or clerical assistance was to be provided by the Army in France. There were to be reserve officers at "Home" ready to exchange duty with the staff on Field Service.

Briefly the major functions of the service as then visualized by the military authorities were to provide: (a) meteorological information for offensive gas operations and defence against enemy gas operations (this was primarily existing and expected direction and strength of the surface wind); (b) forecasts for "battles", wind, weather, cloud and, later, visibility; (c) meteorological information for the Royal Flying Corps, mainly cloud and wind at flying heights, fog and line squalls; (d) the regular issue of general weather forecasts for use in the varied work of the Army; and, later, (e) the supply of information (at short intervals of time and quickly enough for it to be applicable at the time of its receipt by the gunners) of the wind and temperature at the different levels up to the vertices of the trajectories of shells fired from guns and howitzers. An account of this last function, one of the most important parts of the work of the section, has been given in an article in the *Army Quarterly* for October 1943. It introduced into practice the "equivalent constant wind" and "equivalent temperature".

Almost simultaneously with the establishment of the Meteorological Field Service, the Gas Adviser in France, Lt-Col. C. E. Foulkes, arranged for one Meteorological Officer, commissioned R.E., to be included in the establishment of each of the two "Special Companies" which were being formed for offensive gas operations. It appeared to me essential to have a single meteorological service under one control. I discussed this with the Gas Adviser who agreed and the two officers joined the staff at St. Omer (G.H.Q.) and assisted in the preparations for the first gas attack.

The basic meteorological information which furnished our "stock-in-trade" consisted of 5 telegrams daily from London, giving forecasts and coded reports in five-figure groups, 20 groups at 2 a.m., 100 groups at 9.30 a.m. and 80 groups at 7.30 p.m. It was at once apparent that meteorological observers were required to make observations in the British Army area, especially near the front about 50 miles from north to south but in process of extension to about double that distance. None of the staff of the Office could be spared, but four men of meteorological experience already in the Army were transferred, namely J. Durward (of the 4th Gordon Highlanders, the first to report on June 16 and for some time our only assistant), R. Pyser, L. G. H. Lee, and F. J. Parsons. Capt. C. J. P. Cave, who had been commissioned as the reserve Officer, came out on July 7, and undertook the instruction and posting of the local observers of whom 12 were obtained from the Artists Rifles.

The Meteorological Service grew naturally as the Army gradually realized its value. After the battles of Loos and Hulluch in September and October 1915, the Service, which then had no recognized place in the general Army organization, was formally established as "The Meteorological Section of the Royal Engineers" with a Commandant (Major), Captain, 6 Subalterns, 2 Sergeants, 16 Corporals, 1 clerk and 6 batmen; a car for the Commandant, 3 motor cycles for the subalterns and 2 bicycles for the observers not located close to their observation posts. From time to time this establishment was increased;

in 1918 it was 16 Officers and 82 other ranks, with 5 Officers and 20 other ranks attached from Sound Ranging solely for meteorological duties. A further increase to 28 Officers and 187 other ranks was agreed by the Army later in 1918.

The Service began as a purely G.H.Q. establishment, but already by the end of 1915 it had been agreed that there should be a Meteorological Officer at each of the, then three, armies. These started in 1915 as Lieutenants, under a later establishment they became Captains, and provision was made in the final establishment for them to be Majors but the Armistice came and the promotion never took place. The Commandant was promoted Major at the end of 1915 and Lieutenant-Colonel in 1918. Sanction for the latter promotion, agreed by the Commander in Chief in France, was delayed by the War Office until the promotion of Maj. H. G. Lyons had been effected. It was largely due to this delay that the Officers did not get the promotion to Major which they had so long deserved. The section in France became, after March 31, 1919, the Meteorological Section of the British Army of the Rhine under the command of Maj. A. H. R. Goldie.

In December 1917 a detachment was sent to Italy where it remained until the beginning of 1919. It was initially under the command of Capt. A. H. R. Goldie, who wrote "It is worthy of remark that after some initial difficulties the British part of the weather charts was usually completed first both in our own Office and in that of the Italian Aerological Section. It is also noteworthy that the Italian Aerological Section could receive the French data more quickly *via* the British Sections in France and Italy than direct from Paris or *via* the French Section in Italy. These facts impressed the Italian Section with a great respect for British meteorological organization and British telegraphy."

In 1918 a detachment from the Section, under the command of Capt. D. Brunt, went to the Independent Air Force, whose Headquarters were near Nancy, and there gave meteorological advice vital to their operations and greatly appreciated by Gen. Trenchard and his staff.

The use of meteorological information for the offensive use of gas in connexion with the Battle of Loos in September and Hulluch in October 1915, when cylinders discharged from the trenches were used, and later for attacks in which "projectors" were used, is outlined in the article in the *Army Quarterly* for October 1943. The brilliant use, by Capt. Bispham and Capt. Lamb, of katabatic winds, which provoked the enemy's comment that the British used gas when the meteorological conditions didn't justify it, ought to be specially mentioned.

After the Battle of Loos in the winter of 1915-16 when it was expected that the enemy would make further gas attacks, meteorological observations were communicated direct to Divisions whenever the wind was from a quarter favourable for enemy gas attacks, to enable the gas alert to be instituted when it was necessary and only when it was necessary.

It was in connexion with the information required for the use of or defence against gas that the airmeter was introduced to measure the wind at about 4 or 5 ft. above ground level in an open situation. As a result of examining a number of airmeter observations in which the values of speed at 2-min. intervals and the values of direction at intervening 1-min. intervals over a period of about 20 min. were measured, Capt. Goldie discovered the relation  $v/V = \sin \frac{1}{2}A$  where  $v$  is the range of values of speed,  $V$  is the mean speed, and  $A$  is the angle through which the direction varies.

The main information required by the R.F.C. was naturally forecasts of weather and cloud, including cloud height, and visibility. When night flying developed, the upper wind became of great importance. At that time, it was extremely difficult to get observations of upper wind at night and trials were made with electric lamps and with flares but they were not very successful. Sir Napier Shaw sent out some Chinese lanterns but the candles in them blew out when the balloon was released. In November 1916, Lt Bispham tried covering the top of the lantern with the thin metal lid of a cigarette tin and got an ascent to over 3,000 ft. The method proved very successful, and the balloons were watched to as great a height at night as in the day-time. The ingenuity of N.C.O's at the pilot-balloon stations soon enabled them to devise a lantern which could be made, and was made, at the stations.

In connexion with the observations by pilot balloons, the computations were originally done by slide-rule after the ascent had been completed, and the computations took nearly an hour after an ascent lasting half an hour. At the beginning of 1916, with the assistance of Lt Entwistle and Corp. Durward, the procedure was simplified, and instructions prepared which shortened the time for computation very substantially; and after observers had become accustomed to the new method, they were able to do the computations during the ascent of the balloon and complete it within 2 min. of the end of the ascent. This was of outstanding value not only in connexion with the information about upper wind required by the R.F.C. but probably, even more important, in accelerating the issue of information for the Artillery.

A kite balloon was also obtained for meteorological observations. It soon appeared that the observations of wind from the kite balloon were affected by the balloon itself, when the anemometer was placed in its usual position on a trapeze above the basket. These speeds were about 40 per cent. higher than those measured by an anemometer 20 ft. below the balloon and 60 per cent. higher than the speeds obtained by observation of free balloons.

The account of the meteorological arrangements for the Battle of Loos has been given in some detail in the *Army Quarterly* for October 1943. The same article contains a summary of the relevant meteorological facts for the other main battles of the war. The outstanding importance of the success of the forecasts prior to and for Loos was that they established a degree of confidence in the meteorological service which enabled the service to develop and secure a comparatively high degree of use of meteorological information during the war.

The recognition of the importance of visibility was slow in development. It was however emphasized in the preparation for the battle of Cambrai, but the strategic use of predictable natural fog was never adequately examined or applied.

Early in 1918 meteorological aeroplanes were allotted by the R.F.C. and initially were flown by Lt G. Marden and Lt E. H. Sessions. Later, in May 1918, Capt. C. K. M. Douglas became available for meteorological work, and he and Lt Sessions provided not only observations of temperature and humidity up to a height of about 14,000 ft. but also a very illuminating series of cloud photographs from aircraft. The upper air observations of temperature found their most regular application in the preparation of the reports for the Artillery. Naturally, they also proved useful as aids to forecasts. Perhaps the most notable example was at the beginning of the final offensive of the war in August 1918. Gen. Rawlinson, who was commanding the army which initiated the final

series of attacks, consulted me about the weather and I was fortified in my assurance to him that appreciable rain was not to be expected, by the fact which I quoted to him "that the temperature in the upper air was high and the atmosphere therefore stable" (a reason to be used with discretion, in the light of the rest of the synoptic situation).

From the outset copies of the synoptic chart were prepared, at first in very limited numbers by hand, and distributed both at G.H.Q. and A.H.Q. Later, on the instigation of Capt. Goldie, "clay copiers" were introduced which permitted the preparation of a complete local *Daily Weather Report* and a wider distribution, and a new departure, colouring red the isobars of pressure above normal.

It became clear during the war in France that the standard meteorological observations and the code for reporting them were quite inadequate to provide the basis for the preparation of the forecasts required in military operations. Consequently a new code was prepared and used for reports from the stations of "Meteor". It included in addition to the information in the standard code (a) visibility by one figure on a logical scale of distances, which is one of geometrical and not of arithmetical progression, (b) the form and amount of low cloud and of medium or high cloud, (c) the relative humidity, (d) present weather by two figures, (e) past weather by two pairs of figures to permit of reporting a sequence, (f) rainfall twice daily, and (g) maximum day temperature and minimum night temperature.

The code was discussed at a meeting with French meteorologists in London in July 1918, and in the spring of 1919 it was included, substantially without change, in the International Convention for Air Navigation, with the concurrence of the United States meteorological representative at the Peace Conference. The code formed the basis of the codes subsequently adopted by the International Meteorological Organization and was used generally in the interwar years and during the Second World War. The only major change was in the reduction of the scale for past weather to a single-figure scale; this deprived meteorologists of information of substantial assistance.

Another development was the inclusion in the regular forecasts of the expected day and night temperatures. Not until after the lapse of 30 years was it possible to persuade the Meteorological Office to include this information in its regular forecasts.

It would be unpardonable to omit from this account a grateful acknowledgment of all that the Meteorological Office in London did to facilitate the work of the Section in France. First and foremost by the ready, regular and prompt despatch of the collective messages; then by the preparation and issue of numerous forms and blank charts, both general charts and special detailed contour charts of the Army area for plotting local observations; and for the provision of instruments both standard and novel such as the swinging plate anemometer and the accessories for the field use of the airmeter; and improved theodolites and balloons more in number than the sands of the sea.

This article has dealt mainly with the initiation by the Office of the Meteorological Service with the armies in France and the development there in the application of meteorology in the war by land and in the air. The work of the Office for the Navy and the development of the Naval Meteorological Service would require a separate article for a description at all adequate of it.

The same remark applies to the Meteorological Service with the Expedition to the Dardanelles and subsequently to Salonika. This was under the command of Capt. E. M. Wedderburn, who became the leading expert on the problem of the meteorological corrections to gunnery and the refinements necessary for the proper computation of the "equivalent constant wind".

Similarly only brief mention can be made of the detachment which went to north Russia in 1919, officered by Capt. W. H. Pick and Lt M. A. Giblett. Out of this came Pick's *Professional Note* on upper wind and the discovery that at Murmansk the wind in the first 2,000 ft. often backed continuously from the surface wind, when the latter was NE., contrary to the usual veering of the upper wind.

## THE METEOROLOGICAL OFFICE AND THE SECOND WORLD WAR

By J. M. STAGG, D.Sc.

Weather has been a decisive factor in the fate of famous battles through the centuries. For all we know some of the commanders concerned may have consulted the meteorological oracles before engaging their forces; but when the history of meteorology comes to be written it will surely be recorded that it was not until 1915 that a commander decided to commit his troops on the basis of a scientifically prepared weather forecast. By the outbreak of the second world war meteorological advice for military operations on land and sea and in the air had become so much appreciated that the meteorological officer was brought on to the commander's staff at the planning stage, and he could influence decisions on even the largest scale of operations. History will also record that it was more than a coincidence that two of the major advances in weather forecasting were related to those two wars: the development of the idea of fronts and the introduction of three-dimensional analysis as a regular and indispensable procedure in the preparation of forecasts.

To the Director of the Meteorological Office, who in the years before 1939 had to make many decisions about the shape of the organization that would be needed in war time, it was encouraging to know that the fighting services had come to value the help which meteorology could give them. Many of the pre-war decisions were important and far reaching and stood the test of the whole war basically unchanged; a new meteorological organization for the R.A.F. commands and a teleprinter network for rapid collection and distribution of information were two examples. But no one could have foreseen the problems of recruitment and training of a staff that grew from 750 in March 1939 to nearly 6,800 in 1945, or the difficulties created by this rapid dilution of experience in working with a still largely empirical science—difficulties that were certainly not diminished by the range of operational activities on which the Meteorological Office was called upon to advise or by the necessity for deploying the available staff in small and widely dispersed units. Nor was it possible in 1939 to anticipate the radical changes in forecasting practice that were to result from the experiments then in progress at Larkhill on the measurement of high-level winds by the use of radio-triangulation methods. Before long these measurements were developed to a state that allowed similar stations to be set up elsewhere in the British Isles, and much improved information about the atmosphere in all conditions of cloud and visibility became regularly available for the first time.

The first actual moves towards a war-time footing were carried out quietly and smoothly before war was declared. In the latter part of August 1939 the main forecasting centre moved from London to a temporary home in Birmingham, and a few days later those forecasters and assistants who had been selected to meet the first urgent requirements of the Royal Air Force were redistributed to take up their war-time stations at new airfields. On September 1 full security restrictions were imposed on the use of meteorological information; from then until May 1945 all broadcasts of synoptic data in clear were stopped and many limits were set to the issue of weather news to the public. An advance party of meteorological detachments for the expeditionary force arrived in France on September 3, and about the same time the machinery for recruiting and training new staff was set going. The first batch of 40 volunteer officers from other professions were mobilized into the meteorological branch of the R.A.F.V.R., and by the middle of the month those volunteers, along with newly entered civilians who had been recruited into special war-time grades, formed the earliest of what was to be a long series of classes in the Meteorological Office Training School.

With the heavy responsibility laid on the Royal Air Force from the outset it was natural that the biggest demands on the resources of the Office should be for observing and forecasting units to keep pace with the rapidly increasing scale of operations conducted from airfields in the United Kingdom. At first those units were manned on an emergency basis, big enough to maintain a round-the-clock service for only a limited time; they soon needed strengthening. But as the number of bases needed for R.A.F. operational wings and squadrons increased the attachment of even one additional forecaster or one additional assistant to each airfield throughout a command used up the greater part of the output from the training school and left little for coping with the new calls for meteorological assistance that soon began to come in. These ranged from complete forecasting sections for new group headquarters of Coastal and Fighter Command and for reinforcements for the sections in France and for forecasting facilities to deal with oversea delivery flights—from these to advisers for smoke-screen operations and many other specialized tasks.

The diversity of operational tasks for which meteorological advice and information were sought at this time probably perplexed the Director as much as did the number and volume of the demands. For if the new kinds of duty were to be efficiently performed he had to ensure that some of the best and most experienced staff should form the nucleus of each new unit, and that required frequent redistribution of the available forecasters and assistants. To the war-time entrants who perhaps did not appreciate the need for, much less relish these frequent postings, life as a member of the Meteorological Office staff in those early years must have seemed an irksome business; but the careful dilution of experience was essential if the service was to carry out its obligations, and it certainly paid good dividends when the time came to set up self-contained organizations for operating abroad with combined land and air forces.

It is perhaps relevant while dealing with staff matters to refer to another aspect of life in the Meteorological Office that puzzled many in those early years: the question whether or not staff should be in uniform. The idea at first was that civilian staff should serve the home commands of the R.A.F., particularly Bomber, Coastal and Fighter (where indeed the heaviest burden at that stage fell and where most experience was needed) while the members of

the Meteorological Branch of the R.A.F. Volunteer Reserve would work in theatres of operation overseas. As the reservist strength at the outbreak of war was only 7 officers and 22 other ranks this policy had the consequence that after the expeditionary force to the Continent was manned future units sent abroad would be composed mainly of inexperienced war-time entrants. When other defects became evident, such as the difficulty of interchanging staff between home and overseas stations and the need for ensuring confidential relations between the R.A.F. and Army staffs of home-based (though none the less operational) commands and their civilian meteorological advisers, the whole matter was reviewed. In 1942 all forecasters serving abroad, except those in a few clearly non-operational theatres, became R.A.F. officers with a special kind of commission, and early in the following year most of the forecasting staff attached to operational commands at home were mobilized in the R.A.F.V.R. together with those assistants who had not been directly recruited. It may be noted here that, both as officers and airwomen of the Women's Royal Air Force and as civilians, women took a substantial and honourable share in a wide range of meteorological duties. They were debarred only from service overseas and from forecasting duties at operational stations, though even there a relaxation was made in the latter half of the war when they took equal part with their male colleagues in the briefing of aircrews at operational training airfields.

Meanwhile the Army's needs were not overlooked. The main forecasting section which had accompanied the advanced air striking force to France at the outbreak of hostilities was designed to serve the headquarters of the Army as well as the R.A.F., and many of its ancillary units were trained to work closely with the artillery and with survey regiments. In the next phase of the war when the Army was being re-organized after Dunkirk opportunity was taken to provide meteorological advice at more levels than had been possible with the expeditionary force. A forecasting section was formed at G.H.Q. Home Forces with liaison officers at the headquarters of commands, corps and divisions, and mobile units were established for specialized duties. As the pattern of the new Army crystallized, and more especially as the form of air co-operation with the Army took shape, these arrangements were gradually modified, the main meteorological sections being attached to progressively higher echelons so as to serve a dual role at the joint Army/R.A.F. headquarters. This became the accepted pattern throughout the later stages of the war and was carried into the arrangements for "Torch" and the subsequent campaigns in north Africa and Italy, for the British air and land forces in "Overlord" and its follow-up into Germany, and for the organization based on India and Ceylon.

While this kind of composite organization was being evolved to provide forecasts and weather information to the field forces, sections elsewhere had been attached to the schools for the training of airborne troops; and as appreciation of the advice which meteorology could give to parachute and glider operations gradually accumulated, the separate sections were increased and were merged into a single training and operational organization for airborne forces. This organization became part of No. 38 Wing (later Group), and played an invaluable part in the Normandy landings and the subsequent campaign.

The story of the activities of the Middle East meteorological service from 1940 to 1945 is a history in itself. On the entry of Italy into the war the various services based on the Canal Zone expanded rapidly, and the chief meteorological officer in that area soon found himself in control of observing and forecasting



detachments spread over the Western Desert, Iraq, Persia, Palestine, Trans-jordan, Aden, Syria and Cyprus, and at the same time he had to collaborate closely with the sister services of British East Africa and South Africa. Every major event throughout the area had its meteorological counterpart. Meteorological Office staff were with the forces operating in Abyssinia, in Iraq during the rebellion, in Greece, and in Crete, and throughout the long and anxious operations in the Western Desert which ultimately led to the invasion of Sicily and Italy. There the staff of the meteorological service based in the Middle East linked with the organization from the United Kingdom which had served the British forces in the "Torch" landings in Algeria and in the campaign there and in Tunisia.

During those difficult years in the Mediterranean area Office staff of the distributive and forecasting stations at Gibraltar and Malta continued to serve the air and sea routes that kept the United Kingdom in touch with the Middle East and north Africa. But as these became more difficult to maintain just when greater volumes of traffic had to be handled, the other air re-inforcing route which had been established from west Africa into the Middle East came more into prominence; and to serve this trans-African lifeline forecasting stations manned by staff from the Meteorological Office were set up along the chain of airfields that stretched from the main bases in west Africa, through Nigeria into Sudan and Egypt. Meanwhile on the other (eastern) side of Africa and at Aden the commitments of the Meteorological Office had been steadily stepped up to serve the air force units operating there and in the western Indian Ocean; the interdependent service provided jointly by the Meteorological Office and the British East African meteorological service was further strengthened in 1943 when the British East African service came under control of the London Office.

Farther east in India a completely new organization working in close harmony with the Indian Meteorological Service was formed to provide for the needs of British and allied forces in the war against Japan. Under a chief meteorological officer with his headquarters first at Delhi and later in Ceylon this new service grew in the years 1943-45 into a large and complex organization with responsibilities that extended into Burma and throughout the whole area under the supreme allied commander for south-east Asia.

In the meantime important developments had also been taking place nearer home. The Central Forecasting Office had moved from Birmingham in February 1940 to its permanent war-time home near Dunstable, there to become widely known as ETA, the code name for the evacuation site it occupied. During its short stay in the Midlands the experiments in progress at Larkhill just before the war on the measurement of high-level winds by radio began to bear fruit. The first regular issue to outstations of isobaric charts for the 2 Km. and 5 Km. levels began in January 1940, to be superseded a year later by height contours of the 750, 500 and 250 mb. surfaces. Throughout the war years ETA steadily improved its position as the hub of the British synoptic service, both as the collecting and distributive centre of observations and as the guide and adviser behind the scenes of the great family of forecasting stations attached to British and allied forces. As more upper air data became regularly available and covered an increasingly wider area, a new section was set up within ETA specially to deal with high-level analysis, and in its role as adviser in forecast matters both for the operational forces and for other essential services many important and novel tasks were added to ETA's schedule of responsibilities.

In this work and more especially perhaps for the guidance provided in co-operation with the forecasting sections at all levels in Coastal, Bomber and Ferry (later to become Transport) Commands, the weather information transmitted back to ETA by the meteorological reconnaissance crews on their long and often dangerous flights to the north, south, east and west of the British Isles was invaluable.

If space had permitted a whole section of this article should have been devoted to Meteorological Office participation in the decisions which led up to the allied landings in Normandy, and another to the activities of the large organization, modelled in the light of all the earlier experience of meteorological co-operation with land and air forces in the field, which accompanied the Second Tactical Air Force and 21 Army Group to France, and served them in their campaigns through Belgium and Holland and across the Rhine into Germany. In another category though hardly less indispensable was the work of the forecasters and assistants who found themselves manning isolated units in the Faeroes, in Iceland, in the Azores and in the West Indies, and in the operational training schools in Canada and South Africa. In many if not actually most of those enterprises meteorological staff of other services were more or less intimately involved, either in friendly co-operation as in the case of our own Naval Meteorological Service and the meteorological services of Canada, South Africa, France, Portugal, Iceland and of course the Weather Service of the United States Army Air Force both at home and in other theatres, or by actively becoming war-time members of the Meteorological Office as did many meteorologists from Belgium, Czechoslovakia, France, Norway, Poland and other friendly countries. Both as services and as individuals they gave help that was deeply appreciated.

Even if it had been possible to describe all these operational activities, a section would still remain to be written about the less spectacular though scarcely less valuable work of maintaining the climatological service and adapting it to meet war-time needs, and the heavy task of providing so many new units and stations often at short notice with their equipment and instruments. During the war new instruments were designed, developed and came into operational use, among them the Kew-pattern radio-sonde and the Dobson-Brewer frost-point hygrometer; and from radio direction-finding with a triangle of stations the measurement of high-level winds in all weather conditions was transformed by application of radar into a single-station procedure. These and other developments brought to light for the first time many new phenomena of the higher troposphere and stratosphere and the search for explanations led to the opening up of new investigational ground. This and the creation in 1941 of the Meteorological Research Committee began a new era of fruitful research in the Office.

It has been regretfully necessary in this brief story to suppress the human aspects of all these activities and particularly to omit reference to individual members of the staff. But exception must be made of two officers whose contributions to the conduct of the British meteorological services in those war years were inestimable, the Director, the late Sir Nelson Johnson, and his deputy, Mr. E. Gold. To the Director from first to last fell the responsibility for planning and deciding on the most effective use of his resources in staff and equipment, spread throughout every theatre in which British forces operated—from the Arctic Circle to Capetown, from Canada and the United States eastward

through the length and breadth of Africa, western Europe, the Mediterranean, and the Middle East to India and Burma. The development and control of every aspect of the synoptic forecasting service was in Mr. Gold's hands, and to it he made contributions which are now internationally recognized as corner stones in forecasting practice; among them he brought system and order into the distribution of information and he introduced the prebaratic and prontour charts. Under Sir Nelson Johnson and Mr. Gold the staff of the Meteorological Office during the war years made to the nation's effort a contribution of which any scientific organization could be proud, and one which will always stand out as the finest in the first hundred years of its history.

## **THE METEOROLOGICAL OFFICE FACES THE FUTURE**

### **Scientific Research and Development**

By R. C. SUTCLIFFE, Ph.D.

The request comes to me for an article in a trilogy "looking ahead", a task congenial enough, offering scope for imagination, for an expression of opinion not to be tested against the facts so quickly as were many forecasts one has made, and not calling for the exacting scholarship which a historical survey would demand. Yet it is difficult for one who is only the second holder of a post styled "deputy director for research" to resist a glance backwards.

Research, that is organized and planned research, with scientists recruited within an approved establishment and devoting their efforts to a programme of investigations by much the same sort of arrangement as another group of men may run a factory, is so widely practised today that the newcomer from the university may not realize that it is almost a creation of the present generation, and among the most significant of social changes. "Creation" is not quite correct, "rapid growth" would be better, for there have been distinguished research bodies in existence outside the universities for a much longer period. But when many present members of the staff were looking round for a career they will recall that a life that could be devoted in large measure to research was hardly to be found outside university appointments. And even the universities provided little more than an environment in which personal research might flower protected from economic winds, freely without forcing, yielding the useful and the useless indifferently so that it be but satisfying intellectually. We were not so much different in outlook from the Greeks as is sometimes implied, technical advance lay largely with businesses and engineers, illiterate folk with soiled hands of no account to a philosopher.

In the new scientific phase of social evolution the Meteorological Office might well have been a noteworthy pioneer and to some extent it was; for research needed no specific mention as the pursuit of scientists when the Office was young, and the few scientists who joined the staff took their place quite naturally as men of learning.

As happens not uncommonly in other families, distraction came with a new generation. Weather forecasting, a weakly infant at one time almost despaired of, suddenly with World War I began to develop prodigiously, and for some 30 years was like the cuckoo in the nest affording no one time to think of much else. So the Meteorological Office did tend to lose its pronounced research character to recover it again only when social trends overtook it with World War II. There was no cuckoo, only a troublesome but legitimate child, still awkward

but less all-demanding in maturity, and showing distinct signs of yielding to the influence of his gentler sister research now she has come into her birthright.

When one now contemplates the future part research will play in the Office one must not only respond to the general climate of social philosophy which urges us on to material progress whatever moral philosophy may teach, we must also take a domestic view and realize our special responsibilities.

Practical professional meteorology, meteorology as a useful science, is almost a monopoly of the Office in our country. This is not due to any political bias against private enterprise, if there is such bias it is irrelevant, but simply due to the fact that business other than state business is as yet too scattered and too thinly spread to afford a profitable private harvest. We are, after all, a small profession. If we show our worth we shall no doubt expand in numbers, but at present the whole profession comprises less than 200 scientific staff and some 1,000 "experimental officers". If all these were recruited from the universities and had each a professional life of some 40 years, the average annual intake would be no more than 30, perhaps half a dozen research scientists and a score or more of other graduates. Such numbers could not unreasonably be produced by one university department; our professional demands on the universities are in numbers quite small.

This sort of arithmetic does not take us far with the research outlook, but it is material. For if the universities have limited scope for preparing meteorologists their provisions for meteorological research must at least be affected. The Office is accordingly left with a major responsibility not only for service but also for research and we must provide accordingly.

Another of the facts of life, welcome or not, is that research today is the field for the expert. The unique characteristic of this scientific and technological age is that progress by research is everywhere being forced by organization and directed effort instead of being left to advance in leisurely fashion. It has become almost a race, and anyone whose attention is largely devoted to other matters will in a few years fall so far behind as to be almost out of the future running, unless his genius allows him to start a new line of his own. This is significant for the future of the Office in that it hardly seems possible to envisage an effective organization where individuals are interchangeable and may move from research to general service and then back to research again as promotions and other factors throw up vacancies in the structure. Such an arrangement cannot possibly produce first-rank research scientists, and it is questionable whether it will produce first-rank forecasters or administrators either. Unhurried, voluntary, spare-time research is a fine tonic to the general practitioner or the administrator with a taste in that direction, but a preoccupation with research and an eye always on a future return to full-time activity is not calculated to call forth the full effort on public service and efficient management which these things equally demand.

In some way or another we must therefore look for a system which will allow the research scientist to continue indefinitely on research work in his bent. A drift from research to wider human activity seems to be natural, acceptable and beneficent but it is necessarily almost a one-way transition.

Looking now to the field of research which is open to us we must recognize that we are only just beginning to clear a little space, as it were with our two hands, to allow more elaborate tools to come into play. Meteorology, except in

some special little corners, has for long been a science calling for little more than enthusiasm, painstaking work, common sense and a modest scientific training; until of late the applications of advanced skills either experimental or theoretical have been a rarity. Climatology has consisted of the collection of data and their processing by elementary statistical and cartographical methods; investigations on the synoptic scale, the basis of weather forecasting, have been analytical and cartographical, calling for no recondite technique which could not be acquired by practice granted moderate physical knowledge. Smaller-scale studies, the scale of turbulence, have led to the specialist theory of impressive practical utility, but even here the inspiration lay in the pioneering ideas rather than in abstruse analysis or refined experimentation. Cloud and precipitation physics have made little progress although the deep subtleties were gradually becoming recognized, while instrumentation throughout meteorology called rather for the technical skill of the mechanic than for any out-of-the-way specialist training.

All this has been changed, much during the last decade. The climatologist has not only begun to adapt more rigorous concepts from the specialist science of statistics, but, with the advent of much upper air information, is able to think on physical quantitative lines towards theories of climate and of the general circulation of the atmosphere. In time we shall doubtless be able to describe in coherent fashion the significant three-dimensional behaviour of the atmosphere, of climatic change and of seasonal anomalies, we shall be able to test quantitatively any theory which is propounded and shall know, if not how to predict these changes and anomalies, at least why the practical prediction problem defeats us; we shall certainly in time "understand".

Synoptic meteorology is rapidly becoming a coherent branch of hydrodynamics built up on orthodox lines from the basic physical equations and forecasting is taking on the characteristics of an exact science. Again we can see the road being cleared towards an intellectually satisfying understanding of the problems, and subjective estimates or flair must lose ground continuously to calculation and to statistical judgments. Synoptic and forecasting research has entered an exciting phase and the Meteorological Office is in the heart of the battle.

The basic physical problems of radiation, turbulence and condensation must yield to measurement and analysis until rival theories and speculations give way to established textbook presentations of the subject. While we cannot easily see how every unique event in meteorological history, the individual shower, an occurrence of fog, of stratocumulus cloud, of night frost or pollution concentration, for example, will be analysable or calculable, for we cannot envisage observational techniques to provide the complete specifications of the individual problems, yet we can expect to understand, to know quantitatively what processes are involved, and to know what detail in the meteorological complex is within our practical powers of analysis; our theoretical powers must surely lead towards a satisfying comprehension.

To a very large extent this opening up of the problems to theoretical attack is the result of practical techniques of observation and experiment, and the meteorologist must now go along with physicists and engineers in the elaboration of electronic and other techniques of measurement. The radio-sonde, radar methods, modulated and pulsed-light searchlights for cloud heights and for studying very high levels of the atmosphere, self-recording aircraft instruments, the use of rockets, the ozone spectrophotometer, tracer substances as agents for

the study of diffusion, measurements of radio-activity and chemical analyses of the atmosphere, these are but indications of technical developments requiring high specialist skill and knowledge; the experimental meteorologist must have his eyes continually open for new ideas, and for possible applications of ideas emerging in other fields where the general meteorologist cannot hope to keep abreast.

With our science rather suddenly gaining new vitality and opening up refreshing prospects it is hardly the time to point to its limitations, but, recalling that we are being carried along in the new current of technological progress whose explicit aim is the modification and control of nature for the material welfare of mankind, we might rather humbly admit that so far we play a subservient part. Our advice is sought in many and varied practical ways, but we are the handmaidens of aeronautics, of agriculture and many other technologies and have no unrestricted technology of our own. Ahead of the physicist, the chemist, the biologist or the sociologist there are evidently unlimited realms of "engineering", of creating new materials, new processes, new organisms, new organizations. Ahead of the meteorologist lies the understanding of meteorological phenomena, but will not this field tend to be worked out until it yields only more detailed knowledge at the price of much effort, knowledge affording intellectual satisfaction to the few and of little practical utility? Is pure meteorology to be tidied up, put away in textbooks and merely brought out for re-editing as basic theories evolve, or is it to found a line of technological control of nature rivalling atomic physics or engineering chemistry in economic terms? Of this prospect there are indeed signs.

Setting aside the control of very local climate in human and other shelters as barely meteorology, and recognizing such things as wind and frost protection for agriculture as minor interference with nature, we must look to the control of weather and climate on the large scale. I shall make no facile attempt to predict how this may come about, by planned irrigation, by interference with cloud and condensation processes, by modification to the radiation balance through the control of albedo, by controlling evaporation from the oceans through surface films, by triggering off large-scale dynamical changes at critical phases as some speculators have envisaged. We may have our opinions about the ultimate feasibility of such methods, but it would be foolish to dispose of all of them and all other similar notions as entirely pipe dreams.

Whether or not such a future lies ahead, and whether or not we find the prospect alluring if it does, there is no doubt whatever that meteorology is now a developing science, set on a long road of progress and should be able to attract, challenge and satisfy the most exacting scientific intellects which the country can produce. It seems likely that the Meteorological Office will continue to provide the facilities and the sustenance for much of this effort and they must be the best within our reach.

All is not yet perfect but there is much to afford us pride. Our forecasting research group, recently strengthened, has few rivals in the world. Our new division for climatological research is perhaps unique of its kind and its world-wide studies are welcomed everywhere. Our Meteorological Research Flight provides facilities for direct investigations wherever aircraft can reach, on a scale unequalled in any other single institution. Our efficient and closely knit instrument-development group are pioneering continuously and can hold their own in any circle.

I think we can justly claim that we have within our Office a tolerably well balanced research organization of healthy size, perhaps a little too sparing here and there but with effective punch behind its attack. I look to the future to see essential parts brought physically together in a new Office where mind can strike on mind, where new ideas will fertilize each other. I look for flexibility in organization, permitting the productive research worker to continue his specialist activity not broken unnecessarily by promotions and postings. Our recruitment is excellent, it must become superlatively so by affording the material prospects and, above all, the scientific facilities and freedom which alone can contain the urgent spirit of the true man of science.

If we can in justice say that our research organization is now as vital a body as any of its kind anywhere in the world, we must keep it so by planning gently, restricting our passion to control by taking a balanced view of what is or may be utilitarian, by fostering the wild growth and not too soon marking it down as a weed. I do not think we have much cause for fear.

Finally we may think of our relations with the outside world of science and affairs. Other parts of our Office are eager to develop their usefulness to the community, and they must be backed up by applied research. We must co-operate with and support work in the universities with which, especially through the Meteorological Research Committee and the activities of the learned societies, we have and must maintain the happiest relations. And we must keep in step with the growing internationalism of science by visits abroad, by entertaining visitors from other countries and by making our voices heard wherever scientists are gathered together.

I look to see research work in the Office regarded as an enviable career for the chosen, advancing knowledge towards rich humanitarian ends. It is an attractive future.

### **Services for Aviation and Defence**

By A. C. BEST, D.Sc.

The title to this note distinguishes between aviation and defence, but in fact the present-day concept of the defence of most countries includes active participation by military aircraft. The meteorological services for such aircraft are basically similar to those for civil aircraft, though there are differences in the emphasis placed upon the various types of service. There are, however, a few aspects of defence which are not related to aviation, and we shall refer to these at the end.

It is a fact familiar to most forecasters that an attempt to foresee the future sequence of events is sometimes facilitated by examination of the sequence in the near past which has led up to the present moment. So in an attempt to foresee the nature of the meteorological requirements of the aviation of the future, it may be profitable to consider how the changing pattern of aviation during the past few decades has modified the meteorological needs. Unless we expect some fundamental change in the basic concept of an aircraft, the future services for aviation will need to include all those which are supplied today, together with additional services dictated by the operation of more advanced types.

The earliest aircraft were mechanically unreliable, their ceiling was low and their range short, and navigation was largely a matter of comparing a map with

the country flown over. Since those days the aeroplane has been improved enormously as a piece of engineering. Navigational aids allow the whole flight to take place above the clouds, and the range of a modern aircraft almost removes the possibility of running out of fuel, provided pay load is suitably limited. Many of the earlier hazards have thus disappeared. Their disappearance has emphasized the remaining hazard of the weather. The development of the meteorological-forecast services for aviation has continuously operated to diminish the weather hazard, but has been continuously countered by the completely justifiable wish of the operator to fly, for economic or military reasons, in worse and worse weather. With this pattern behind us, we may expect that the task of the aviation meteorologist of the future will be even more exacting than it is today, until such time as blind landing is fully effective. Commercial competition in the world of civil aviation and tactical reasons where military aircraft are concerned, will together ensure that new devices or procedures for safe flight are also directed to facilitating flight in weather conditions which today would cause postponement.

There is an urgent reason why the meteorologist should endeavour to foresee the future aviation pattern. Aircraft are designed to serve specific purposes, to operate at specific heights, speeds and ranges. The designer needs to know what meteorological conditions will be encountered by the aircraft in normal operation. Generally his need is for meteorological statistics relating to the aspects of weather which will affect the operation of aircraft in use several years hence. But the statistics themselves take a long time to collect if they refer to some variable which is not currently being observed, so that 10 years or so would not be an unduly long time between starting to observe a new meteorological variable and the routine operation of a new-type aircraft affected by that variable. This is particularly true when new air routes are under consideration. In recent years there have been a few transpolar flights. We must expect that such flights will become increasingly frequent in the future, and the meteorologist will be called upon to supply first climatological statistics (for both the surface and the upper air) and later operational forecasts for these little-known areas.

Turning now to the detailed changes which have occurred during the past few decades and which have directly affected the meteorologist, it is convenient to group them under,

- (i) Take-off and landing (including ascent to and descent from operating height)
- (ii) Flight at operating height.

With regard to the first group, take-off and landing speeds have increased significantly. By itself this would imply the need for higher minimum cloud base and better visibility for landing, but this need has been more than cancelled by the development of approach aids and runway marking. The result is that aircraft are now able to land with a lower cloud base or poorer visibility than was possible previously. The higher landing speeds have nevertheless involved longer runways, and it may well be that this factor will restrict any further increase in landing speeds. Approach aids, however, are likely to improve so that we may expect future aircraft to be able to land at a fully equipped airport in worse conditions than are at present acceptable. Naturally it is in marginal conditions that the greatest accuracy in forecasting is required. Unfortunately the marginal conditions for landing aircraft today are already within the range



in which casual variations, both with space and time, are significant. Forecasts of cloud height and visibility must always quote, or imply, a range within which the value will lie. It may well be that the accuracy of forecasting these two variables will improve in the future, but it seems much less likely that we shall be able to be more precise about cloud height and visibility at a given time and place in conditions which are marginal for landing. This is because the range is now largely governed by the residual casual variations which seem quite unpredictable. If this is true there is likely to be an increasing demand for accurate measurements nearer and nearer to the time and place which are critical for an aircraft attempting to land. This, however, is not a complete solution. Aircraft of today—and probably still less those of the future—cannot afford to use a lot of fuel circling an airfield at low level awaiting an opportunity to land. If diversion to another airfield is to be made, the pilot needs to know if possible while still at operational height. There may thus be a requirement in the future for short-period aerodrome forecasts (an hour or two in advance) of cloud height and visibility, the forecasts to give maximum and minimum values.

Temperature at airfield level is important for take-off purposes. For example, in limiting conditions, with the Comet 1 an increase of  $1^{\circ}\text{C}$ . in the ambient temperature decreases the lift to such an extent that the load must be lightened by one passenger. With the present trend in aircraft design it seems that this factor may become of greater importance.

It has always been true that for very short flights, a pilot has tended to rely upon the latest actual weather report from the destination aerodrome. This habit has arisen because the weather changes in a short time are unlikely to be greater than the errors in the forecast based upon a synoptic chart constructed from observations made several hours previously. In this context a "short" flight means one lasting a short time, and even today it is possible for an aircraft to leave London and reach Rome before a synoptic chart based upon observations made at the moment of leaving has been drawn in the forecast office. With the increasing speed of aircraft there is a need to reduce the present interval between the making of observations and the completion of the corresponding synoptic chart. It may be that further developments in facsimile transmission will assist in a solution of this problem.

The meteorological information supplied to facilitate the in-flight operation of aircraft may be conveniently grouped under two headings. There is the information which is designed to assist navigation; this consists primarily of upper winds and, in more recent years, upper air temperatures. The second group deals with the factors which directly affect safety or comfort, and may be said generally to deal with dangerous phenomena. With very few exceptions, aircraft are used as means of transport; the cargo may consist of passengers, freight, bombs, guns and ammunition or other commodities, and all these can be grouped under the title "pay load". The fuel required for a long flight represents a considerable fraction of the total weight lifted, and any increase in the fuel required must be compensated by a decrease in the pay load. The operator usually requires to know several hours before the flight starts what fuel will be required in order that he may plan his pay load. On long trips (e.g. Atlantic crossings) it is sometimes possible to plan a course which, though longer than the shortest crossing, uses less fuel because the headwind component is less. Flight planning such as this is a comparatively recent development, and we may expect it to assume greater importance as the length of non-stop flights increases.

The problem becomes increasingly difficult as the operating height of aircraft increases, owing to the difficulty of constructing satisfactory contour charts for the higher levels. To some extent this difficulty arises from the fact that errors in heights computed from the ordinary radio-sonde ascents are cumulative. Other techniques for forecasting the winds at high levels are being explored. This poses the instrumental problem of providing a method of making upper air soundings to great heights regularly and at a cost which is not prohibitive. The importance of this navigational information has been underlined in recent years by aircraft encountering jet streams.

There is a close connexion between the importance of winds for navigational purposes and the forecasting of landing conditions. Because landing forecasts are not 100 per cent. accurate, an aircraft must carry sufficient fuel to permit diversion to one or more alternate airfields in the event of the primary destination being unfit for landing. This extra fuel is carried at the expense of pay load, and there is an urgent need to reduce this economic handicap.

Turning now to the information which we have classed as "dangerous phenomena", it is interesting to note that the situation is almost continually fluctuating. The vertical currents associated with thunderstorms have always been potentially dangerous. Investigations in recent years have led to the view that the danger can be minimized by appropriate action on the part of the pilot. On the other hand the increased speed of aircraft has increased the risk if it should be caught, unexpectedly, in such conditions. In the early days of aviation, ice accretion was not particularly important because aircraft seldom operated in such conditions. With improved aircraft and instruments, flying in such conditions became more frequent and the meteorologist was called on to forecast the areas where it might occur. More recently the larger aircraft have been equipped to deal with ice accretion, but this in turn involves the weight penalty associated with the equipment. Aircraft of the future may operate at heights where icing is unknown—but they must ascend to this level and, later, descend. Similarly with clear-air turbulence. In the earliest days, it was not encountered. Then for a period it was encountered, but was of no great significance. Now it is recognized as important from the point of view of the passengers' comfort or of the bomb aimer. Each advance in aviation technique is likely to be accompanied by its own meteorological problems. The meteorologist cannot always forecast the significance of meteorological phenomena to aircraft of the future (e.g. how many meteorologists would guess that the size of airborne dust particles may be important in engine design?), but he can make every effort to study the region of the atmosphere in which aircraft of the future will fly in order that he can give the best advice when problems do arise.

So far, we have assumed that aircraft of the future will be of the present conventional type. Nevertheless, there is obviously a probability that vertical-lift aircraft or helicopters may be in common use in the future and it may be profitable to speculate on what, if any, differences this will make to the meteorological services required. If such aircraft could land and take off from airfields of the present type it is probable that the requirements with regard to cloud height and visibility would be much less stringent than at present. Past developments in aviation, however, suggest that, for economic reasons, such aircraft may be required to operate from very confined spaces. The vertical speed, even of present-day helicopters, is very low when landing. This must make them susceptible to the effects of wind gustiness, and this phenomenon is

notoriously accentuated in the neighbourhood of buildings. It is likely then that for aircraft of this type landing on a small landing ground, the pilot will need to see his landing point from a height of a few hundred feet in order to take the action necessary to counter the gusts. The marginal weather conditions may thus approximate to those for present-day aircraft landing on a conventional airfield. More generally, it seems likely that the pilots of helicopters of the future will need more detailed knowledge of the structure of the lowest few hundred feet of the atmosphere than is included in present-day aviation forecasts.

It is improbable that the rotating-wing type of aircraft will ever travel as high or as fast as the fixed-wing aircraft. Owing to this the wind at operational height may be more important than it is with the faster fixed-wing aircraft of today.

Pilotless aircraft flying at great heights and great speeds is another new type with which we may be confronted in the distant future. It is perhaps unlikely that such aircraft will carry passengers—the aircraft in fact may be the descendants of the V.2 rocket. From our present point of view such aircraft—or perhaps missiles is a more appropriate word—may be divided into three convenient categories. The first category comprises those over which there is no control after leaving the launching ramp. The meteorological problems for these will be similar to those for conventional artillery, but the vertex of the trajectory may be substantially higher. The second category comprises missiles which have incorporated within themselves some device for maintaining a prescribed course. Meteorologically these do not seem to pose any additional problems. The third category comprises what are generally known as guided missiles. For such missiles, the guiding inevitably implies control by radio waves, and this introduces a new meteorological problem. Radio waves suffer attenuation during passage even through cloud-free atmosphere. If clouds are present, the attenuation is increased both by absorption and scattering. It may be that in the future there will be a need to forecast the physical characteristics of cloud in this connexion.

To some extent this new commitment is already bringing some compensation in that radar is already in use as a means of observing clouds from the ground. For short-period forecasting for a particular locality this use may well increase.

We have introduced the subject of guided missiles as an extension of the aviation question, but this brings us to considerations of “defence” other than in connexion with aviation. The use of radio waves seems to be increasing rapidly in various defence projects, and since the travel of such waves can be greatly influenced both by the liquid or frozen water suspended in the atmosphere and by the temperature and humidity structure of the atmosphere in the vertical we may expect that there will be an increasing demand for forecasts of such factors. It is unlikely, however, that the use of guided missiles will render conventional artillery obsolete and the need for artillery meteors will remain.

A meteorological problem of defence which is not related directly to aviation concerns the distribution of debris from an atomic explosion. The writer does not know to what height the explosions from present-day atomic bombs may reach, but it seems likely that, in the future, such explosions may reach a height between 100,000 and 200,000 ft. The travel of the debris will then be partly governed by winds at such heights. Whether or not such bombs are ever used, the meteorologist must expect to be questioned about the probable wind there. We may hope that this will never be more important than an academic exercise.

## Forecasting and Public Services

By S. P. PETERS, B.Sc.

Many people imagine the Meteorological Office to be a Department occupied almost exclusively with telling the general public, through the medium of the British Broadcasting Corporation and the Press, whether wet or dry, warm or cold, weather is to be expected during the ensuing 24 hours. Before the First World War 1914-18 this quite restricted responsibility in the matter of weather forecasting did very largely obtain, apart from the supply of information to shipping, but then, as now, there were numerous other scientific activities in which the Meteorological Office was engaged. In the realm of forecasting, however, the passage of the years has been accompanied by ever-growing demands on the Office, and these have represented not only a substantial broadening of the field of application of weather forecasting, but also a very marked increase in the severity of those demands. In this connexion the following extract from the Annual Report of the Meteorological Committee for the year ended March 31, 1915 is significant:—

Up to the middle of November\* there were prolonged periods of quiet, anticyclonic weather during which forecasting was exceptionally easy, while from the middle of November onward there was a very wet boisterous period. Depression followed depression in what may be called normal sequence for weeks on end, and the preparation of forecasts for periods not exceeding 24 hours presented no great difficulty.

Today the detailed information required by various sections of the community to be included in forecasts, and the necessity for advising the probable times of occurrence of particular features of the weather, render outmoded any statement of complacency such as the above. "Quiet anticyclonic weather" can provide forecasters with as much anxiety in regard to the formation or dispersal of fog or of a cloud sheet as "a very wet boisterous period" can do in timing the onset, duration and character of rain, or the arrival of clearing weather associated with a cold front, all of which phenomena are matters of vital concern, directly or indirectly, to some section of the public.

With the rapid development of aviation during the war years 1915-18 a burden of work and responsibility was placed on the forecasting department which was quite unprecedented. To the extent that this was effectively assumed and discharged, competence was acquired to enable a wider and more detailed service to be given to the community in general after the war, and also to civil aviation during the critical early years of its development. In particular, a service of harvest forecasts consisting of notifications to subscribers of the onset of spells of settled weather was inaugurated in the summer of 1919, whilst the supply of forecasts to the B.B.C. for broadcasting with the evening news bulletin began in November 1922.

During the years that followed, and up to the outbreak of the Second World War 1939-45, a slow but steady advance was made in providing forecasting services to meet specialized requirements. After the serious Thames floods which occurred in January 1928, a warning service was introduced by which the Meteorological Office notified certain authorities when weather conditions appeared likely to cause unusually high tides in the Thames. By about the year 1933 the value of forecasts in connexion with pigeon racing had come to be recognized by the organizations controlling long-distance pigeon flights, and the practice became established of obtaining forecasts to minimize the risk of

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\* From the outbreak of war in August.



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SIR NAPIER SHAW, F.R.S.,  
DIRECTOR OF THE METEOROLOGICAL OFFICE  
1900-20  
AND SCIENTIFIC ADVISER TO H.M. GOVERNMENT  
ON METEOROLOGY 1918-19

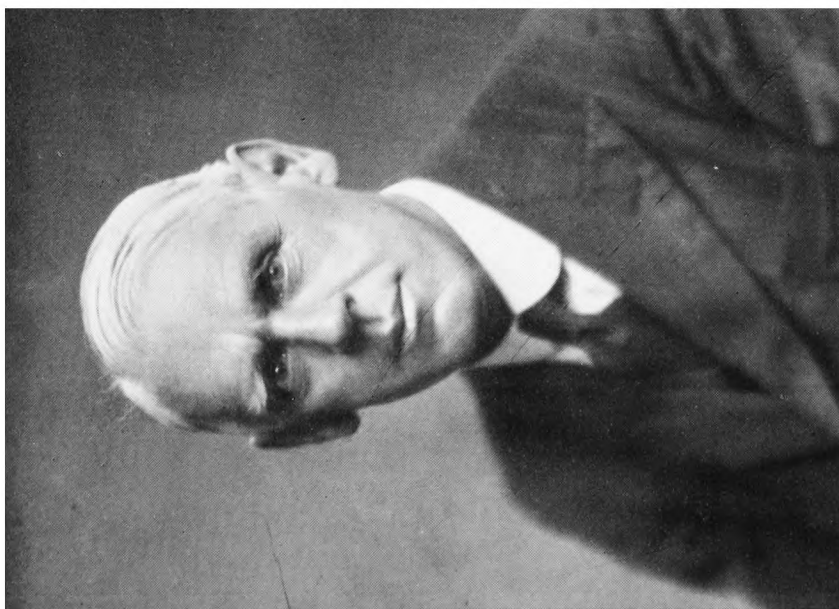


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COLONEL SIR HENRY LYONS, F.R.S.,  
ACTING DIRECTOR OF THE METEOROLOGICAL OFFICE  
1918-19



SIR GEORGE SIMPSON, K.C.B., C.B.E. F.R.S.,  
DIRECTOR OF THE METEOROLOGICAL OFFICE  
1920-38



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DIRECTOR OF THE METEOROLOGICAL OFFICE

1938-53



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DIRECTOR OF THE METEOROLOGICAL OFFICE

1953-

valuable birds being lost through encountering unfavourable winds and weather. The introduction during April and May 1936 of special forecasts of frost, for the benefit of horticulturists, is recorded in the Director's Report for that year. From the same Report is taken the following historical reference to forecasts by television:—

An experiment was made between November 2 and 28 of issuing weather charts by the television process and accompanying them by a spoken description of the chart and a short forecast. This experiment was made at the Alexandra Park television station of the British Broadcasting Corporation, and as the radius of the transmission is limited the forecast referred to London only. The experiments indicated that there were possibilities in this method which might have to be reviewed later when television becomes one of the amenities in the lives of the majority of the inhabitants of the country.

At the outbreak of war in 1939 current weather information was immediately placed on the secret list, and all forecasting services for the benefit of the public at large were suspended, but very little time elapsed after VE day before the restitution of most of these services was called for, and gradually achieved.

That very many activities of daily life are dependent on, and influenced by, the weather is a platitude, and although agricultural and marine activities receive the special attention of forecasters, there are numerous other interests which the Meteorological Office endeavours to help. In the forefront of its means of reaching those who would employ its services the B.B.C. continues to be found, and every effort is made to exploit to the full both the sound and television programmes as media for informing the general public. With the discontinuance in 1950 of the AIRMET broadcasts, a service which was inaugurated several years before the war and revived in January 1946, a valuable channel of communication was lost, and the passage of time, together with the success of the personal presentation of forecasts on the television service, has only served to underline the advantages of a talk by forecasters on the weather situation over a bulletin supplied by the Meteorological Office and read by an announcer. It is much to be hoped that, in collaboration with the B.B.C., the return of forecasters to the microphone will be achieved by the Meteorological Office during its centenary year.

The days are gone when newspapers can be regarded as primary vehicles for supplying the public with the most up-to-date forecasts. It is manifest that the bulletins broadcast on the B.B.C. Home Service in the early morning, which are based on the 0000 and 0300 G.M.T. charts, must supersede those appearing in the morning newspapers, which are based on the previous 1200 and 1500 G.M.T. charts in summer, and on the 1500 and 1800 G.M.T. charts in winter. There is little that can be done about this, and it can happen, and it sometimes does, that the morning B.B.C. and newspaper forecasts are divergent. The Press could, however, perform a useful service for meteorologically minded readers by printing a weather chart showing either the actual synoptic situation at a particular hour, 12 or 18 hr. earlier, or a forecast chart. In view of the errors which may occur in a chart constructed to represent the situation expected 24 hr. ahead it would be preferable for "actual" and "forecast" charts to be printed alongside each other, but if space is available for one chart only there is a good deal to be said for this being an "actual" rather than a "forecast" chart. In order to give forecasts for the various parts of the United Kingdom conveniently, the country is divided into 26 districts. Each comprises a number of counties, selected to form a group which can be described by a geographical name that is reasonably self-explanatory and can also be said to have some claim to being a climatological unit. There is inevitably a certain arbitrariness about

the grouping, but the serious reader will of course take steps to find out to what district the place in which he is interested belongs. The grouping was revised and improved in 1954, but the most satisfactory arrangements may not yet have been made, at least in so far as Scotland is concerned.

The influence of various aspects of the weather on all forms of transport needs no emphasis. The stimulus given to forecasting by the advent of flight has already been alluded to, and the history of aviation forecasting is outside the scope of this article. The crippling effects on ground transport which may result from such weather hazards as snow, ice and fog can, however, be considerably minimized by the dissemination of suitable warnings.

In addition to including snow warnings in bulletins for broadcast by the B.B.C. the Meteorological Office provides special subscription services of snow forecasts, one of which is designed for the use of municipal authorities responsible for snow clearance, whilst another is for the benefit of skiers in Scotland. To electrified railways, the deposition of ice (and snow) on conductor rails and cables is a matter of concern, since such deposits can readily act as insulators and bring electric trains to a standstill. A warning service has consequently been in operation for about six years, which provides for controllers of electrified sections of railway, chiefly those of London Transport and the Southern Section of British Railways, being advised each afternoon when conditions are expected which will be favourable for the occurrence of rail or cable icing in specified areas during the ensuing night. The receipt of such advice enables the authorities to take steps to counteract the ice, by such means as the running of special trains which spray oil over conductor rails or the switching into operation of oil baths, inserted into those rails, from which oil is automatically sprayed over the rail by passing trains.

The fog hazard is one which can be said, in general, to affect all forms of transport equally, and here again subscribers to the special warning service receive notification of the fog prospects. After the "smog" of December 1952 arrangements were made to provide the B.B.C. with special warnings for broadcast with the routine weather bulletins whenever fog is expected to persist for at least 24 hr. in stated areas of the country. Industrial and domestic users of coal are then expected to reduce to a minimum their contributions of smoke to the pollution of the atmosphere.

Knowledge of the general level of temperature to be expected is of particular value to electricity and gas companies in the anticipation of demands, and temperature forecasts are accordingly supplied daily to units of the British Electricity Authority in various parts of the country, and gas companies are advised whenever significantly colder weather is in prospect. Frost warnings for substantial areas of the country are passed to the B.B.C. for broadcasting with the routine forecast bulletins, whilst the expectation of frost in a specific place can be notified to registered subscribers.

Sudden changes of humidity are of particular concern to manufacturers of confectionery, and certain of these avail themselves of a special forecasting service which gives warning of the arrival of air of high humidity, particularly following a cold spell, with the attendant probability of heavy condensation on cold surfaces.

Sudden and substantial decreases of atmospheric pressure are closely related to the efflux of gas in mines, and warnings of rapid falls of pressure are supplied to certain collieries.



Earlier passing reference has been made to the forecasting services which the Meteorological Office provides for mariners and agriculturists. For the benefit of the former there are the well known shipping bulletins and gale warnings which are supplied to, and broadcast by, the B.B.C., and in addition, broadcasts are made by wireless telegraphy concerning the weather situation over the Atlantic. Indeed, the bulletins issued by various means for the benefit of shipping around the British Isles and in the eastern and central parts of the North Atlantic are as comprehensive as anywhere in the world. The accuracy of many of the forecasts which are included in these bulletins is considerably dependent on the number and distribution of ship reports available to the forecaster. The North Atlantic ocean weather stations render particularly useful service in this connexion, but there remains a constant need for reports from a large number of merchant ships to enable reasonably accurate synoptic charts of the weather to be constructed.

The requirements of the farmer, the market gardener, and the small holder in regard to the weather to be expected are met to a considerable degree in the B.B.C. bulletins. The forecasters at the Central Forecasting Office at Dunstable are kept informed, through the medium of the Agricultural Branch of the Meteorological Office, of the current agricultural and horticultural activities in different parts of the country and the related weather factors of special importance, and cognizance is taken of these in the preparation of the forecast bulletins. However, in regard to factors which are subject to considerable local variations, such as frost and wind, and for very short-period forecasts, the best and most detailed service is to be obtained by telephone from one of the forecasting offices listed in the "Post Office Guide" and elsewhere. Whilst there is probably no section of the community which does not stand to reap some benefit from any advances made towards extending the period for which reasonably reliable forecasts can be given, it is doubtless the grower who, by and large, would be the most advantaged.

The problem of forecasting for several days ahead has been under continuous study in the Meteorological Office in recent years, with particular reference to the upper air circulation over a large area of the northern hemisphere, and trials have shown that some measure of success can be achieved in forecasting the general character of the weather and temperature over the British Isles up to 3 days ahead. On the other hand, attempts to forecast details of the weather and temperature at individual places on individual days beyond 24 hours have not been altogether encouraging.

Reliable assessment of the accuracy of period forecasts, or indeed of any forecasts, is beset with difficulties, and any figure of percentage accuracy, or terse statement that the forecasts are "seldom right" or "seldom wrong", should be treated with extreme reserve, until it is known exactly how the assessments were reached. In view of the fact that, by reason of the recognized limitations of forecasting, official forecasters act in the capacity of advisers rather than prophets, it is essential that by the phraseology they employ they should indicate as far as possible the degree of probability of the occurrence forecast, or the confidence with which the forecast is endowed. However, the use of such phraseology complicates the subsequent verification of the forecast and introduces an element of subjectivity into the checking. The problem of forecast verification is, nevertheless, receiving continuous attention in its various aspects.

What should be said of the future in regard to forecasting? Are there grounds for optimism? In so far as the attainment of greater accuracy by the employment of conventional and current methods is concerned, realism requires it to be recognized that progress during the past decade has been slow, and that notwithstanding the steady prosecution of research the rate of progress during the next decade seems unlikely to be substantially greater, at any rate so far as can be seen at the present time. It would, however, be wrong to infer that the value of the forecasting service to the community will not go on increasing, since, apart from an extension of services in spheres of human activity wherein they are already established, there are additional spheres in which forecasts of various meteorological elements can well be employed and be of a useful standard of accuracy in the existing state of knowledge. The important thing is to get potential users, particularly in industry and commerce, to realize how the forecasting service can help them in their special problems, and for the meteorologist to assist them in framing their application for service in the manner best calculated to secure the most efficient results. As regards the effect on forecasting of the use of electronic computers, it is too early to express any definite opinion, since the employment of such computers in numerical forecasting is at present only in the research stage. There are, however, some grounds for supposing that, so far as obtaining forecast charts for 24 hours ahead is concerned, the electronic computer will prove to be a valuable aid, and its adoption in forecasting a very significant milestone in the history of synoptic meteorology.

## **THE METEOROLOGICAL OFFICE AND THE INTERNATIONAL ORGANIZATION**

By E. GOLD, D.S.O., F.R.S.

Meteorology today rests on international foundations. These have been laid by combined effort but the Meteorological Office has contributed in high degree to their solidity. There were meetings and exchanges before the Office was constituted, notably the Conference in Brussels in August 1853, concerned primarily with ocean meteorology, out of which the Meteorological Office may be said to have been born—a sea nymph.

For the next 20 years Europe was in a disturbed state—the Crimean War; the German wars against Austria, Denmark and France—and it was not until 1873 that the first general International Meteorological Congress was held at Vienna, for which there had been preliminary discussion a year earlier at an informal meeting in Leipzig (August 1872). This Vienna Congress stands out almost as the founder of international meteorology. Early in July 1873 the Foreign Office notified the Board of Trade that Her Majesty's Government had decided to nominate Mr. R. H. Scott, Director of the Meteorological Office, and Mr. Alexander Buchan, Secretary of the Scottish Meteorological Society and, later, a member of the Meteorological Council, as "delegates to represent this country at the Meteorological Congress to be held at Vienna in September next", and three weeks later the Board of Trade sent the two delegates instructions for their guidance "You should attend at the Conference as a deliberative assembly and impart and glean such information as you may be able. I am however to observe that you should abstain from pledging Her Majesty's Government in any way". The Army Medical Department asked Scott if he would be willing to represent them and also if he thought a separate representative would be better. Scott said yes to both questions, but the Department

decided on Scott and expressed, more spaciouly and graciously, "the Director General's gratification at being afforded the opportunity of confiding the interests of the Army Medical Department to such safe and able hands and, in the event of proposals involving expense being made, of securing the assistance of so sound a judgment in selecting for support such only as are necessary for the *bona fide* furtherance of science".

So Scott and Buchan went to Vienna, and on their return reported very briefly to H.M. Government that the Congress took no decisions involving expenditure.

But this Congress under the Presidency of Buys Ballot took many decisions which have governed meteorological practice since, and may be found in the two standard textbooks, the "Codex of Resolutions adopted at International Meetings 1872-1907" by H. H. Hildebrandsson and G. Hellmann and the "Répertoire des Résolutions de l'Organisation Météorologique Internationale", by E. Van Everdingen which covered the period up to 1939 and was published in 1943.

The principal recommendations at Vienna specified (a) the units of time to be used, namely the mean solar day of the place of observation ending at midnight, the calendar month, and the civil year, and Dove's 73 5-day periods for means of temperature; (b) suitable combinations of hours for observations, e.g. 7, 13, 21 or 9, 15, 21; (c) the weather symbols, essential in the absence of an international language, for the representation of "hydrometeors"; (d) the specification of wind direction "the English designations should be used generally: N = North, E = East, S = South, W = West"; (e) the definitions of meteorological stations, Central Office, Central Station, Stations of the First, Second and Third Orders. The most important decision was the establishment of a Permanent Committee of seven members to act between Congresses, which met every five or six years. R. H. Scott was Secretary of this Committee from its first meeting in Vienna on September 16, 1873 until the meeting in St. Petersburg in 1899, which he could not attend owing to the sudden death of the, then, Marine Superintendent of the Office, Nav. Lt C. W. Baillie, R.N. H. H. Hildebrandsson succeeded Scott as Secretary.

One of the first actions of the Permanent Committee was to agree upon a code for the exchange of telegraphic reports—a code of 5-figure groups because each such group was charged as one word. There were two primary groups BBBDD FFWTT for barometer, wind, weather and temperature and two supplementary groups T'T'RRR MMmmS for wet-bulb temperature, rain, maximum and minimum temperatures and state of the sea. This was the British form; the Continent had three figures for temperature, and only one for wind force and two for rainfall. The Beaufort scale was adopted for wind force for observation at sea "with the addition of the amount of sail which Beaufort's ship would have carried had she been rigged with double topsails". Another important action was the specification of the form of register to be used at sea, largely the work of Capt. H. Toynbee, and the corresponding specifications of the forms for the publication of daily observations and monthly summaries for land stations.

Subsequent Meetings and Conferences refined and added to the recommendations of the Vienna Congress. [It should be emphasized that there were no compulsory decisions; the recommendations, to be effective, had to be agreed with substantial unanimity.] Naturally as the leading maritime nation Great Britain took a prominent part in all matters of marine meteorology. But

the British representatives were always ready to assist in getting the best use made of good proposals put forward by other maritime nations—an example is their agreeing in 1876 that Great Britain should take 50 sets of “Hoffmeyer’s” synoptic charts covering Europe and the North Atlantic. Of other countries, Austria took 40, Russia 30 and the rest, numbers varying from 1 to 15—total 205. At the meeting at Paris in 1900, Sir Napier Shaw was elected a member of the Committee, and from 1907 to 1923, the year of the Conference at Utrecht, he was its President, bringing to that Office both the optimism of his predecessor, M. Mascart, expressed in the *mot* “the greatest and most terrifying difficulties are those which do not really exist” and his own administrative and scientific ability. These resulted in a comprehensive statement of the constitution and functions of the International Meteorological Organization, the revision of the telegraphic code, the publication of an English edition of the “Codex of Resolutions”, and the re-establishment of the Organization as an effective instrument of international meteorological collaboration after the disruption caused by the First World War.

Among the major changes in the last 35 years have been the complete revision of the codes for international exchange, by telegraph and wireless, of reports of surface observations, largely on the basis of British proposals put forward as a result of experience during the war of 1914–18; agreement on codes for upper air reports; the establishment of a comprehensive decimal classification of meteorological literature, a most valuable and notable step forward for which Dr. C. E. P. Brooks was in large measure responsible.

The first comprehensive publication of the details of the issues by wireless telegraphy in different countries of the collective reports of observations was prepared by M. A. Giblett, who lost his life in the disaster to the Airship R 101. These issues between the world wars formed the basis of forecasting and of what is generally understood by “synoptic meteorology”. The publication mentioned was the prototype of the International Publication, No. 9, issued after the establishment of a Permanent Salaried Secretariat of the International Meteorological Organization. Sir George Simpson played an important part in bringing to birth this embryo of its full grown successor in the World Meteorological Organization. It was also Sir George Simpson’s work on the Beaufort Scale of wind force which enabled international agreement to be finally reached on a scale of equivalent speeds, at the meetings at Zurich and Vienna in 1926. Diversity between the Continental and British equivalents had been long a source of contention, impossible of reconciliation, but when Dr. Hesselberg said briefly and emphatically “Simpson’s proposal is good” the matter was clinched. Notable also was Mr. E. G. Bilham’s success in securing the revision of the specifications, largely on the lines of the British proposals, at Paris in 1946 and his fight, gallant though unsuccessful, at Toronto in 1947 for the logical and practical scale of visibility. Sir Nelson Johnson’s work, as President of the International Meteorological Organization from its re-establishment in 1946 until his retirement in 1953, in securing agreement at Washington in 1947 on the Convention establishing the World Meteorological Organization may well be described as putting the coping stone on the contribution of the Meteorological Office to the International Meteorological Organization. When the Washington Conference was on the point of breaking down, “it was”, said the Chief of the United States Weather Bureau, “the deliberate and skilful guidance of the President” which brought them through all obstacles.

## WEATHER OF APRIL 1955

The highest mean pressure of the month in the Atlantic sector was again over the British Isles (Kew had the highest figure 1023 mb. and the greatest anomaly +10 mb.). This expressed recurrence of blocking situations, chiefly between the 12th and the 25th. Continuity between the anticyclones of March and April over the eastern North Atlantic was broken by two sequences of depressions and fronts travelling east in late March and again after April 2, though pressure was generally above normal over France and Biscay during these intervals. The lowest mean pressure in April was 999 mb. off south-east Greenland near 35°W., an anomaly of -10 mb. which apparently represents deeper depressions than usual with little or no position anomaly. There were few remarkable features in the pressure pattern elsewhere in the hemisphere, although pressure seems to have been below normal over much of the polar basin and the usual spring anticyclones over the Canadian archipelago gave a pressure maximum farther south than usual over Baffin Land with a positive anomaly +6 to +8 mb.

Temperatures were a little above normal over most of western Europe and generally below normal farther east—the greatest anomalies were +5°C. at Spitzbergen, and -4°C. in south-west Finland and Greece.

In the British Isles a mild westerly air stream predominated during the first ten days and the last week of the month; during the remainder, the weather was anticyclonic with drought conditions affecting a large part of the country.

A centre of high pressure gave a fine sunny day on the 1st, but the following day an active trough to a depression near Iceland crossed the country accompanied by widespread rain. On the 3rd an influx of milder air into the south-west was marked by locally heavy rain, but there were good sunny periods in the north, though with scattered thunderstorms. During the next three days a mild south-westerly air stream predominated, while minor troughs crossed the country giving occasional, mainly slight, rain alternating with sunny periods. Temperatures were above average and exceeded 60°F. in places. The moister air gave rise to hill and coast fog in the south-west, patches of fog in the English Channel and Irish Sea, and an increase in early morning fog elsewhere. Still warmer air spread from the south-west on the 7th as fronts associated with a deep Icelandic depression crossed the British Isles with widespread rain, heavy in places particularly in Scotland, where among the heavier falls in 24 hr. that day were 2·60 in. at Polnish Lochailort, 2·24 in. at Arisaig House, both in Inverness-shire and 2·06 in. at Aros, Isle of Mull. But on the 9th an anticyclone off our south-west coasts increased in intensity, and in consequence rain accompanying the passage of a trough of low pressure across the country that day was only slight in the south. The anticyclone began to move north-eastwards on the 11th, became centred over the British Isles by the 14th and thereafter persisted in the neighbourhood till the 20th. During this period the weather was dry, sunny and mild by day, but ground frost occurred most nights; it was the warmest Easter Monday at many places on the south coast for six years, and on the 14th sunshine totals exceeding 12 hr. were reported from a number of places throughout the country. As the anticyclone drifted slowly westward on the 21st slightly cooler air spread southwards over the eastern side of the country; the grass minimum temperature fell to 20°F. at Kew during the early hours of the 20th and 22nd and snow showers were reported from Lerwick on the 21st and 24th. The anticyclone began to collapse on the 23rd, and thereafter a return to a westerly type gradually brought to an end the drought which had developed over much of England, though rainfall amounts in the south-east were small. There was widespread rain, heavy locally in the west, associated with the passage of an active trough across the country on the 27th when more than 3 in. of rain was recorded at Blaenau Festiniog, Merionethshire. An influx of air from France resulted in the highest temperatures of the year so far on the 29th; several places in Kent recorded 77°F. With a total rainfall for the month of 0·15 in. Shoeburyness reported the driest April since records began in 1920. Rainfall was more than average in places in the extreme west, but over much of Great Britain there was less than 75 per cent. Over the greater part of south-east England less than 25 per cent. was recorded with as little as 12 per cent. from Felixstowe and Edenbridge.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	77	21	+1·8	65	-4	111
Scotland ...	74	20	+2·8	76	-3	124
Northern Ireland ...	65	23	+2·8	103	-2	121

# RAINFALL OF APRIL 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	·43	28	<i>Glam.</i>	Cardiff, Penylan ...	2·04	82
<i>Kent</i>	Dover ...	·21	13	<i>Pemb.</i>	Tenby ...	2·75	120
"	Edenbridge, Falconhurst	·23	12	<i>Radnor</i>	Tyrmynydd ...	3·38	92
<i>Sussex</i>	Compton, Compton Ho.	·65	33	<i>Mont.</i>	Lake Vyrnwy ...	3·18	100
"	Worthing, Beach Ho. Pk.	·21	13	<i>Mer.</i>	Blaenau Festiniog ...	10·27	166
<i>Hants.</i>	St. Catherine's L'thouse	·57	31	"	Aberdovey ...	3·50	135
"	Southampton (East Pk.)	·36	19	<i>Carn.</i>	Llandudno ...	·95	56
"	South Farnborough ...	·21	14	<i>Angl.</i>	Llanerchymedd ...	2·50	113
<i>Herts.</i>	Harpenden, Rothamsted	·44	27	<i>I. Man</i>	Douglas, Borough Cem.	3·13	128
<i>Bucks.</i>	Slough, Upton ...	·34	24	<i>Wigtown</i>	Newton Stewart ...	3·11	122
<i>Oxford</i>	Oxford, Radcliffe	·65	59	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·41	60
<i>N'hants.</i>	Wellingboro' Swanspool	·69	46	"	Eskdalemuir Obsy. ...	2·51	74
<i>Essex</i>	Southend, W. W. ...	·19	15	<i>Roxb.</i>	Crailing ...	·76	47
"	Felixstowe ...	·14	12	<i>Peebles</i>	Stobo Castle ...	·78	37
<i>Suffolk</i>	Lowestoft Sec. School ...	·38	26	<i>Berwick</i>	Marchmont House ...	·64	32
"	Bury St. Ed., Westley H.	·38	25	<i>E. Loth.</i>	North Berwick Gas Wks.	·85	62
<i>Norfolk</i>	Sandringham Ho. Gdns.	·97	64	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	·44	30
<i>Wilts.</i>	Aldbourn ...	·52	27	<i>Lanark</i>	Hamilton W. W., T'nhill	1·13	60
<i>Dorset</i>	Creech Grange ...	1·02	47	<i>Ayr</i>	Colmonell, Knockdolian	2·78	110
"	Beaminster, East St. ...	1·25	53	"	Glen Afton, Ayr San. ...	2·66	89
<i>Devon</i>	Teignmouth, Den Gdns.	·96	48	<i>Renfrew</i>	Greenock, Prospect Hill	3·76	109
"	Ilfracombe ...	2·95	141	<i>Bute</i>	Rothsay, Arden Craig ...	4·87	163
"	Princetown ...	4·14	82	<i>Argyll</i>	Morven, Drimnin ...	4·75	130
<i>Cornwall</i>	Bude, School House ...	1·57	83	"	Poltalloch ...	5·08	168
"	Penzance ...	1·53	63	"	Inveraray Castle ...	6·08	132
"	St. Austell ...	1·59	56	"	Islay, Eallabus ...	3·33	116
"	Scilly, Tresco Abbey ...	1·31	67	"	Tiree ...	2·87	117
<i>Somerset</i>	Taunton ...	·90	51	<i>Kinross</i>	Loch Leven Sluice ...	1·23	64
<i>Glos.</i>	Cirencester ...	1·01	54	<i>Fife</i>	Leuchars Airfield ...	·64	40
<i>Salop</i>	Church Stretton ...	1·60	73	<i>Perth</i>	Loch Dhu ...	4·85	102
"	Shrewsbury, Monkmore	1·19	80	"	Crieff, Strathearn Hyd.	1·53	70
<i>Worcs.</i>	Malvern, Free Library ...	·95	53	"	Pitlochry, Fincastle ...	1·23	55
<i>Warwick</i>	Birmingham, Edgbaston	1·10	57	<i>Angus</i>	Montrose, Sunnyside ...	·64	35
<i>Leics.</i>	Thornton Reservoir ...	1·11	65	<i>Aberd.</i>	Braemar ...	·82	35
<i>Lincs.</i>	Boston, Skirbeck ...	1·44	107	"	Dyce, Craibstone ...	·77	37
"	Skegness, Marine Gdns.	1·31	98	"	New Deer School House	1·08	54
<i>Notts.</i>	Mansfield, Carr Bank ...	1·07	62	<i>Moray</i>	Gordon Castle ...	1·34	77
<i>Derby</i>	Buxton, Terrace Slopes	2·88	98	<i>Nairn</i>	Nairn, Achareidh ...	1·07	76
<i>Ches.</i>	Bidston Observatory ...	1·52	93	<i>Inverness</i>	Loch Ness, Garthbeg ...	·94	41
"	Manchester, Ringway ...	1·87	104	"	Glenquoich ...	6·28	97
<i>Lancs.</i>	Stonyhurst College ...	3·22	119	"	Fort William, Teviot ...	4·42	98
"	Squires Gate ...	1·50	84	"	Skye, Broadford ...	5·60	124
<i>Yorks.</i>	Wakefield, Clarence Pk.	·51	30	"	Skye, Duntuilin ...	2·95	91
"	Hull, Pearson Park ...	·61	39	<i>R. &amp; C.</i>	Tain, Mayfield ...	·94	51
"	Felixkirk, Mt. St. John ...	1·51	90	"	Inverbroom, Glackour ...	2·38	64
"	York Museum ...	1·10	69	"	Achnashellach ...	5·17	97
"	Scarborough ...	1·00	64	<i>Suth.</i>	Lochinver, Bank Ho. ...	2·27	80
"	Middlesbrough ...	·90	66	<i>Caith.</i>	Wick Airfield ...	1·32	66
"	Baldersdale, Hury Res.	·88	40	<i>Shetland</i>	Lerwick Observatory ...	2·98	130
<i>Nor'l.d.</i>	Newcastle, Leazes Pk. ...	·67	42	<i>Ferm.</i>	Crom Castle ...	2·61	102
"	Bellingham, High Green	·84	34	<i>Armagh</i>	Armagh Observatory ...	2·75	131
"	Lilburn Tower Gdns. ...	·49	25	<i>Down</i>	Seaford ...	2·19	84
<i>Cumb.</i>	Geltsdale ...	2·23	105	<i>Antrim</i>	Aldergrove Airfield ...	2·61	124
"	Keswick, High Hill ...	1·99	65	"	Ballymena, Harryville ...	2·42	92
"	Ravenglass, The Grove	2·94	119	<i>L'derry</i>	Garvagh, Moneydig ...	2·39	98
<i>Mon.</i>	A'gavenny, Plás Derwen	1·03	37	"	Londonderry, Creggan	2·34	91
<i>Glam.</i>	Ystalyfera, Wern House	5·84	154	<i>Tyrone</i>	Omagh, Edenfel ...	...	...

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METEOROLOGICAL OFFICE

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## ATOMIC EXPLOSIONS AND CONDENSATION NUCLEI

By A. C. BEST, D.Sc.

Recent speculations about a possible connexion between the explosion of atomic bombs and the weather lend an interest to a quantitative examination of the influence of an electric charge in enhancing the effectiveness of a nucleus of condensation.

The vapour pressure over a small droplet of water is reduced by the presence of an electric charge on the drop, the extent of the reduction being described by the equation<sup>1</sup>

$$R\theta \log_e \frac{p}{P} = \frac{M}{\sigma} \left[ \frac{2T}{a} - \frac{n^2 e^2}{8\pi a^4} \right] \dots\dots\dots (1)$$

where

- $R$  = universal gas constant ( $= 8.315 \times 10^7$  c.g.s. units),
- $\theta$  = absolute temperature,
- $p, P$  = vapour pressure over the drop and a plane surface,
- $M$  = molecular weight of water ( $= 18$ ),
- $\sigma$  = density of drop,
- $T$  = surface tension constant (74 c.g.s. units for water),
- $e$  = unit electronic charge ( $4.77 \times 10^{-10}$  e.s.u.),
- $n$  = number of electronic charges on drop,
- $a$  = drop radius (cm.).

Examination of this equation by the usual methods shows that as the droplet radius increases from near zero, the value of  $p/P$  rises steeply from a value much less than unity, reaches a maximum value which exceeds unity, and then decreases asymptotically to unity.

If the droplet is suspended in the atmosphere, condensation on or evaporation from the droplet will occur according as the ambient vapour pressure exceeds or is less than the value of  $p$  corresponding to the droplet radius and the electric charge. If a droplet initially in equilibrium with the ambient vapour pressure is brought into a region where the vapour pressure is greater the droplet will grow by condensation. Assuming that we start with an extremely small droplet, i.e. that the initial droplet radius corresponds to a point on the curve represented by equation (1) where the value of  $p/P$  increases with increasing radius, the droplet will grow by condensation until it is again in equilibrium with the new ambient vapour pressure. But if the new value of the ambient vapour pressure exceeds that represented by the maximum value of  $p/P$  equilibrium will never be attained and the droplet will grow indefinitely.

Let us now examine these considerations quantitatively. Inserting the numerical values given above and putting  $\theta = 283^\circ\text{A.}$ ,  $\sigma = 1$ , we find that the maximum value of  $p/P$  and the corresponding critical drop radius  $a_c$  are given by

$$\left. \begin{aligned} \log_{10} \left( \frac{p}{P} \right)_{\max} &= \frac{0.59}{n^{2/3}} \\ a_c &= 6.2 \, n^{2/3} \times 10^{-4} \text{ microns} \end{aligned} \right\} \dots\dots\dots(2)$$

Equations (2) have been used to compute the relative humidity ( $= 100 \, p/P$ ) necessary to promote indefinite growth on droplets which initially have a radius less than  $a_c$ . The results were as follows:—

	<i>n</i>					
	1	2	5	10	50	100
Relative humidity ...	389	235	159	134	111	107
Critical drop radius...	$6.2 \times 10^{-4}$	$9.9 \times 10^{-4}$	$1.8 \times 10^{-3}$	$2.9 \times 10^{-3}$	$8.4 \times 10^{-3}$	$1.3 \times 10^{-2}$

Thus if the radius of a droplet carrying single electronic charge is to grow beyond  $6.2 \times 10^{-4}$  microns it must experience an ambient relative humidity exceeding 389 per cent. The molecular radius of oxygen and of nitrogen is about  $2 \times 10^{-4}$  microns, so that if condensation is to occur on singly charged ions, the relative humidity must reach about 400 per cent. This corresponds to condensation in a Wilson chamber, but such supersaturations do not occur in ordinary atmospheric processes. The writer has no knowledge of what charge may occur on ions resulting from an atomic explosion, but it seems unlikely that, at great distances (a few hundred miles or more) from the scene of the explosion,  $n$  will exceed 100. Even with a charge of this magnitude a relative humidity of 107 per cent. would be necessary to permit an ion to grow to cloud-droplet size. We shall return later to the question of the maximum relative humidity which can occur in, for example, strong convective currents, but for the present we may note that 7 per cent. supersaturation is very unlikely, and hence it is improbable that the ions resulting from an atomic explosion can be effective as condensation nuclei except perhaps in the immediate vicinity of the explosion.

There remains the possibility that solid charged particles resulting from the explosion and which are larger than the critical size may be charged so highly that the vapour pressure over the charged particle is significantly less than over the same particle uncharged. We are now dealing solely with difference between the vapour pressure over charged and uncharged particles of the same size and so use equation (1). Inserting numerical values in that equation we easily obtain

$$\log_{10} \frac{p}{P} = \frac{3.02}{10^{14}} \left[ \frac{1.63 \times 10^{10}}{a} - \frac{n^2}{a^4} \right],$$

where  $a$  is now measured in microns. If now we denote the equilibrium vapour pressure over an uncharged particle by  $p_0$  and the corresponding quantity for a particle carrying  $n$  electrons by  $p_n$  we have

$$\log_{10} \frac{p_0}{p_n} = \frac{3.02 \, n^2}{10^{14} \, a^4}.$$



Now the relative humidity likely to occur naturally is of the order 100 per cent. A difference between  $p_0$  and  $p_n$  of less than 0.1 per cent. would certainly be insignificant in the present context, so that in order that the charge on the particle shall have a significant effect (and since  $\log_{10} 1.001 = 0.00042$ ) we need,

$$\frac{3.02 n^2}{10^{14} a^4} > 0.00042$$

or approximately,

$$n > 12 \times 10^4 a^2,$$

where  $a$  is measured in microns. Now there is both an upper and a lower limit to the values of the radius which need consideration. The lower limit is set by the fact that if the radius is too small the particle may be smaller than the critical size discussed above. The table of critical sizes given earlier suggests that the radius must certainly exceed  $10^{-2}\mu$ . The upper limit is set by the fact that the larger particles will not remain airborne for many hours. Probably  $10^{-2}$  to 10 microns includes the range we need to consider, and we see that for the charge to have a significant effect on the equilibrium vapour pressure the corresponding value of  $n$  ranges from 12 to  $12 \times 10^6$ . Had we chosen 1 per cent. relative humidity as the minimum significant difference between  $p_0$  and  $p_n$  these values of  $n$  would have been about three times greater. Unless the smallest solid particles resulting from an atomic explosion carry charges of the order of 50 electronic units then their effectiveness as condensation nuclei is not significantly affected by the electric charge.

So far we have assumed that supersaturation exceeding a few per cent. is unlikely to occur in the atmosphere in natural processes. Most meteorologists would accept this view, and indeed Johnson<sup>1</sup> (p. 206) suggests that relative humidities exceeding 100.1 per cent. are not to be expected. Howell<sup>2</sup> has computed the supersaturation likely to occur in convective cloud and suggests a maximum value of about 0.36 per cent. The reasoning behind the general belief that substantial supersaturations do not occur in nature is that no evidence has ever been found that nuclei of condensation are lacking in the atmosphere. As soon as saturation is reached (actually before that since the condensation nuclei are hygroscopic) cloud droplets are formed. As the air continues to rise in the convection current, the temperature falls and the relative humidity tends to rise. This leads to a more rapid rate of condensation on the cloud droplets, thus limiting the rise in relative humidity. The value of the latter is in fact determined by the two opposing processes. Naturally the stronger the vertical current is, the greater is likely to be the supersaturation achieved. We can obtain a reasonable approximation to the order of magnitude of the supersaturation from some computations in two earlier papers<sup>3,4</sup> by the present writer. In the first<sup>3</sup> of these two papers the liquid water contents at various heights in a convective cloud are computed. The figures in Table V of that paper show that the rate of release of water is unlikely to exceed 4 gm./m.<sup>3</sup> for 5,000 ft. ascent even with a high cloud-base temperature. If the strength of the convection current is  $V$  ft./sec., the rate of release of water is  $4V/5,000$  gm./m.<sup>3</sup>/sec. In the other paper<sup>4</sup> the rate of growth of a drop of water upon a salt nucleus in various ambient conditions is discussed. The size of the nucleus is important only in the early stages of the life of the drop. Subsequently the rate of growth depends upon the size of the drop, the supersaturation and

the temperature. From Table II of that paper it can be seen that the time required for a drop to grow from  $10\mu$  to  $15\mu$  radius is as follows:—

Temperature ( $^{\circ}\text{A.}$ )	...	273	293	293
Relative humidity (%)	...	100.05	100.05	100.5
Time (sec.)	...	2,400	1,230	130

If there are  $r$  drops per cubic centimetre and they take  $t$  sec. to grow from radius  $10\mu$  to  $15\mu$  the average rate of increase of liquid water is approximately  $r/100t$  gm./m.<sup>3</sup>/sec. If the relative humidity indicated above is to be maintained, this must be equal to the rate of release of water, i.e.

$$\frac{r}{100t} = \frac{4V}{5000}.$$

In selecting a value for  $r$  we must have regard for the implied liquid water content. A value of 500 implies about 2 gm./m.<sup>3</sup> of liquid water if the drops have a radius of  $10\mu$  and is in accord with observation. Substituting this value for  $r$  we get

$$V = \frac{6250}{t} \text{ ft./sec.}$$

Thus a relative humidity of 100.05 per cent. might be maintained by a vertical current of 2.6 ft./sec. at  $273^{\circ}\text{A.}$  and 5.1 ft./sec. at  $293^{\circ}\text{A.}$ , but a vertical current of 48 ft./sec. would be necessary to maintain a relative humidity of 100.5 per cent. at  $293^{\circ}\text{A.}$  Despite the many approximations, both stated and implied, it is difficult to avoid the conclusion that the supersaturation is hardly ever likely to exceed 1 per cent. We may conclude that atomic explosions are not likely to have any significant effect upon the condensation of water vapour into cloud droplets at distances far removed from the scene of the explosion.

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## PRESENT POSITION OF THEORIES OF CLIMATIC CHANGE

By C. E. P. BROOKS, D.Sc.

In 1947 in an article in the *Meteorological Magazine* on the "Unsolved problem of climatic change"<sup>1</sup>, five groups of theories were examined—variations of solar radiation, changes in the elements of the earth's orbit, movements of the continents, changes in the constitution of the atmosphere, and changes of configuration—but the conclusion was that all the theories so far advanced remained unproved. The seven years which have elapsed have, if anything, made confusion even greater. It may be of interest to take a brief glance at some of the recently published work and to assess the present position.

Variations of solar radiation, either alone or combined with some other cause, are now first favourite. The theory which has been received with most interest is that of E. J. Öpik<sup>2</sup>, first put forward in 1952 and completed in 1953, in which all changes of climate from major cycles of the order of 250 million years down to glacial and interglacial alternations are attributed solely to internal changes

in the constitution of the sun. On the other hand, the theory of F. Hoyle and R. A. Lyttleton<sup>3</sup> that variations of solar radiation are due to the passage of the sun through concentrations of inter-stellar matter, is still actively maintained by Hoyle and was supported by M. Krook<sup>4</sup> in the volume on climatic change (reviewed in the *Meteorological Magazine* for November 1954) which also includes a discussion of Öpik's theory. Cycles of solar radiation with no ultimate cause assigned were also postulated by J. Wolbach in this volume<sup>4</sup>. B. M. Rubashev<sup>5</sup> combines cyclical variations of solar activity with variations in the speed of rotation of the earth. All these theories are at present almost entirely hypothetical, with little or no evidence to support them.

D. H. Menzel<sup>4</sup> finds the cause of ice ages in clouds of ions reaching the earth from the sun and providing sublimation nuclei in the upper atmosphere, but he remarks that volcanic dust could adequately fulfil the same role.

Most writers adopt the view, which will certainly commend itself to meteorologists, that changes of solar radiation, especially in the ultra-violet, take effect through changes in the atmospheric circulation, but two opposing points of view still prevail. Thus H. C. Willett<sup>6</sup> supports with modifications Sir George Simpson's view<sup>7,8</sup> that glaciation could be attributed to increased solar radiation in selected wave-lengths acting through changes of circulation. His idea is that an increase of solar radiation would raise temperature in low latitudes more than in high latitudes, increasing the poleward transport of heat and water vapour and so causing more snow in the subarctic regions. In a later paper<sup>4</sup> he summarizes a comprehensive review of the evidence as: quiet sun—interglacial; steady moderately disturbed sun (minor sun-spot maxima)—glacial; extreme solar disturbance (major sun-spot maxima)—chaotic climatic stress and deglaciation. On the other hand H. Flohn<sup>9,10</sup> from a study of the circulation during the cold winters of 1939–42 attributes glaciation to a marked decrease of solar radiation, especially in the ultra-violet, resulting in a strengthened meridional circulation and weakened W. winds (low-index type).

Orogenesis and changes of land and sea distribution do not now appear to be accepted as the major cause of climatic changes, but several authors express the view that both solar and geographical changes are required for ice ages. R. F. Flint<sup>4</sup> explains the glaciations of Alaska on these lines, with emphasis on the solar changes, while M. Schwarzbach<sup>11</sup> places the emphasis rather on orogenesis, and B. Bell<sup>4</sup> postulates high ground, a change of solar radiation and favourable topography, with possibly increased corpuscular radiation, to warm the polar stratosphere and so produce polar low-pressure areas.

Changes in the elements of the earth's orbit and the inclination of the axis are rather out of favour. They are still maintained by F. E. Zeuner<sup>12</sup> and G. Bacsák<sup>13</sup>, while D. Brouwer<sup>4</sup> has produced a new solution, but they are rejected as insufficient by A. J. J. van Woerkom<sup>4</sup>.

The third group, continental drift or pole shifts, also has a few adherents, among whom may be mentioned K. A. Pauly<sup>14</sup> who adopts Sir Arthur Eddington's theory of a sliding of the earth's crust over the interior due to tidal friction, and J. Goguel<sup>15</sup> who attributes displacements of the pole to winds, ocean currents and tides.

Changes in the constitution of the earth's atmosphere now reduce almost entirely to the effects of volcanic dust, H. Wexler<sup>16</sup> having revived W. J. Humphreys's theory of the cooling effect of a volcanic-dust veil, while volcanic

dust plays a subordinate role in several other theories. In a recent one by C. A. Zapffe<sup>17</sup> volcanism in the Atlantic region plays a dual role, submarine eruptions causing a large supply of water vapour and aerial ones the necessary veil to lower temperatures generally, but Zapffe also brings in theosophy and the destruction of Atlantis to buttress his case.

From this rapid survey it will be seen that the problem of climatic change is really little nearer to a solution than it was seven years ago. The theories current in 1947 are still being argued; even some old ones have been revived. Thus in 1950 E. le Danois<sup>18</sup> brought back O. Pettersson's theory of climatic changes due to internal oceanic tides, and in 1952 H. Gerth<sup>19</sup> revived C. E. P. Brooks's geographical theory of the Permo-Carboniferous glaciation. Perhaps the most hopeful sign is that in 1954 palaeoclimatologists are not quite so tied to single causes to the exclusion of all others as they seemed to be in 1947; it is becoming accepted that combinations of two or more causes are necessary to explain the facts. The most urgent need now is for some credible method, direct or indirect, of reconstructing the variations of solar radiation during geological time; when that point has been cleared up the way may be open for the evaluation of other factors.

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### SPEED AND DIRECTION OF MOTION OF SIMPLE WARM-SECTOR DEPRESSIONS

By H. D. HOYLE, B.Sc.

A considerable amount has been written on the subject of the movement of depressions and several empirical rules are in use, applied with varying degrees of confidence.

Results of empirical investigation of such rules have usually been somewhat unsatisfactory. In an unpublished work by Hollis<sup>1</sup> and an empirical study by

Austin<sup>2</sup> fair agreement was found with the direction of motion of depressions using the 1000–500-mb. thermal wind and the upper level winds respectively, angular deviations usually being within about 30°. Hollis, however, found no correlation between thermal wind speed and depression speed and no such attempt appears to have been made by Austin. Most previous work has considered all types of depressions together. The possibility of better results being obtained by considering separately different types of depression suggested the approach made here.

In measuring upper winds and thermal winds to investigate “steering” rules the mean flow over an area was measured rather than the “spot” geostrophic wind (measured at one place). This was not only in view of the theoretical concept of the barotropic advection of a vortex in a general stream, but also to lessen the effect of the subjective details of chart drawing.

In addition to steering values, other possible parameters were measured, for purposes of comparison and in the hope that they might be of use in finding empirical corrections to steering rules or in determining conditions under which such rules could be applied.

**Selection of cases.**—Depressions in the six months January to June 1951 were considered. To avoid complication by orographic and diurnal effects, depressions over the Atlantic alone were considered. Depressions which were occluded and depressions with very complex or doubtful analyses, or whose position was in doubt from lack of observations, were also omitted.

Great care was taken to see that the upper air flow was typical of unoccluded warm-sector depressions. Any cases with a closed cyclonic circulation at 500 mb. in association with the surface centre were excluded. The 1000–500-mb. thickness pattern had to be of conventional type also, cases being excluded if the thermal trough behind was unusually well marked or if there was marked diffuence or confluence in the neighbourhood of the depression. There were 16 satisfactory cases in the period considered.

**Extraction of data.**—The motion of the depression was measured by its west-to-east and south-to-north components over a 12-hr. period ( $H$  to  $H + 12$ ). Preliminary work indicated that the original drawing of the charts was somewhat erratic. Consequently all the surface charts, including the ones for several 6-hr. intervals before and after the 12-hr. measured period, were completely redrawn, so as to satisfy fully all available observations and at the same time give a track for the depression which was as smooth as possible.

The upper flow over an area centred on the surface depression was estimated by measuring the difference in contour height (or thickness) at points a known distance due north and south, and again due east and west of the centre. This readily gave west-to-east and south-to-north speed components. The size of the area used was chosen in order to facilitate conversion into knots, a diameter of about 600 nautical miles being used. A scale was prepared for this purpose (Fig. 1) which incorporates a correction for map distortion. The line AB is placed over the depression centre with the lines perpendicular to AB in the required direction (due north, say) and such that the latitude figure on the scale conforms to the latitude immediately under it on the chart. The height (or thickness) is then read off on the line XY at the point appropriate to this latitude line on the scale. The height (or thickness) is similarly read in the

opposite direction (due south, say). For the 1 : 10<sup>7</sup> charts used, the scale was so drawn that the speed component in knots was given by multiplying the diametrical height difference by 4. It is a simple matter to prepare such a device for use with charts of any scale. Values for the area mean geostrophic wind at 1000, 700, 500, 300 mb. and the 1000–500-mb. thermal wind were found in this way, there being two upper air charts (at  $H + 3$  and  $H + 9$ ) during the 12-hr. measured period. The values used in this investigation were means of the readings from these two consecutive charts.

Measurements were also made of the warm-sector geostrophic wind; the depression size (radius of outer closed isobar), change of size, and the change of central pressure were also noted. In addition, 6-hr. isallobars were drawn by gridding consecutive surface charts.

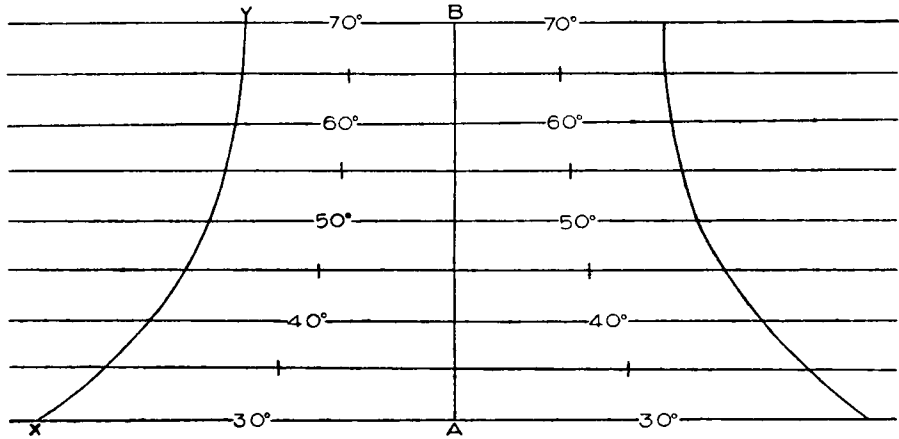


FIG. 1—SCALE FOR OBTAINING MEAN FLOW OVER AN AREA

This scale, incorporating a correction for map distortion, is reduced from that used for 1 : 10,000,000 charts.

**Results.**—Previous writers have used angular deviation as a measure of the success of steering rules, and values obtained in this investigation are given in Table I. The apparently smaller variability of the deviation from the 700-mb. direction is not thought to be significant, as this is based on only 15 cases. The case omitted is one in which lack of observations at 700 mb. made it impossible to give any reliable reading at this level—and it is by far the worst case of the 16 at the other levels, so that the 700-mb. level is doubtless favoured by its omission.

TABLE I—ANGULAR DEVIATIONS

Track of depression minus direction of:	Mean	Standard deviation	Mean ignoring signs
		<i>angular degrees</i>	
Area mean 300-mb. wind ... ..	−4·1	8·3	7·4
Area mean 500-mb. wind ... ..	−2·9	8·3	6·5
Area mean 700-mb. wind ... ..	−5·5	7·2	7·6
Area mean warm-sector wind ... ..	−6·1	11·9	10·2
Area mean 1000–500-mb. thermal wind ...	−0·6	9·8	6·3
Isallobaric gradient ... ..	−2·3	8·3	6·3

These results show that for this type of depression mean angular deviations for all the steering parameters shown are small, the smallest being that for the 1000–500-mb. thermal wind. It is noteworthy that the agreement between depression track and thermal wind direction during the measured period is as consistent as that between depression track and isallobaric gradient during the measured period.

Correlation coefficients were calculated between the component velocities of the depressions and the wind components for the various levels and these are given in Table II. There were 32 pairs of numbers (two components for each of the 16 cases) in the correlations. The correlation coefficient between the motion of the depression and the “spot” value of the 1000–500-mb. thermal wind, using a geostrophic scale in the usual manner, is also given.

TABLE II—CORRELATION COEFFICIENTS BETWEEN COMPONENTS OF DEPRESSION VELOCITY AND OTHER VELOCITIES

With area mean 300-mb. wind	...	...	0·89
With area mean 500-mb. wind	...	...	0·90
With area mean 700-mb. wind	...	...	0·86
With area mean 1000-mb. wind	...	...	0·47
With area mean warm-sector wind	...	...	0·81
With area mean 1000–500-mb. thermal wind	...	...	0·92
With spot value of 1000–500-mb. thermal wind	...	...	0·80

These values show that for depression speed the best correlation coefficient is that for the 1000–500-mb. thermal wind, but for this type of depression upper winds at all levels shown are quite strongly correlated with the speed of the depression. The improvement obtained by using an area mean is clearly shown, the spot value of the 1000–500-mb. thermal wind giving a correlation coefficient only comparable with that for the warm-sector wind.

The ratio of the depression speed  $c$  to the 1000–500-mb. thermal wind speed  $v'$  varied between 0·66 and 0·98 with a mean value of 0·80. The variations of  $c/v'$  were studied in relation to all the other parameters measured. No worthwhile correlation was evident. It was found impossible to formulate any empirical rule to improve upon the thermal steering results by using any of the other parameters. In view of the concept of the advection of a vortex in a general current it is particularly interesting that no success could be achieved in this way by using the 1000-mb. wind.

**Errors.**—A rough check of the magnitude of the errors involved in using thermal steering was thought to be worth while. Means and standard deviations were calculated and are given in Table III. Now (a) is a measure of the reliability of using  $4v'/5$  as an estimate for  $c$ , whilst (b) is to some extent a measure of the reliability of the charts. As this latter includes only errors of inconsistency

TABLE III—MEANS AND STANDARD DEVIATIONS OF VARIOUS POSSIBLE ERRORS

	Mean kt.	Standard deviation kt.
(a) Difference between the 32 components of $c$ and corresponding components of $4v'/5$ ... ..	–0·5	1·5
(b) Difference between components of $v'$ and the components found by subtracting the measured 1000-mb. components from the 500-mb. components ... ..	+0·5	2·4
(c) Difference between the components of $c$ read off the charts before and after redrawing ... ..	+2·4	5·4

in gridding and measurement, whereas there are also other errors (consistent drawing errors, observational errors, errors due to the geostrophic assumption) likely to worsen the reliability of our measurement of upper winds, (*b*) is very probably an under estimate of the errors one might expect to find in the investigation by these methods of even a perfect steering law. Consequently the fact that (*a*) is less than (*b*) suggests that little improvement can be expected, using present charting technique, over the thermal steering result found.

The fact that (*c*) is more than twice as large as (*b*) and about four times as large as (*a*) suggests that considerably greater errors can exist in the placing of surface depressions on the Atlantic on the current surface chart than the errors involved in using thermal steering. Such errors in the position of the depression centre on the surface map affect the speed and direction which would be used in applying an extrapolation technique.

**Further test cases.**—A further 18 cases were found satisfying the conditions above during the six-month period July 1 to December 31, 1950. The following results were obtained for these depressions.

The correlation coefficient between area mean 1000–500-mb. thermal wind and the depression velocity components was 0.94;  $c/v'$  varied between 0.71 and 1.20 with a mean value of 0.97.

The standard deviations of possible errors found by an analysis similar to that above were somewhat larger than those quoted there, but still gave a probable error of less than 5 kt. in using  $4v'/5$  as an estimate for  $c$ .

**Conclusions.**—(1) Simple warm-sector depressions on the Atlantic move with the direction of and slightly over four-fifths of the speed of the 1000–500-mb. thermal wind (meaned over an area) with a probable error of less than 5 kt. in speed and less than  $10^\circ$  in direction.

(2) Better results are obtained by measuring the mean thermal wind over an area than by reading a “spot” value of the thermal wind at the depression centre. Such a mean value may readily be obtained by using the type of scale shown in Fig. 1.

(3) The surface pressure distribution in the vicinity of the depression seems to have little effect, so that the barotropic advection of a surface vortex in the surface stream does not seem to be a very helpful theoretical concept in connexion with these depressions.

(4) Although cases of marked “development” in the thermal pattern were excluded from this investigation, during the course of the investigation several cases were noted where there was marked diffuence ahead of the surface centre. A cursory check suggested that in all such cases the speed of the depression was greater than would otherwise have been expected. The presence of marked development areas<sup>3</sup> in the thermal pattern in the vicinity of the depression may well have some considerable effect on the motion of the depression.

(5) Although the figures quoted throughout this investigation apply to measurements of the thermal wind simultaneous with the measured motion of the depression and not to the reliability of thermal steering at any instant as a guide to the motion of a depression over the subsequent 24 hr., the technique of preparing “pre-thickness” charts is already sufficiently well developed for them to be used with reasonable confidence for forecasting the subsequent 24-hr. motion of a depression if and when thermal steering is known to be the right



principle to employ. No such technique is available for forecasting the isallobars 24 hr. ahead (see comments on p. 209). The results thus suggest that for the limited class of depressions considered, thermal steering by the 1000–500-mb. thermal wind might well give better results than extrapolation of the past track or the use of isallobars, provided that the mean thermal wind is estimated over a substantial area centred on the depression.

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## AN EXPLANATION OF THE BEHAVIOUR OF THE DEPRESSION OF OCTOBER 4–6, 1952, IN TERMS OF THERMAL-DEVELOPMENT THEORY

By F. E. LUMB, M.Sc.

C. A. S. Lowndes<sup>1</sup> has recently discussed the depression which formed near Greenland on October 4, 1952 and moved southwards then south-eastwards towards Denmark. He has described its thermal structure as unusual and complex and its movement as abnormal; nevertheless its behaviour can be explained in terms of Sutcliffe's thermal-development theory<sup>2,3</sup>.

**Growth of the thermal rear trough.**—At 0300 G.M.T. on October 4 the incipient depression was at the crest of a markedly diffuent thermal ridge (Fig. 1). According to thermal-development theory the maximum of cyclogenesis would be situated just to the west of the ridge crest. Since thermal steering at the diffuence was weak the depression initially deepened with little movement. Deepening associated with slow movement resulted in the rapid growth of a thermal trough in the baroclinic zone immediately to the west of the centre of the depression. Also the thickness lines in the vicinity of the ridge

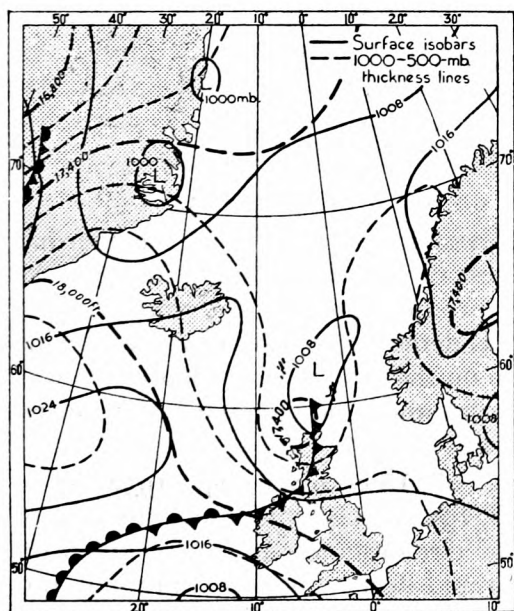


FIG. 1—SYNOPTIC CHART, 0300 G.M.T., OCTOBER 4, 1952

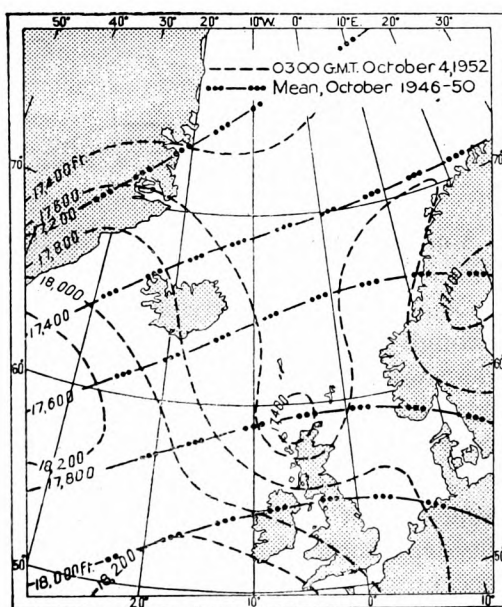


FIG. 2—THICKNESS CHART

crest were displaced well to the north of their mean geographical position for October (shown in Fig. 2) as given in *Meteorological Reports* No. 13<sup>4</sup>. Consequently the northerly winds to the west of the centre of the deepening depression strengthened in a thermal-geographic environment extremely favourable for the southward movement of the thickness lines by advection. The northward displacement of the thickness lines in the thermal ridge from their mean position was therefore also a factor favourable to rapid growth of the thermal rear trough.

**Cyclogenetic transfer of the centre of the depression.**—By thermal-development theory the maximum of cyclogenesis would be transferred to a position a little to the east of the tip of the developing thermal trough. Since thermal steering was weak, the centre of the depression was transferred southwards with the maximum of cyclogenesis. The position of the centre at 0300 on October 5 (Fig. 3) was in close agreement with theory, since it was situated very near to the point where Sutcliffe's cyclonic-development term (product of the thermal wind and the rate of decrease of cyclonic vorticity down the thermal wind) was a maximum.

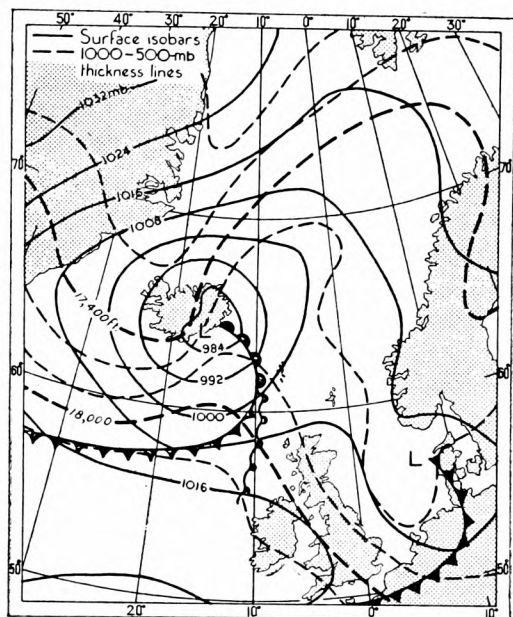


FIG. 3—SYNOPTIC CHART, 0300 G.M.T., OCTOBER 5, 1952

**Vortex stage.**—Deepening of the depression and growth of the thermal rear trough being interdependent processes, rapid growth of the trough was associated with a correspondingly rapid progress towards the vortex stage, through the agency of dynamical cooling as demonstrated by Lowndes<sup>1</sup>. This stage was reached approximately by 1500 on the 5th when the depression was between Iceland and the Faroes. It then assumed the character of a vortex travelling in the west-north-westerly current.

**Comparison with the depression of December 29, 1952.**—The behaviour of the depression of October 4–6, 1952 can be compared with that of the depression which formed under similar circumstances near Greenland on December 29, 1952. During the stage of rapid deepening this depression also moved south-eastwards, almost perpendicular to the thickness lines, in association with a rapidly developing thermal trough.

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## METEOROLOGICAL OFFICE DISCUSSION

### Recent investigations of fronts

The last discussion of the 1954–55 series, which was held on Monday, March 21, 1955, at the Royal Society of Arts, was opened by Mr. I. J. W. Potheary who described recent research on fronts in the Forecasting Research Division at Dunstable.

The opener dealt briefly with frontal movement. The work of Matthewman<sup>1</sup> had shown that the “two-thirds geostrophic” rule for the speed of warm fronts over land was reliable in straightforward situations. Ageostrophic motion, which depended on the rate of change of the geostrophic wind component parallel to the front, was more difficult to forecast although the isobaric patterns associated with large ageostrophic movements could be recognized and taken into account. Recent work by Hinkel and Saunders had suggested that a “five-sixths geostrophic” rule was more appropriate for the speed of warm fronts over the Atlantic.

Warm-front rainfall had been correlated with 13 different synoptic parameters in an investigation by Corby into the possibility of forecasting rainfall amount or intensity. No single parameter was well enough correlated with rainfall to be of use in forecasting, but 60 per cent. of the variance of the average rainfall over England could be predicted by using pressure and frontal contrast in a multiple regression relation. Frontal contrast was defined in the investigation as the change in the mean 1000–500-mb. thickness over 250 miles ahead of the front. The results showed that even a completely successful forecast of the average rainfall over an area might be 100 per cent. in error for any one place, owing to the large spatial variability of warm-front rainfall.

The investigation of fronts by aircraft was described in some detail. From 1950 to 1952 23 fronts were flown through at various levels by the Meteorological Research Flight. The results of these flights, which had been analysed by Sawyer<sup>2</sup>, were illustrated and amplified by flights from a second series which was still in progress.

The analysis of the first series showed a front to be a baroclinic zone extending upwards through a less baroclinic region. The total horizontal temperature contrast between air masses, which averaged about 15°F., took place through about 600 miles in the frontal region. An average change of 9°F. was concentrated in the frontal zone which had a horizontal width of about 130 miles. Half the air-mass contrast took place in the frontal zone which occupied only about a quarter of the frontal region. The observed slopes of the fronts varied from 1:30 to 1:250. Any one front varied in slope from level to level but the Margules relation between slope and temperature contrast was generally observed.

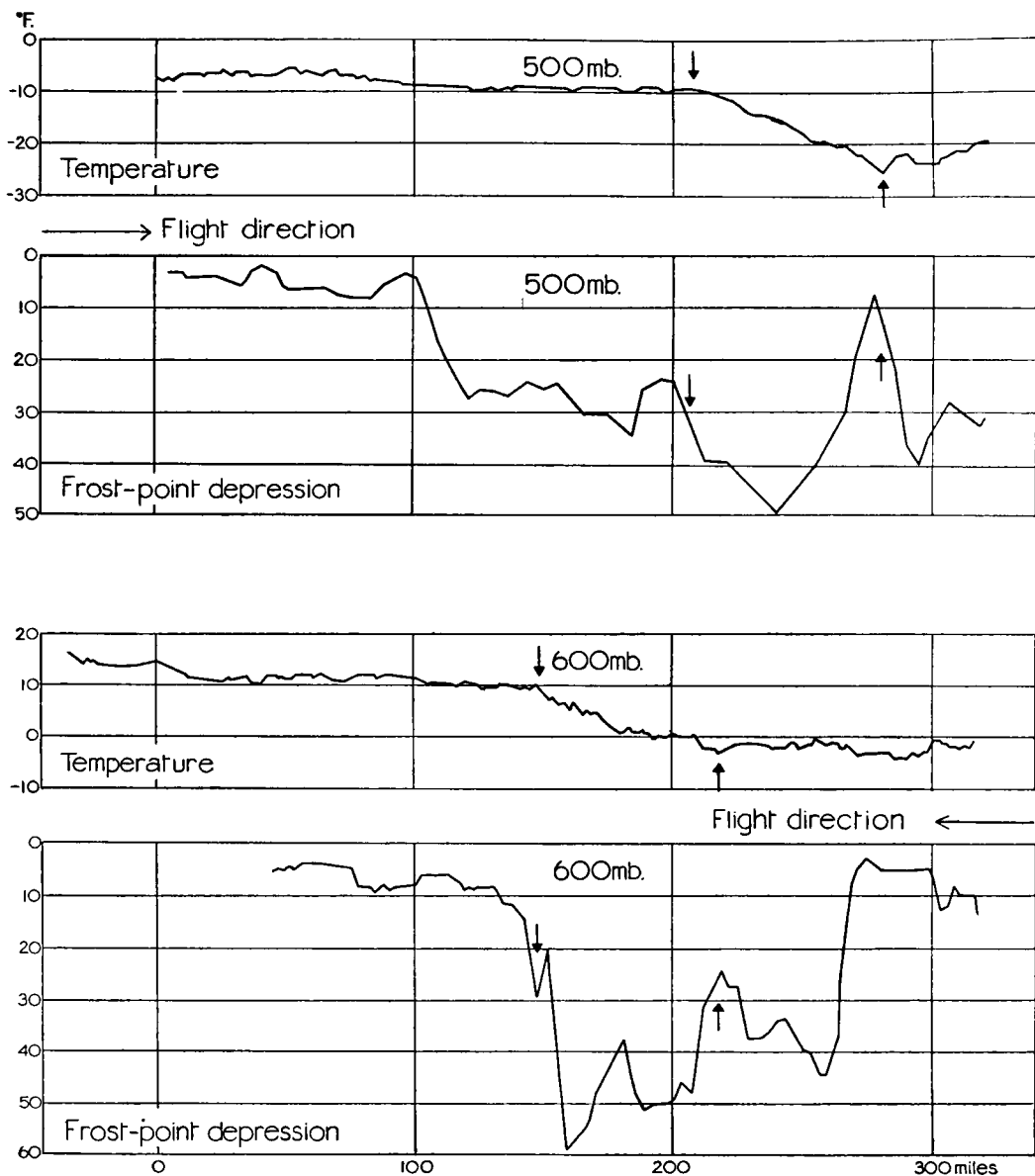


FIG. 1—AIRCRAFT OBSERVATIONS OF A WARM FRONT,  
1200–1600 G.M.T., NOVEMBER 29, 1954

The boundaries of the frontal zone are shown by arrows

The flight discussed in detail took place on November 29, 1954, through the upper levels of a warm front associated with a deepening depression off south-west Ireland. Radio-sonde cross-sections along the line of flight were compared with cross-sections prepared from the flight observations (Fig. 1). The temperature cross-sections were almost exactly similar but the aircraft cross-section of frost-point depression showed that the humidity had a more complicated structure than the radio-sonde information suggested. The frost-point depression reached 60°F. in the frontal zone, indicating humidities of less than 5 per cent. Similar low humidities had been observed in association with other fronts.

In all the fronts investigated dry air was present as a more or less well developed tongue extending downwards in or near the frontal zone, and in about half the fronts of the first series the driest air was in the frontal zone.

The very dry air in the frontal zone of the warm front of November 29, 1954, was traced back westwards along an isentropic trajectory for 36 hr. from the time of observation. The air had been passing through a jet stream for the previous 24 hr. and had subsided only 15 mb. For 12 hr. before that this same air had been accelerating into the left entrance of the jet stream and had subsided 50 mb. as a result of the anticlockwise cross-axis circulation in the entrance region of the jet. Air that was probably already dry in the upper troposphere and lower stratosphere over mid Atlantic had been brought down to lower levels in the frontal zone and further dried by subsidence. Similar cases were noted in the first series.

An analysis of the position of cloud relative to the frontal zone showed that the main frontal cloud mass was often in the warm air away from the frontal zone. This was a fairly common feature. The presence of dry air on the cold side of the jet stream was proposed as the reason for the observed dissociation of the cloud system from the frontal zone.

The opener inferred from this that the humidity information from an individual radio-sonde ascent could not be regarded as a reliable indication of the activity of a front. The presence of dry air in or near the frontal zone did not necessarily indicate descending motion at the time, neither did the presence of dry air mean an inadequate supply of moisture for frontal rain.

The occurrence of clear-air turbulence at several places in the frontal zone of a cold front was illustrated, and it was suggested that, if the necessary wind shears are present, the cloud-free upper parts of frontal zones are preferred regions for turbulence.

*Mr. Sawyer* presented some recent theoretical work, supported by analyses of synoptic charts, which pointed to the process of confluence of two air streams in a region of strong horizontal thermal gradient as fundamental to the development and maintenance of recognizable frontal characteristics. The rain and cloud system of a front were due not only to the strong temperature contrast between adjacent air masses but also to the presence of a pattern of horizontal flow which tended to increase the temperature gradient.

Under these circumstances a vertical circulation is set up in which the warm air mass rises and the cold air mass sinks with ageostrophic flow towards the warm air at the ground and towards the cold air aloft. Theoretical calculation of the magnitude of the effect had given vertical velocities considerably less than those observed, unless the effect of saturation of the warm air on its stability was taken into account. Saturation of the air in a region of strong horizontal temperature gradient might lead to the condition for dynamical instability specified by Solberg<sup>3</sup>, namely that the horizontal wind shear along a wet-bulb potential-temperature surface should be anticyclonic and exceed the Coriolis parameter. Calculation showed that when this state was approached the vertical circulation in the vicinity of fronts would be much larger, and the existence of such wind shears may well have an important influence on the activity of a front.

*Mr. Matthewman* pointed out that the boundaries of frontal zones as drawn in cross-sections by various authors showed several different interpretations of the

structure of fronts in the upper part of the troposphere. From analogies with the mathematical properties of families of curves he argued that a structure in which the frontal-zone boundaries are continuous with the tropopause was the most satisfactory choice.

*Dr. Sutcliffe* remarked that the picture of frontal structure presented by the opener was a complicated one, far removed from the simple models presented in textbooks and training courses. The presence of dry air in or near frontal zones was a new and interesting feature of the picture. Instead of the single sloping surface separating warm and cold air evidence had been presented of two surfaces or rather narrow zones of discontinuity of temperature gradient. In the light of Sawyer's critical examination of upper air temperature observations, this complex picture might not be physically the best. *Dr. Sutcliffe* remarked that *Matthewman's* reasoning on the continuity of frontal and tropopause surfaces was based on geometrical continuity, but he wondered what it meant physically and whether it could really be argued that the tropopause and the stratospheric air came down to near the surface.

*Mr. Durbin* described the conditions on frontal flights of the Meteorological Research Flight, and said that out of about 40 flights there were only two occasions on which it had been necessary to discuss diverting the aircraft because of bad weather at base. On only two occasions had heavy icing been encountered. He felt that the present method of choosing fronts with a definite thermal contrast could be modified, together with the method of investigation, to give more information to the forecaster, and to make better use of the large amount of time at present spent flying through clear air in regions primarily of thermodynamic interest. *Mr. Durbin* added that a series of flights in bad-weather situations had been undertaken at Farnborough from which there was evidence that cloud above about 15,000 ft. was rarely extensive. Moderate to heavy rainfall sometimes occurred with cloud entirely below that level. *Mr. Potheary* replied that it was important that the thermal structure which defined the front should be investigated even in clear air as this provided a frame of reference into which the weather might be fitted.

*Mr. Bannon* asked if *Mr. Potheary* was satisfied that the temperature discontinuities in the upper troposphere above 500 mb., which were marked in the diagrams as boundaries of the frontal zone, were also the regions of change of air mass. The observations of frost point indicated that the air in the frontal zone had subsided through a considerable depth, and there was the possibility that the temperature discontinuity which was assumed to mark the cold boundary of the frontal zone might have been caused by subsidence and that the true frontal zone might be elsewhere. *Mr. Potheary* replied that in the cases which he had analysed the distribution of wet-bulb potential temperature indicated that the boundary between the two air masses was coincident with the frontal zone as defined by temperature alone. *Mr. Bannon* also referred to the low correlation between rainfall and the *Sutcliffe* development term, and asked if this was due to the difficulty of measuring development.

*Mr. Corby*, in reply, said that somewhat higher correlations between development and rainfall had been obtained by *Sawyer* in the past. He thought that estimates of development from charts were liable to considerable uncertainties.

*Dr. Stagg* commented that so far the discussion had been concerned almost entirely with frontal structure, but the question of frontal movement was of



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**GROUND FOG AT STEVENAGE, HERTFORDSHIRE**  
(see p. 226)





METEOROLOGICAL OFFICE STAFF CENTENARY DINNER  
March 11, 1955  
(see p. 228)

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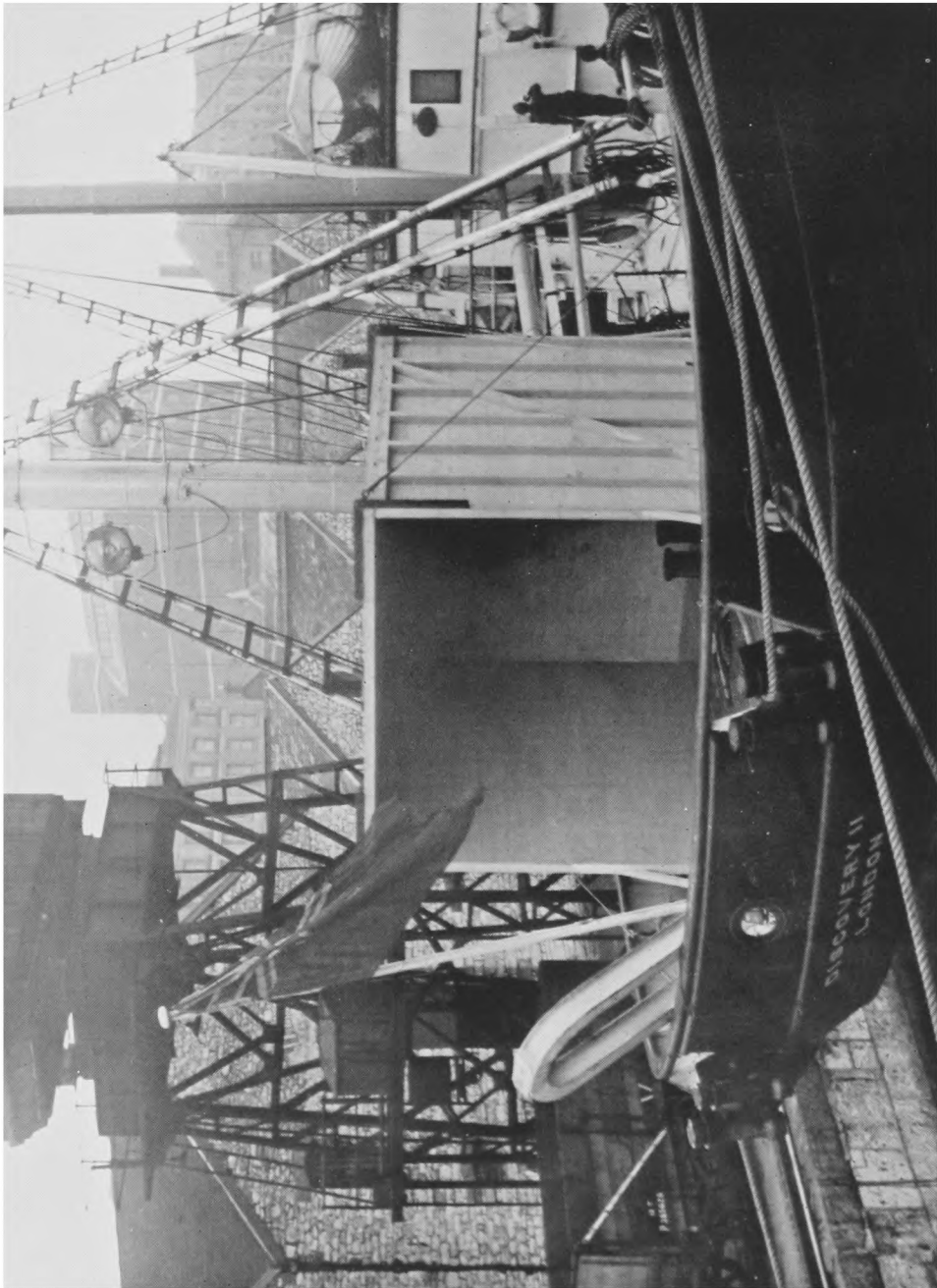


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**METEOROLOGICAL OFFICE STAFF CENTENARY DINNER**

**March 11, 1955**

(see p. 228)



Reproduced by courtesy of The National Institute of Oceanography

R.R.S. *Discovery II* IN DOCK AT PLYMOUTH, SHOWING THE TEMPORARY  
BALLOON-FILLING SHELTER ERECTED ON THE AFTER DECK  
(see p. 227)

great practical importance. He asked how the rules relating the speed of fronts to the geostrophic wind could be reconciled with the work of Goldie some 25 years previously. Goldie dealt not with the displacement of lines on synoptic charts but with the movement of rain areas, and found that in western Scotland the greater part of warm-front rain fell in the early morning and cold-front rainfall was greatest in the afternoon, suggesting preferred times of the day for the arrival of the fronts. The suggested explanation was the difference in diurnal heating over land and sea, and its effect on cloud. If frontal movements respond to temperature differences between land and sea might they not also be affected by the patchiness of sea temperature?

*Mr. Sawyer* replied that it was difficult to interpret statistics of precipitation amounts at fronts because of the uncertainty of frontal analyses. If frontal rain ceased the front was likely to be omitted from the analysis. *Mr. Sawyer* did not think that Goldie's figures of fewer frontal rain areas at one time of the day could be interpreted simply as meaning fewer fronts.

*Dr. Robinson* asked if any relation between the occurrence of cirrus and the position of the dry zone was apparent.

*Mr. Bradbury* asked if condensation trails were observed on flights through frontal zones, and whether trails were observed in the dry region. *Mr. Potheary* replied that the investigating aircraft flew too low to make trails, but those made by other aircraft at higher altitudes were recorded as well as the occurrence and distribution of cirrus cloud. Uncertainty about the position or existence of the dry region at high levels precluded the establishment of any definite relation between the dry region associated with a front and the formation of condensation trails or cirrus cloud.

*Mr. Absalom* asked if dry air was associated with all the fronts that had been examined, and if there was any relation between the degree of dryness and the rainfall from the front. *Mr. Potheary* replied that no noticeable dry region was flown through in the investigation of one or two very weak fronts, but the presence of dry air was definitely shown in all the other fronts that had been examined. Frost-point depressions of up to  $70^{\circ}\text{F.}$ , corresponding to relative humidities well below 5 per cent., had been observed. No correlation between the dryness of the dry region and the rainfall from the front had so far been attempted.

*Mr. Illsley* remarked that few aircraft ascents were available and the deduction of cloud detail from radio-sonde ascents was difficult. He had found in practice that cloud might be present if the reported dew point was within  $4^{\circ}\text{F.}$  of the dry-bulb temperature. *Mr. Illsley* hoped that this problem might be given attention when the flights were fully analysed. *Mr. Illsley* also suggested that statistical investigations into the movement of fronts should be treated with caution. In his earlier work *Matthewman* had found that warm fronts over land moved on the average at about five-sixths of the geostrophic wind across them, but defining his warm fronts more rigorously he found that a ratio of two-thirds was more appropriate. Perhaps *Hinkel* and *Saunders's* investigation of the movement of warm fronts over the sea might give different results with a different selection of fronts. Practising forecasters relied more on extrapolation than on a statistical rule for short-term forecasts, and over longer periods a warm front had to be placed with due regard to numerous other factors. *Mr. Potheary* replied that *Hinkel* and *Saunders's* data had been

re-examined according to Matthewman's rigorous criteria so that the difference in the speed of warm fronts over land and sea appeared to be real.

*Mr. Reed* emphasized the importance of icing in fronts to the aviation forecaster. Aircraft had on occasions to be routed along a front and were likely to be subjected to icing over a considerable period. The forecaster was expected to provide an accurate assessment of the icing risk which necessarily varied with the direction in which the aircraft was flown. *Mr. Reed* also asked if any allowance was made for the lateral displacement of the radio-sondes when the cross-sections were drawn.

*Dr. Pepper* asked if the observed slopes of the fronts were checked against the Margules formula. *Mr. Potheary*, in reply, said that no quantitative measurement had been made but both the radio-sonde and aircraft temperature cross-sections showed a qualitative agreement between frontal slopes and the Margules formula.

*Mr. Wallington* said that fronts were used to describe the weather pattern, to interpret the dynamical situation and to mark the progress of recognizable air masses. The first two requirements were met by analyses of the synoptic and thickness charts, but to give the third aspect the detailed attention it deserved it would be necessary to analyse the distribution of some conservative physical property of the atmosphere at about 800 mb.; such charts would, of course, be even more subjective than our more familiar analyses.

*Dr. Stagg*, in closing the meeting, remarked upon the clear presentation of *Mr. Potheary's* opening statement, and said that this had been one of the best of recent discussions. Nevertheless there was still much to be learnt about the structure and movement of fronts.

#### REFERENCES

1. MATTHEWMAN, A. G.; Speed of warm fronts. *Met. Mag., London*, **81**, 1952, p. 266.
2. SAWYER, J. S.; The free atmosphere in the vicinity of fronts. *Geophys. Mem., London*, **12**, No. 96 (in the press).
3. SOLBERG, M.; Le mouvement d'inertie de l'atmosphère stable et son rôle dans la théorie des cyclones. *P.V. Mët. Un. géod géophys. int. 6ième Assemblée Générale, Edimbourg*, 1936, Paris, 1939, Vol. II, p. 66.

### METEOROLOGICAL RESEARCH COMMITTEE

The 19th meeting of the Instruments Sub-Committee was held on February 17, 1955. Two papers<sup>1,2</sup>, which had previously been discussed by the Synoptic and Dynamical Sub-Committee, regarding corrections which might be applied to radio-sonde temperatures were discussed and approved. The Sub-Committee then considered a paper<sup>3</sup> giving the results of humidity measurements from Meteorological Research Flight aircraft at heights up to 50,000 ft. On most of these ascents the frost point at 50,000 ft. was found to be between  $-110^{\circ}\text{F}$ . and  $-120^{\circ}\text{F}$ . *Mr. Rider* presented a paper<sup>4</sup> describing an instrument for the continuous recording of soil temperature. The Sub-Committee then went on to discuss the proposed amendments to Part I of the Research Programme for the coming financial year. The draft report of the Chairman to the Meteorological Research Committee was also approved.

The 34th meeting of the Synoptic and Dynamical Sub-Committee was held on February 24, 1955. A paper<sup>5</sup> by *Mr. Sawyer* on some characteristics of fronts and their relation to frontogenesis was presented by the author and evoked considerable interest. A report by a sub-committee which had been

considering the problem of air flow over mountains was adopted and recommended to the Director for further consideration. The proposed amendments to Part II of the Research Programme and the draft report of the Chairman to the Meteorological Research Committee were then approved.

The 32nd meeting of the Physical Sub-Committee took place on March 3, 1955. A paper<sup>6</sup> by Mr. Blackwell was presented which dealt with five years' continuous recording of total and diffuse solar radiation at Kew Observatory. The Sub-Committee discussed and approved the draft programme for meteorological research at the Chemical Defence Experimental Establishment, Porton, and approved amendments to Part III of the Research Programme. The draft report of the Chairman to the Meteorological Research Committee was approved.

The 69th meeting of the Meteorological Research Committee was held on March 31, 1955. The reports of the Chairmen of the three Sub-Committees were received and the Research Programme for 1955-56 approved. The Annual Report to the Secretary of State for Air was agreed. Various changes in membership of the Committee and Sub-Committees were agreed, and the Chairman, Sir David Brunt, announced his retirement from the Chair and from the Committee. The Director expressed his appreciation of Sir David Brunt's advice and services as Chairman over the past three years and as a member of the Committee since its inception in 1941. Sir Charles Normand was elected as the new Chairman. Following the meeting there was a discussion of the work of the Meteorological Research Flight. Mr. H. W. L. Absalom opened the discussion and Mr. R. J. Murgatroyd answered questions regarding the work of the Flight. The Committee expressed their satisfaction with the progress being made and congratulated Mr. Murgatroyd on the work already done by the Flight.

#### ABSTRACTS

Abstracts Nos. 1-3 have been given in the May 1955 *Meteorological Magazine*, p. 154, Nos. 2, 3 and 5.

4. RIDER, N. E.; A note on an instrument for the continuous recording of soil temperatures. *Met. Res. Pap.*, London, No. 883, S.C. I/93, 1954.

The instrument consists of a Tufnol tube in which thermo-couples are inserted at depths of 1, 5, 10, 20 and 40 cm. and connected to a six-colour recording galvanometer. Wiring is shown and a tracing of a record is reproduced. The instrument is simple, requires a minimum of attention and of soil disturbance.

5. SAWYER, J. S.; Some characteristics of fronts and their relation to frontogenesis. *Met. Res. Pap.*, London, No. 896, S.C. II/183, 1954.

A front is regarded as an area into which active confluence of air currents at different temperatures is taking place. It is shown that frontogenesis must be accompanied by a vertical circulation. Air trajectories from the surface to 300 mb. are drawn and discussed. Temperature changes are consistent with a vertical circulation upwards in the warm air and downwards in the cold air. The field of frontogenesis near well defined precipitating fronts is examined, and the theory of confluence is applied to different fields of specific volume.

6. BLACKWELL, M. J.; Five years continuous recording of total and diffuse solar radiation at Kew Observatory. *Met. Res. Pap.*, London, No. 895, S.C. III/179, 1954.

Records of Moll-Gorczyński solarimeters for total and diffuse radiation on a horizontal surface from 1947 to 1951 are described. Sources of error are exhaustively examined. Tables give corrected hourly means of total and diffuse radiation, computed extraterrestrial radiation on a horizontal surface, and hourly means of sunshine, all for 10-day periods. Values are shown in graphs, which also include diffuse and total radiation on cloudless days and correlation of total radiation with sunshine.

## ROYAL METEOROLOGICAL SOCIETY

At a meeting of the Society held on March 16, 1955, the President, Sir Graham Sutton in the Chair, the following papers were read:—

*Lamb, H. H.—Two-way relationship between the snow or ice limit and 1000–500-mb. thicknesses in the overlying atmosphere\**

The 1000–500-mb. thickness is closely associated with the temperature of the air at different levels, the largest variation being at the surface. Mr. Lamb showed in addition the relation with the freezing level and dwelt for some time on the relation between thickness and the occurrence of different types of precipitation. The change-over from frozen to unfrozen precipitation occurred at a thickness of 17,300 ft. at an inland station, and at 17,150 ft. at a coastal or oceanic station such as Lerwick. With snow on the ground this critical thickness would be increased to 17,500 ft., as shown by data from Stockholm, but the change-over was more gradual, the likelihood of unfrozen precipitation increasing from 30 to 70 per cent. as the thickness increased from 17,450 to 17,800 ft. Mr. Lamb thought that this was because slight snow would fall from stratus cloud lying beneath an inversion induced by the snow-cover, even when the higher atmosphere was warm.

It was also possible to correlate the thickness with the edge of the area with extensive snow lying. Mr. Lamb found a mean thickness of 17,297 ft. over the snow limit in north-west Europe and 17,260 ft. over the Dutch whaling ship *Willem Barendsz* near the edge of the antarctic pack-ice. An attempted correlation with the mean position of the 0°C. isobar over North America and Russia was not justified because of the difference between the periods of the data. Mr. Lamb also considered the incursion of various thickness lines across the ice or snow limit. Many of the incursions of warmer air to great distances occurred with high winds or anticyclonic inversions at low levels. The 17,400 ft. line could travel 2,500 miles across a snow surface with the help of subsidence but only 1,500 miles without. Warming of cold air over the sea gave similar limitations to the advance of lower thicknesses from the snow or ice margin.

In the discussion that followed, Mr. Murray drew attention to the slightly different critical thickness of 17,150 ft. that he had found† which was due solely to the difference in grouping of the various forms of precipitation. Mr. Lamb agreed with Mr. Murray, but stressed the higher critical thickness over a snow surface; he quoted Baur's criterion that if the mean temperature during the first half of December in Berlin was more than 2½°C. above normal then the winter would be mild. Mr. Craddock gave a brief résumé of an inconclusive investigation at Dunstable into Baur's criterion; among other conclusions they had found a greater loss of thickness due to radiational cooling at the top of the layer than from contact with a snow surface at the ground. Prof. Gordon Manley had been considering running means going back 200 yr. but could find no long persistence of cold weather; however, a cold February could be followed by a cold March because of extensive snow-cover. Dr. Sutcliffe thought the thickness criterion for type of precipitation would be very useful with modern numerical forecasting methods, but it would be better to associate the higher critical thickness in certain cases with stability rather than with snow-cover.

*Moore, D. J. and Mason, B. J.—The concentration, size distribution and production rate of large salt nuclei over the oceans‡*

This paper gives the observed distribution of salt nuclei from aboard ocean weather ships. Two types were observed. The first was particularly pronounced with strong winds, was possibly produced from the sea surface, and had a maximum concentration of nuclei heavier than  $2 \times 10^{-14}$  gm. of  $10/\text{cm}^3$ . A discontinuity in the distribution occurred at a critical size, depending on the wind speed, probably caused by sedimentation of the larger nuclei. The second type, which was only found on 5 occasions out of 30 when the wind speed was less than 7 m./sec., was shown to be very similar to the distribution found by Dessins at Haute Garonne in which only the largest droplets (1 per cent. of the total) were found to contain sodium-chloride crystals. It was concluded therefore that with light winds the nuclei were of land origin. Later Mr. Mason quoted Japanese research figures of nuclei proportions: 50 per cent. combustion nuclei, 20 per cent. sea salt, 20 per cent. soil nuclei, and 10 per cent. unidentified.

Using a wind tunnel with waves breaking inside it, Mr. Mason had found a production rate of  $40/\text{cm}^2/\text{sec.}$  for nuclei heavier than  $10^{-13}$  gm. in a speed equivalent to 16 m./sec.; by consideration of observed size distribution he calculated a production rate of  $43/\text{cm}^2/\text{sec.}$  for nuclei heavier than  $10^{-13}$  gm. in a wind speed of 15 m./sec. or  $86/\text{cm}^2/\text{sec.}$  for nuclei heavier than  $2 \times 10^{-14}$  gm., the minimum size of nuclei captured. Laboratory studies by means of high-speed camera and collection in a confined space were made to show how the bursting of air bubbles could produce smaller nuclei. The smaller droplets were produced by disintegration of the

\* *Quart. J.R. met. Soc., London*, **81**, 1955, p. 172.

† MURRAY, R.; Rain and snow in relation to the 1000–700-mb. and 1000–500-mb. thicknesses and the freezing level. *Met. Mag., London*, **81**, 1952, p. 5.

‡ *Quart. J.R. met. Soc., London*, **80**, 1954, p. 583.

bubble film; only two or three large droplets were produced by the breaking of the jet following the burst bubble. By converting the confined space into a Wilson cloud chamber he had, however, been able to show that, since a dense cloud was formed, many very small nuclei were produced by the bursting bubble.

Prof. Sheppard asked how the Japanese sorted out the types of nuclei; it was done by matching electron micrographs with those of known particles. There was also some discussion as to how the breaking of bubble films could produce such small droplets.

The Annual General Meeting of the Society was held on April 20 with Prof. P. A. Sheppard, Vice-President, in the Chair. After the passing of the Report of the Council for 1954, Prof. Sheppard presented the Symons Memorial Gold Medal for 1955 to Dr. R. C. Sutcliffe for outstanding work in the field of synoptic and dynamical meteorology. The Darton Prizes for original work of high quality in instrumental meteorology were also presented, the first prize jointly to Dr. J. T. Houghton and Dr. A. W. Brewer and the second prize to Dr. L. G. Smith. Special Canadian awards of Darton Prizes were also announced, the first jointly to Dr. D. P. McIntyre and Mr. R. Lee, and the second to Dr. J. S. Marshall.

Owing to the unavoidable absence of Sir Graham Sutton in Geneva instead of the customary Presidential Address there was an informal discussion on the weather of 1954.

The first speaker, Dr. J. Glasspoole, gave a brief outline of the weather in the British Isles. It was comparatively dry during the first four months of the year but was then wetter than the average for seven consecutive months in England and Wales and eight months in Scotland; this length of spell of wet weather has only been equalled six times, and exceeded twice, in the last 200 yr. in England and Wales. Taking the year as a whole there have been seven wetter years since 1869 in England and Wales and only three in Scotland. The number of rain-days in the year was also excessive; since 1919 in Scotland the number of rain-days in 1954 was only exceeded in 1923; during the last four months there were 102 rain-days out of a possible 122. Temperature during the summer was much below average, chiefly due to colder days, but this is only remarkable when compared with the warm summers prevailing since 1932; during 1902-31 there were 12 cooler summers. The daily mean sunshine for the year was 0.3-0.4 hr./day less than average throughout the country, but there was little change from the average general pattern. Mean annual pressure over the country was rather less than average in the south and 2.5 mb. less than average in the north showing an increased pressure gradient with more frequent winds with a westerly component; although it was windy on the whole the year was not the windiest on record nor a year of outstanding gusts.

Dr. A. G. Forsdyke referred to the weather over the world as a whole, and remarked that the year was not exceptional. Every year some part of the world experiences unusual weather; it so happened that in 1954 the British Isles seemed to get the worst of what was going. He divided the year into periods according to the weather over the British Isles, and showed charts, extending from the Rocky Mountains to the Urals, of monthly pressure anomaly and monthly 1000-500-mb. thickness anomaly for each of the periods. The January 1954 charts, representing January-March when the weather over the British Isles was changeable and cold with wintry spells, showed a large pressure anomaly near the British Isles and nearby a strong gradient in the mean thickness. The April charts, when it was dry and sunny in the British Isles, again showed a high pressure anomaly and thickness still below normal; the main feature of this thickness chart was a long trough over north-west Canada. The July charts in the middle of the dismal summer showed a substantial low pressure anomaly near the British Isles with a tendency for W.-NW. gradient winds; the thickness was also low just south-east of the British Isles but high over the United States and Russia. The September charts at the end of the summer showed an intensified westerly current over the British Isles and low thickness to the north. The stormy, mild, wet end of the year showed a low pressure anomaly stretching in December from Greenland to the coast of Norway with a high thickness anomaly over Iceland. Dr. Forsdyke also exhibited a diagram showing at a glance the types of monthly pressure anomaly in 11 different regions of the northern hemisphere; he could find no similarity of the anomalies in different parts with that over the British Isles except possibly that of the neighbouring region of Iceland. Also there was no obvious connexion between cyclonicity over the British Isles and over Newfoundland.

Dr. H. L. Penman discussed the effect of the weather on farming, confining his remarks to cereals, root crops and grass. After the cold dry start to the year and with droughts in some parts during April, crops were late starting and the dismal summer continually held them back throughout the year. The wetness encouraged weeds, fungus and virus diseases, and delayed and in some cases prohibited the harvest. In the end, thanks to modern harvesting methods, the harvest, although delayed, was up to 1947 and 1949 yields but well below the high yields of 1953. For instance, the largest crop, grass, yielded well above average, but difficulty was experienced in grazing or cutting it. The weather on the whole did good to the salt-damaged lands that suffered in the January 1953 floods.

In the general discussion, Mr. R. F. M. Hay showed that although sea temperatures over the eastern North Atlantic were above or near normal to a depth of at least 450 ft. in the first half



of the year, they were much below in the summer when the positive anomalies would have been expected to continue if the overlying weather conditions had not been so exceptional. Mr. H. H. Lamb discussed the weather of the year in relation to the orientation and strength of the frontogenetic col in the western Atlantic. In a discussion on the effect of the melting of icebergs Mr. Hay showed that even the melting in an exceptionally heavy year would not lower the sea temperature over an appreciable area by as much as 1°F. Dr. Rainey closed the discussion with a report of the appearance of desert locusts in 1954—the first in the British Isles since 1869. Mr. Corby had worked out the 500-ft. trajectory which brought them from north Africa to the Scilly Isles on October 17, 1954.

## ROYAL ASTRONOMICAL SOCIETY

### Hydrodynamical processes in meteorology and geophysics

A joint meeting of the Royal Astronomical and Royal Meteorological Societies was held at Burlington House on February 25, 1955, with Sir Graham Sutton in the Chair. In opening the meeting Sir Graham remarked that the present period, with the prospects of being able to apply mathematical methods and machines to test meteorological ideas, is as significant in meteorology as was the period in the early 1920's when the Norwegian theories of frontal analysis were being formulated.

The first paper, presented by Dr. R. Hide, dealt with magnetic effects in relation to internal motions of the earth's core. The earth is known to consist of a hard mantle surrounding a liquid core of about 3,500-Km. radius. It is not possible to observe the core directly, but since it is mainly iron, its motion can be inferred from changes in the earth's magnetic field. Three possible causes of motion in the core were suggested by Dr. Hide: precession in the mantle, iron sinking from the mantle into the core (Urey's proposal), and radioactivity in the core. Each of these causes can provide sufficient energy to meet the known dissipation of  $2 \times 10^{16}$  ergs/sec. After a demonstration of some of the mathematical arguments, Dr. Hide showed photographs of experiments designed to show the sort of motion that might occur with differential heating of a rotating fluid, such as the earth's core or atmosphere. The centre of a rotating fluid in a cylinder was maintained at one known temperature and the outside at another known temperature. Under certain conditions the motion, as shown by dye stains, consisted of a narrow stream flowing in waves round the cylinder, the wave pattern drifting slowly relative to the boundary. As the conditions varied the number of waves round the cylinder varied, but this wave number was limited by the relative dimensions of the inner and outer boundaries of the rotating fluid, being larger for smaller differences. As conditions changed with a tendency to increase the wave number beyond the limit the waves were disturbed violently.

Mr. J. S. Sawyer read a paper on the basis of numerical methods in dynamical meteorology. The most frequently used meteorological methods of solution were to solve idealized and simple problems and then apply the conclusions to the more complicated situations found in nature. After Richardson's pioneer attempt in 1922, the first numerical method, using electronic calculating machines, was that in the United States based on the barotropic model of Dr. Charney using only one independent parameter, the height of the 500-mb. surface. Further work in this country by Sawyer and Bushby used two independent parameters, the height of the 600-mb. surface and the 1000-600-mb. thickness. This method depended on the high correlation between temperature gradients at all levels. Mr. Sawyer illustrated this two-parameter method by comparing calculated forecast charts with actual charts of weather situations in western Europe. Mr. Sawyer also referred to work done in the United States by Dr. Charney using a three-parameter model which was claimed to have given a better indication than did a two-parameter model of the Thanksgiving Day storm of 1950. Mr. Sawyer thought, however, that the two-parameter model used by Dr. Charney might have given better results if lower-level data had been used instead of the 700-mb. and 300-mb. levels, which were rather too near the tropopause. Further increase in the number of parameters would take more machine time, but, in Mr. Sawyer's opinion, might not lead to greater accuracy because information errors would be more important.

Mr. Charnock showed a film of a rotating-disc model which simulated ocean currents. The stronger currents were induced on the western sides of the oceans. A pronounced circulation was evident in the Atlantic Ocean, but flow in the Pacific was more zonal with a tendency for a separate circulation in the west.

Dr. E. T. Eady read a paper on the mathematical aspects of "turbulent" hydrodynamical processes. Because turbulence was of so irregular a nature study had to be confined to its statistical properties which depended on the nature of the turbulence. Properties of the fluid could be transferred by turbulence either directly by the fluid (primary transfer) or indirectly (secondary transfer). Primary transfer would affect the turbulent motion and would tend to damp it out; secondary transfer might be in the form of momentum as well as heat and might be carried against the gradient as well as with the gradient. Applying these principles to the general circulation of the atmosphere Dr. Eady showed that the preferred direction of transfer had a smaller



slope on the north-south vertical cross-section than the isentropic surfaces. If the Richardson number was large the form of break-down of the circulation led to active weather systems; if the Richardson number was less than 1 the systems were on a small scale; and for a Richardson number very much less than 1 the small-scale activities grew only very slowly.

Dr. Eady went on to consider possible motion in the core of the earth; the main difference, arising from the different nature of the heat source, was that the Richardson number was small and negative. Since there were small changes in the length of the day there must be free convection in the centre, not merely forced convection, although this convection is limited because the flow of heat is small. Considering the electro-magnetic effect it was possible for an electric flow to have more energy than a simple dipole, but Dr. Eady could not convince himself that there was a natural dynamo. From analogy with the atmosphere closed loops (eddy) may break away and flow with the normal convection, but with a tendency to set themselves in the same direction as the dipoles where the field was stronger.

The meeting ended with general discussion, mostly of a speculative nature regarding the motion in the earth's core.

## LETTERS TO THE EDITOR

### Distortion of condensation trails

Fig. 1 shows a series of condensation trails observed at Waterbeach between 1700 and 1800 G.M.T., on March 10, 1955. At the time of the observation a large slow-moving anticyclone was centred over north-east Ireland, and a 20-kt. north-easterly gradient wind covered East Anglia.

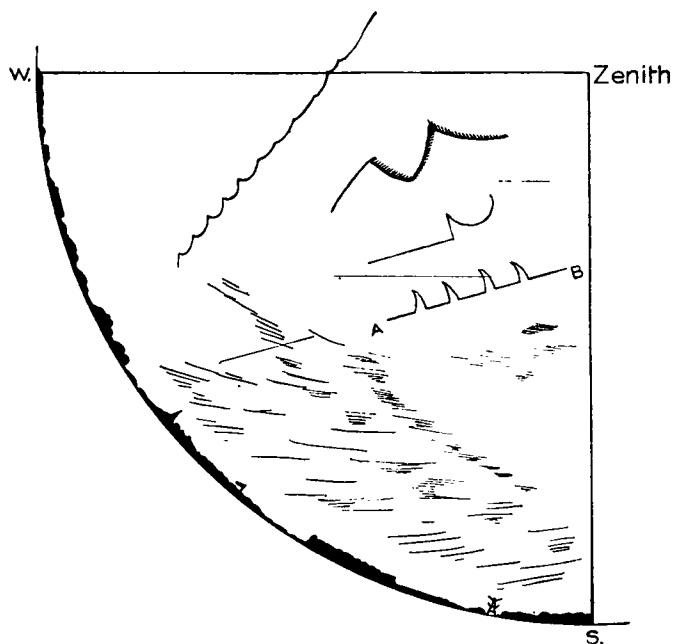


FIG. 1

Throughout the day, 5-7 oktas of variable thin cirrus and cirrostratus, the base of which according to an aircraft report at 1300 G.M.T. was 30,000 ft., had been present, and although trails had been forming previously they had exhibited no noticeable distortions. Aircraft flying over East Anglia at 1500 also reported dense persistent condensation trails of 3-4 miles in length between 29,500 and 39,500 ft.

The winds above Hemsby at 1400 were 50° 90 kt. at 300 mb. (29,760 ft.), 50° 95 kt. at 250 mb. (33,600 ft.), and 50° 63 kt. at 200 mb. (38,020 ft.). There was no change in the wind direction of 50° between 20,000 and 45,000 ft. The tropopause was at 36,000 ft., and the Mintra height\* at 23,000 ft.

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\* Theoretical minimum height at which condensation trails can form.

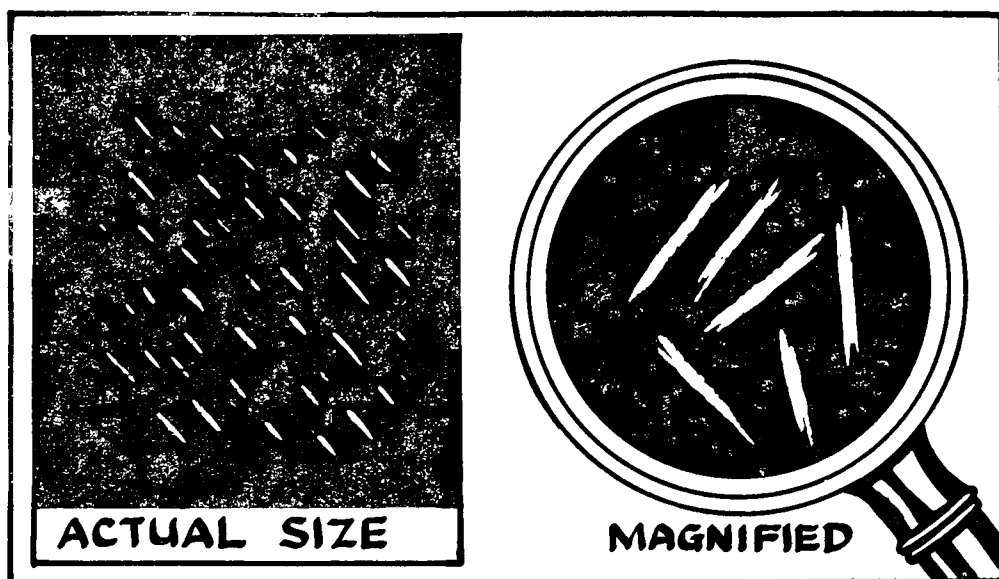
The trail AB, which unfortunately was not observed during its formation, appeared to be just above the cirrus, and probably at about 31,000–32,000 ft. It persisted from 1715 to 1800 and moved in the direction of the strong upper wind with no change of shape. The other trails shown, which were semi-persistent and well above AB, were probably between 35,000 and 40,000 ft. They formed as straight lines and then rapidly took on the configurations shown.

The distortions on AB were very similar to a previous case observed at Wick\*. On that occasion a theory was put forward suggesting that the distortion was due to a vector wind change at a warm frontal surface. An examination of the upper air data for England on the present occasion has yielded no explanation of the phenomenon.

J. A. CLEMENTS

### Ice needles at Ipswich

On February 24, 1955, an unusual type of continuous slight snowflakes fell in the Ipswich area between 1945 and 2050 G.M.T. Each particle of snow was in the form of a hard, opaque needle varying between 2 and 5 mm. in length. The needles were falling very thickly, reducing visibility to just under 300 yd., and were flying almost horizontally with the wind. Myself and a friend examined the needles closely as they stuck into a dark woollen pullover I was wearing at the time, completely covering it within 4 min.



During the snowfall the wind direction was about  $120^\circ$  true at a speed of between 18 and 25 kt. At 2100 the needles lay on the ground to a depth of almost  $\frac{3}{4}$  in. causing glass-like surfaces on roads used by much traffic. At 2103 the continuous fall of needles changed to a normal fall of granular snow.

Was I correct in assuming that this phenomenon was a fall of ice needles? In the 1942 edition of the "Meteorological observer's handbook" it states that

\* PHILLIPS, P. E.; Distortion of condensation trail at a frontal surface. *Met. Mag., London*, **83**, 1954, p. 279.

ice needles usually occur in cold, clear weather and are distinct from an ordinary fall of snow. In the latest edition, however, it states "Another form of crystallization sometimes seen in light snowfalls consists of detached single rods about 2 mm. long. When these occur alone they are recorded as 'ice needles'".

K. E. BLOWERS

10 Sherrington Road, Ipswich, Suffolk, March 10, 1955.

[There seems little doubt from Mr. Blowers's letter that the phenomenon he described was a fall of ice needles of unusual intensity.—Ed., *M.M.*]

### **Aircraft icing at very low temperature**

Mr. J. B. Shaw\* drew attention to the occurrence of water droplets in the free air at temperatures as low as  $-65^{\circ}\text{C}$ . Mr. A. Campbell, Meteorological Officer at the R.A.F. Station, Binbrook, has obtained the following account of weather experienced by Flt-Lt Steele of 617 Squadron, R.A.F., on a flight from Juba to Nairobi on December 7, 1954, between 1200 and 1319 G.M.T. "Extensive cumulonimbus clouds encountered south-east of Juba, tops extending above 40,000 ft. Moderate, and very occasionally severe, turbulence in cloud at 48,000 ft. Aircraft in cloud for ten minutes. A coating of ice formed on the leading edges and swirl vanes."

The radio-sonde observations at Nairobi at 0600 G.M.T. on that day indicated a temperature of  $-70^{\circ}\text{C}$ . at 48,000 ft. (127 mb.); the following day at the same time the temperature was  $-69^{\circ}\text{C}$ . The average temperature at Nairobi at 127 mb. during the month of December was  $-70^{\circ}\text{C}$ . over the years 1947–53. Allowing for the temperature within the tops of the cumulonimbus clouds to be perhaps a degree or two above the temperature in the air outside the clouds, there seems little doubt that Flt-Lt Steele's aircraft encountered water droplets at a temperature between  $-67^{\circ}$  and  $-70^{\circ}\text{C}$ .

J. K. BANNON

## **NOTES AND NEWS**

### **Abnormal radio propagation December 3, 1954**

The B.B.C. Research Department, using a receiver at Beddingham, near Lewes, frequently monitor a transmission on  $180\cdot4$  Mc./sec. made from the B.B.C. station at Sutton Coldfield. Radio transmissions on these high frequencies normally have a range not much greater than that of the optical horizon from the transmitting aerial, but with certain meteorological conditions in the lowest few thousand feet of the atmosphere this range can be very greatly increased. Such conditions occur when there is an inversion of temperature or lapse of humidity of sufficient gradient and depth over the path of the radio waves. Thus, for example, in anticyclonic conditions when warm subsiding air lies above a colder and moister surface layer, or when warm dry air from the land travels over the colder sea, abnormal ranges of very high frequency radio transmissions are often reported.

Since Beddingham is 147 miles from Sutton Coldfield the normal field strength of the Sutton Coldfield transmission is very small but on the evening of December 3, 1954, the measured field strength increased considerably

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\* SHAW, J. B.; Aircraft icing at very low temperatures. *Met. Mag., London*, **83**, 1954, p. 281.

between 1400 and 2300 G.M.T. reaching a value 40 db. above the normal (i.e. an increase in field strength by a factor of 100). This increase was the highest ever measured and led to an inquiry in the Meteorological Office to explain its cause. A first glance at the charts for this period did not suggest abnormal conditions but examination of radio-sonde reports showed the presence of extraordinarily dry air at levels as low as 2,200 ft., as well as an inversion of temperature. Thus the 0200 G.M.T. ascent from Hemsby on December 4, 1954, showed an inversion of temperature of 9°F. between 570 ft. and 1,170 ft. above mean sea level and a dew-point change from 39°F. at 780 ft. to -14°F. at 2,200 ft. It seems quite likely that this dry air was present even at the top of the inversion at 1,170 ft. At Crawley at 0200 the inversion amounted to 4°F. and was at a greater height (2,190-2,670 ft.); the dew point decreased from 40°F. at 2,310 ft. to 3°F. at 3,730 ft.

Air as dry as these readings indicate must surely be extremely rare at such low levels in this country, and the accompanying large lapse of humidity with height was undoubtedly the cause of the unprecedented field strength at Beddingham.

I am indebted to Mr. L. F. Tagholm of the B.B.C. Research Department for the information of measured field strength.

R. F. JONES

### **Ground fog at Stevenage, Hertfordshire**

The photograph facing p. 216 was taken by Hunting Aero Surveys Ltd between 9 and 9.30 a.m. on February 2, 1949, over Stevenage.

An intense anticyclone with a central pressure of 1043 mb. covered the British Isles. The centre of the high was situated over or near the Wash, but pressure over the whole of England was almost uniform, with calm or light winds over an extensive area. The previous evening the central region of the anticyclone had been situated near the Scottish border, with north-easterly winds and moderate or good visibility in eastern districts of England, but fog developed fairly extensively during the night as a result of the decrease of the pressure gradient.

### **Awards to civil airline personnel**

Weather reports from civil aircraft on standard routes are of great assistance to the Meteorological Office. Such reports help the forecaster to compile forecasts for other aircraft and also facilitate the checking of forecasts made earlier. This is particularly true when the reports refer to areas (such as over the oceans) where there are comparatively few standard reporting stations. In recognition of the value of such reports the Air Ministry has decided to institute a system of awards to personnel of airline companies registered in the United Kingdom. The awards will be made annually and will be of two kinds. A number of awards of books, suitably inscribed, will be made to captains or navigators who have provided the best series of reports (in flight, post-flight or on debriefing) during the twelve months ending April 15. Up to two awards will also be made annually to captains of aircraft for long and meritorious service in the provision of weather reports.

The awards of both kinds will be made by the Director of the Meteorological Office who will be guided by weather reports received at offices maintained by the Meteorological Office.

## **The Royal Research Ship *Discovery II* on temporary duty as an ocean weather ship**

In February 1955 the ocean weather ship *Weather Explorer* had to be "laid up" for fairly extensive repairs to one of her boilers. She was due to relieve the Netherlands ocean weather ship *Cumulus* on February 20 at ocean station K to the westward of the Bay of Biscay in 45°N. 16°W. It was most desirable that this British commitment should be fulfilled and, as the boiler repairs could not possibly be done during the ship's normal period in Greenock, it was decided that a ship should be chartered to take the *Weather Explorer's* place. Fortunately the R.R.S. *Discovery II* was available, and arrangements were made with the National Institute of Oceanography for her to be chartered for the voyage.

The *Discovery II*, Captain H. O. L'Estrange, D.S.C., R.D., R.N.R., was at Plymouth, and the necessary special stores and equipment had to be sent there from the ocean weather ship base at Greenock. A wooden balloon-filling shelter was designed, and was built on the ship's poop and secured by wire stays. Although somewhat small, it proved in practice to be quite adequate. Stowage racks had also to be fitted on deck for carrying about 100 hydrogen cylinders. In addition to the ship's own radio equipment an emergency V.H.F. transmitter/receiver was taken from the *Weather Explorer* and fitted in the *Discovery II*. Radio-sonde equipment was also installed. Her usual Captain and crew remained in the ship, and in addition the Meteorological Officer-in-charge from the *Weather Explorer* and five of his staff, together with the Radio Overseer of that ship and two radio operators, joined the ship for the voyage.

The *Discovery II* sailed from Plymouth on February 17, 1955, and relieved the Netherlands o.w.s. *Cumulus* on the 19th at station K. She remained on that station until March 15 when she was relieved by o.w.s. *Weather Watcher* and returned to Plymouth, arriving on March 18. At the beginning of the voyage the weather was unsettled with some snow showers. Later there was a long spell of NE. winds with cloudy skies and showers. While on station K hourly meteorological observations were made and recorded and the usual main synoptic observations were transmitted. The *Discovery II* does not carry radar equipment suitable for tracking balloons so the upper air observations were confined to TEMP soundings; 49 successful TEMP soundings were made. Wind soundings were attempted with the aid of a marine theodolite which had been obtained on loan from the Admiralty, but this instrument proved generally unsuccessful, due partly to the rapid motion of the ship. Difficulty was also experienced at times in getting azimuth bearings of the balloons by the compass mirror, and bearings were usually unobtainable when the balloons were over 6,000 ft. Attempts were made at pilot-balloon soundings using 500-gm. balloons suitably ballasted, but cloud conditions were almost wholly unfavourable. The radio-sonde gear worked well and reception was good throughout the voyage. Also the ship's radio equipment seems to have operated extremely well and communication with both Rennes, the French station, and Dunstable was excellent. The V.H.F. set from the *Weather Explorer* functioned well. The *Discovery's* deck officers soon accustomed themselves to its use and during the voyage they made contact with 134 aircraft. This work was a change from their normal oceanographical work and it seems they enjoyed it. On the night of March 3-4 a weather message from Prestwick was relayed by *Discovery II* to the aircraft *Canopus* which was flying H.R.H. Princess Margaret home from the

West Indies. Three mail drops by R.A.F. aircraft were made during the voyage; always a pleasant break in the routine and much appreciated. Two schools of whales were sighted and other sea life observed. Air/sea rescue drills were carried out, as is usual in ocean weather ships. Altogether a quite satisfactory voyage due to the ready and friendly co-operation of the National Institute of Oceanography and the Captain and ship's company of the "temporary acting" ocean weather ship *Discovery II*.

### **Meteorological Office Staff Centenary Dinner**

This was held on the evening of March 11 at the Holborn Restaurant and was attended by no less than 218 members, or former members, of the staff with their guests. Sir Graham Sutton acted as President and the company were graciously received by him and Lady Sutton.

After an excellent meal, reminiscent of pre-war standards, and the loyal toast to Her Majesty the Queen, Mr. H. L. B. Tarrant proposed the toast of the Meteorological Office, reminding his audience of the days when the staff numbered less than 40. In his reply, Sir Graham reminded his audience of some of the great names of the past and expressed his delight in seeing so many old members of the staff. He also paid tribute to the present staff for the way in which they carried on the great tradition of service, and said that he hoped in his term of office to see them brought closer together by the provision of a national weather building worthy of the name.

Before the toast of the Ladies, proposed in characteristic maritime vein by Cmdr Frankcom, each lady was presented with a thermos jug. In her reply, Lady Sutton looked forward to the day, already envisaged by Sir Graham, when, with the Headquarters establishments housed under one roof, social functions and activities of various kinds would be much easier to arrange and to attend; and wives would get to know each other better.

In proposing the toast of the officers and members of the Social and Sports Committee, Dr. Stagg outlined its history, and referred to the successes achieved on the football field and in the athletic arena, the winning of the Air Ministry Challenge Cup and the Bishop Shield for 7 and 6 years in succession respectively. Mr. N. H. Smith, Chairman, replied, paying a tribute to the organizing genius of Mr. Ben. G. Brame (Treasurer) and Miss Joan Wordsworth (Secretary) which had done so much to ensure the success of the dinner. He also reminded his hearers of the sources of Committee funds, and that, but for support from those funds it would have been impossible to meet the expenses of those representative football and athletic teams which, under the enthusiastic guidance of Mr. H. A. Scotney, had proved so successful in departmental competitions. He also called attention to a Centenary Souvenir in the shape of an attractive perpetual calendar which was now available to purchasers on application to the Secretary.

Amongst former members of the staff present were Sir David Brunt, Sir George Simpson, Mr. E. Gold, Mr. R. G. K. Lempfert, Mr. R. Corless and Mr. W. Heinemann—a veteran of 90 years.

It was generally agreed that the occasion had proved a delightful and memorable one, although there was regret that time did not permit, as was intended, of the mingling together of old colleagues and friends in an after-dinner conversazione.

## REVIEW

*Seismology*. By K. E. Bullen. *Methuens Monogr. phys. Subj.*, 6½ in. × 4½ in., pp. viii + 132, *Illus.*, Methuen & Co. Ltd, London, 1954, Price: 8s. 6d.

This excellent little book is one of a series of monographs designed "to supply—at University level—a compact statement of the modern position". It can be recommended most strongly to all who wish to know what can be learned about the earth by the study of earthquakes and the elastic waves to which they give rise, and who are prepared to exert a little effort to acquire the knowledge. The emphasis is on general theory and geophysical applications rather than on instrumental seismology and the interpretation of seismograms, aspects of the subject which are well catered for in existing texts. The chapter on microseisms will be of most direct interest to meteorologists, and it provides a good example of the conciseness and relevance of the book as a whole. In six pages it lists the most recent and comprehensive descriptive studies, introduces the salient features of Longuet-Higgins's theory of microseism formation, and discusses the possibilities and difficulties of hurricane tracking by microseism recording.

G. D. ROBINSON

## OBITUARY

*Miss L. E. Weaver*.—It is with deep regret that we learn of the death on March 13, 1955, of Miss Weaver at the age of 66 after a long and painful illness, cheerfully borne.

Miss Weaver came to the Meteorological Office about five years before the war as secretary-typist to Mr. E. Gold, then President of the International Commission for Synoptic Weather Information, a position which involved much international correspondence and intense work for Miss Weaver at meetings of the Commission at Warsaw in 1935 and Salzburg in 1937. Her service was beyond praise, and was commended with general applause at the closing session at Salzburg. In September 1940 her home in Mecklenburgh Square was bombed at night and she narrowly and miraculously escaped with her life from beneath the wreckage of the building. The shock was one which would have unnerved a less courageous woman, but Miss Weaver was back on duty immediately she could get re-clothed. In March 1945 Miss Weaver was lent by the Air Ministry for two years' service with U.N.R.R.A. A few months after her return in 1947 she resigned and went abroad again to serve in the Church of Scotland (Welfare) Canteens for nearly two years. She returned home in 1950 suffering from strain and overwork from which she never really recovered. Miss Weaver was a woman of untiring energy and enthusiasm for any work she undertook; she was restless in her efforts to render the best service to her fellows which it was in her power to give. Her many friends in the Meteorological Office, remembering her with affection and gratitude, mourn for her suffering and her death.

## HONOUR

It was announced in the Birthday Honours List 1955 that Mr. R. A. Hamilton had been awarded the O.B.E. for his services as Chief Scientist of the British North Greenland Expedition, 1952–54.

## METEOROLOGICAL OFFICE NEWS

**Retirements.**—*Mr. H. W. L. Absalom, O.B.E.*, Senior Principal Scientific Officer, retired on April 30, 1955. At a ceremony in the Conference Room in Victory House on May 6, Dr. R. C. Sutcliffe presented Mr. Absalom with a cheque subscribed by his colleagues. In expressing his thanks Mr. Absalom recounted some interesting recollections of his experiences in the Office and events with which he had been associated. Mr. Absalom has accepted a temporary appointment in the Meteorological Office.

*Miss T. M. Hunt*, Experimental Officer, retired on May 7, 1955, on grounds of ill health. Miss Hunt joined the Statistical Division of the Office in February 1918 and was transferred to the Library in 1920. In 1929 she became assistant to Dr. C. E. P. Brooks and helped to introduce the Universal Decimal Classification into Library practice. She also assisted with the introduction of the present set of bibliographies, classified by subject and geographically, which form the main source of information on meteorological literature in the Office. In 1937 Miss Hunt returned to the Library staff where she served, up to the time of her sudden illness about a year ago, as Assistant Librarian. Miss Hunt took an active part in various social activities of the Office, both at Stonehouse during the Second World War and at Harrow.

**Sports activities.**—The Meteorological Office defeated the Directorate General of Organization by 3 goals to 2 in the final of the competition for the Air Ministry Football Cup at Northolt on April 29. The Meteorological Office has won this cup on each of the last eight occasions on which the competition has been held.

At the 1955 Spring Regatta of the Royal Air Force Yacht Club, Habbaniya, the Snipe Class Challenge Cup was won by Mr. G. E. Parrey of the Meteorological Office.

This year's Air Ministry Contract Bridge Singles competition has been won by Mr. R. A. Ogden, who also won the Doubles competition with Mr. G. T. Smith.

## ERRATA

APRIL 1955, PAGE 121; line 2, for "increased with height" read "decreased with height"; line 24, for "standing wave" read "standing lee eddy"; line 25, for "although the wave-lengths are increased" read "and the first lee wave is displaced down stream".

## WEATHER OF MAY 1955

The circulation patterns over the Atlantic and Europe represented a notable break with the previous months, and were unusual for May, showing a prevalence of largely zonal movements with depressions passing eastwards across, or near, the British Isles. Mean pressure was lowest in mid Atlantic (1008 mb., anomaly  $-6$  mb. near  $50^{\circ}\text{N}$ .  $30^{\circ}\text{W}$ .) and across central Scandinavia to north-west Russia (1006–1007 mb., anomaly  $-8$  mb. over a wide area). Pressure was about normal in the high-pressure belt from the Azores across southern Europe (greatest anomaly  $+4$  mb. in south France and Thrace) as well as in the Polar Basin anticyclone with its usual extension in May towards Iceland. In the general region of north-west Europe the usual northerly and southerly flow associated with blocking patterns returned to dominate the second half of the month.



The month as a whole was a little colder than normal over the northern Atlantic and Greenland, and over Europe, except Spain.

Precipitation ranged from 120 to 200 per cent. of the May normal in a broad belt across the British Isles and northern and central Europe. Rainfall was deficient over France, Spain, Italy and from north Scotland to Spitsbergen.

In the British Isles the weather was changeable with thundery rains during the first nine days as depressions moved quickly across the north of the country; it was unusually cold, with sleet and snow from the 10th to the 21st and brilliantly fine and warm during the last three days of the month.

On the 1st there were widespread thunderstorms in the path of a depression as it crossed Northern Ireland and southern Scotland and also heavy rainfall in central and southern England. The following day was sunny, although isolated thunderstorms persisted in south-east England, but there was further heavy rain in west Scotland on the 3rd associated with the eastward passage of a trough across the country. With a deep depression off the coast of Scotland, strong south-westerly winds were maintained over most of the country during the next two days, especially on the 5th when a gust of 60 kt. was recorded at Dishforth and local duststorms occurred in East Anglia, one of which reduced the visibility at Mildenhall to as little as 200–300 yd. for much of the afternoon; there were also heavy showers in the west and north which developed into local thunderstorms in west Scotland. Thunderstorms were also experienced in the south-west and widespread rain elsewhere in the south, as an active depression crossed southern England on the 6th, and during a severe thunderstorm the following day over 1 in. of rain fell at West Raynham. By the end of the week Eskdalemuir had recorded more than 3 in. of rain. An anticyclone developed near Greenland on the 6th, and after the passage of minor disturbances on the 8th and 9th, there was some particularly heavy rain in the west on the 9th (2·25 in. fell at Oakley Quarries, Blaenau Festiniog, Merionethshire), an inflow from the north of arctic air over the British Isles caused temperatures to fall sharply by about 10°F. on the 10th; rain turned to sleet and snow in the north and thunderstorms occurred in the south-east ahead of the cold air. The cold weather continued with only brief interruptions until the 21st. During this period rainfall in many districts was more than three times the average, there were outbreaks of sleet or snow most days and thunderstorms, which were widespread on the 14th and 15th, were fairly frequent. A depression which crossed southern England on the 16th and 17th and invaded the northerly air stream, was accompanied by gales and heavy rain. Many places in eastern England recorded more than 1 in. of rain on the 17th, and East Kirkby, Lincolnshire, 2·25 in.: the rain turned to snow later in many parts of England and Wales, even as far south as the London area and the Channel coast. The 17th was also the coldest May day on record at many places, temperature only reaching 39°F. at Harlech and Buxton while a lower maximum temperature in May had not been registered at Ross-on-Wye since records began 80 years ago. During the days which followed an anticyclone developed west of the British Isles and moved slowly across the country giving mostly bright weather but with showers and local thunderstorms or slight rain from time to time, until on the 26th the high-pressure system withdrew temporarily northward and a slow-moving frontal system brought substantial rainfall to some southern and midland districts; more than 1 in. of rain fell during the night of the 26th–27th at London Airport. By the 29th high pressure had spread south again to cover the country and the month ended with three days of warm, sunny weather, although it remained cool on the eastern seaboard and dull in some windward coastal areas. On each of the last three days over 15 hr. of sunshine were recorded in many districts, particularly in Scotland and northern England. In spite of the fact that much of southern and midland England had more than twice the average amount of rain for May, and several stations reported it as being the wettest May on record, many places recorded more than average sunshine.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	76	25	—2·6	179	+5	109
Scotland ...	77	21	—1·9	112	+2	125
Northern Ireland ...	68	32	—1·5	117	+4	113

# RAINFALL OF MAY 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	4·49	255	<i>Glam.</i>	Cardiff, Penylan ...	5·12	209
<i>Kent</i>	Dover ... ..	4·73	285	<i>Pemb.</i>	Tenby ... ..	3·06	133
<i>"</i>	Edenbridge, Falconhurst	5·26	283	<i>Radnor</i>	Tyrmynydd ... ..	..	..
<i>Sussex</i>	Compton, Compton Ho.	4·66	210	<i>Mont.</i>	Lake Vyrnwy ... ..	7·93	246
<i>"</i>	Worthing, Beach Ho. Pk.	3·65	221	<i>Mer.</i>	Blaenau Festiniog ...	9·02	160
<i>Hants.</i>	St. Catherine's L'thouse	3·12	190	<i>"</i>	Aberdovey ... ..	4·80	191
<i>"</i>	Southampton (East Pk.)	4·25	213	<i>Carn.</i>	Llandudno ... ..	1·91	107
<i>"</i>	South Farnborough ...	3·50	200	<i>Angl.</i>	Llanerchymedd ...	3·35	143
<i>Herts.</i>	Harpenden, Rothamstead	4·56	234	<i>I. Man</i>	Douglas, Borough Cem.	2·65	106
<i>Bucks.</i>	Slough, Upton ... ..	3·39	237	<i>Wigtown</i>	Newton Stewart ...	3·26	123
<i>Oxford</i>	Oxford, Radcliffe ...	4·47	239	<i>Dumf.</i>	Dumfries, Crichton R.I.	2·57	93
<i>N'hants.</i>	Wellingboro' Swanspool	3·22	166	<i>"</i>	Eskdalemuir Obsy. ...	4·10	124
<i>Essex</i>	Southend, W. W. ...	4·21	290	<i>Roxb.</i>	Crailing ... ..	2·06	102
<i>Suffolk</i>	Felixstowe ... ..	2·19	166	<i>Peebles</i>	Stobo Castle ... ..	2·93	129
<i>"</i>	Lowestoft Sec. School ...	1·61	100	<i>Berwick</i>	Marchmont House ...	1·85	75
<i>"</i>	Bury St. Ed., Westley H.	2·26	124	<i>E. Loth.</i>	North Berwick Gas Wks.	1·91	97
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·23	122	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	2·11	103
<i>Wilts.</i>	Aldbourn ... ..	5·37	258	<i>Lanark</i>	Hamilton W. W., T'nhill	3·38	141
<i>Dorset</i>	Creech Grange... ..	4·64	227	<i>Ayr</i>	Colmonell, Knockdolian	..	..
<i>"</i>	Beaminstor, East St. ...	4·48	217	<i>"</i>	Glen Afton, Ayr San. ...	4·07	136
<i>Devon</i>	Teignmouth, Den Gdns.	3·61	197	<i>Renfrew</i>	Greenock, Prospect Hill	4·56	140
<i>"</i>	Ilfracombe ... ..	3·81	185	<i>Bute</i>	Rothsay, Arden Craig ...	3·72	125
<i>"</i>	Princetown ... ..	8·70	203	<i>Argyll</i>	Morven, Drimnin ...	2·88	89
<i>Cornwall</i>	Bude, School House ...	2·89	157	<i>"</i>	Poltalloch ... ..	3·11	108
<i>"</i>	Penzance ... ..	4·24	192	<i>"</i>	Inveraray Castle ...	4·40	112
<i>"</i>	St. Austell ... ..	4·40	182	<i>"</i>	Islay, Eallabus ... ..	2·75	104
<i>"</i>	Scilly, Tresco Abbey ...	3·87	229	<i>"</i>	Tiree ... ..	1·97	79
<i>Somerset</i>	Taunton ... ..	3·47	203	<i>Kinross</i>	Loch Leven Sluice ...	2·70	111
<i>Glos.</i>	Cirencester ... ..	4·90	238	<i>Fife</i>	Leuchars Airfield ...	2·02	104
<i>Salop</i>	Church Stretton ... ..	5·30	209	<i>Perth</i>	Loch Dhu ... ..	5·27	117
<i>"</i>	Shrewsbury, Monkmore	3·95	203	<i>"</i>	Crieff, Strathearn Hyd.	2·54	102
<i>Worcs.</i>	Malvern, Free Library...	5·18	240	<i>"</i>	Pitlochry, Fincastle ...	2·28	108
<i>Warwick</i>	Birmingham, Edgbaston	5·17	219	<i>Angus</i>	Montrose, Sunnyside ...	1·58	77
<i>Leics.</i>	Thornton Reservoir ...	4·40	219	<i>Aberd.</i>	Braemar ... ..	2·05	86
<i>Lincs.</i>	Boston, Skirbeck ... ..	2·55	145	<i>"</i>	Dyce, Craibstone ...	3·07	120
<i>"</i>	Skegness, Marine Gdns.	3·30	194	<i>"</i>	New Deer School House	3·78	173
<i>Notts.</i>	Mansfield, Carr Bank ...	..	..	<i>Moray</i>	Gordon Castle ... ..	3·36	158
<i>Derby</i>	Buxton, Terrace Slopes	5·49	177	<i>Nairn</i>	Nairn, Achareidh ...	2·06	116
<i>Ches.</i>	Bidston Observatory ...	2·58	136	<i>Inverness</i>	Loch Ness, Garthbeg ...	3·55	143
<i>"</i>	Manchester, Ringway...	2·64	125	<i>"</i>	Glenquoich ... ..	5·49	100
<i>Lancs.</i>	Stonyhurst College ...	3·57	125	<i>"</i>	Fort William, Teviot ...	3·42	87
<i>"</i>	Squires Gate ... ..	1·83	88	<i>"</i>	Skye, Broadford ... ..	2·78	66
<i>Yorks.</i>	Wakefield, Clarence Pk.	2·80	142	<i>"</i>	Skye, Duntuilin ... ..	3·28	115
<i>"</i>	Hull, Pearson Park ...	3·33	173	<i>R. &amp; C.</i>	Tain, Mayfield... ..	2·41	117
<i>"</i>	Felixkirk, Mt. St. John...	2·06	110	<i>"</i>	Inverbroom, Glackour...	4·75	158
<i>"</i>	York Museum ... ..	2·19	110	<i>"</i>	Achnashellach ... ..	5·97	141
<i>"</i>	Scarborough ... ..	3·27	171	<i>Suth.</i>	Lochinver, Bank Ho. ...	2·56	101
<i>"</i>	Middlesbrough... ..	2·00	104	<i>Caith.</i>	Wick Airfield ... ..	2·55	123
<i>"</i>	Baldersdale, Hury Res.	2·89	117	<i>Shetland</i>	Lerwick Observatory ...	2·00	96
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	1·78	90	<i>Ferm.</i>	Crom Castle ... ..	3·49	126
<i>"</i>	Bellingham, High Green	2·33	97	<i>Armagh</i>	Armagh Observatory ...	2·76	116
<i>"</i>	Lilburn Tower Gdns. ...	2·25	97	<i>Down</i>	Seaforde ... ..	2·90	110
<i>Cumb.</i>	Geltsdale ... ..	2·34	91	<i>Antrim</i>	Aldergrove Airfield ...	2·57	113
<i>"</i>	Keswick, High Hill ...	6·08	191	<i>"</i>	Ballymena, Harryville...	2·78	97
<i>"</i>	Ravenglass, The Grove	2·00	71	<i>L'derry</i>	Garvagh, Moneydig ...	3·41	123
<i>Mon.</i>	A'gavenny, Plás Derwen	6·61	223	<i>"</i>	Londonderry, Creggan	3·42	131
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## VERTICAL TEMPERATURE GRADIENT IN THE FIRST 2,000 FT.

By J. B. SHAW

**Introduction.**—A number of publications have described in detail the variations which occur in the vertical temperature gradient in the surface layer of the atmosphere up to a height of 300–400 ft. The data for such investigations have usually been obtained from instruments mounted on a tower or mast, and it is this which has limited the height to which the observations were made. Temperature gradient in the atmosphere from 2,000 ft. upwards has also been extensively studied on the basis of radio-sonde observations. The region between about 350 ft. and 1,500 ft. is an awkward one since it is normally out of reach of towers and masts, and the radio-sonde is quite unsuitable for giving anything other than a very broad picture of the temperature variations which occur at these heights. Yet this region is of considerable interest meteorologically.

For a number of years a captive balloon has been used at Cardington, Bedfordshire, to lift meteorological instruments to heights which have varied with circumstances to a maximum of about 4,000 ft. The routine ascents have been made at 0730, 1200 and 1800 G.M.T. (0700 instead of 0730 in late spring, summer and early autumn) and observations of dry-bulb and wet-bulb temperatures and wind speed have been taken at fixed heights up to the ceiling of the balloon. During most of the period under review these heights were 4, 30, 50, 100 and 250 ft. and then at intervals of 250 ft. They were based upon the length of balloon cable paid out, and inevitably this introduced some error in the assumed height of the instruments, but it is believed that the error seldom exceeded 10 per cent. of the nominal height, and in light winds would be appreciably less. Although every effort was made to ensure regularity a number of ascents were missed for the usual reasons associated with kite balloons. The usual surface meteorological observations were also made at the time of each ascent.

In order to ensure homogeneity in the observations used the investigation described below was restricted to the lowest 2,000 ft., that height having been reached by the balloon on all the ascents analysed.

Analysis of the data obtained from the routine balloon ascents made during a period of four years from March 1949 to February 1953 has not yielded any surprising results. The value of the analysis resides in the fact that it has provided quantitative and detailed data for a region of the atmosphere on which there is little detailed published information. For this reason it has been considered preferable to present the results in the form of tables, which are easy to read, rather than in the form of graphs, which have a greater visual appeal but are less suitable for giving numerical answers.

The variables which might be expected to affect the vertical temperature gradient are time of day, season, state of sky and wind speed. The observations were therefore grouped according to these parameters. State of sky was divided into three categories, 0 or 1 okta of low or medium cloud, 2-6 oktas of low or medium cloud and 7 or 8 oktas of low or medium cloud. In the following paragraphs these states have been designated clear sky, cloudy sky and overcast respectively for convenience of writing. Wind speed was divided into the classes 0-10 kt., 11-20 kt., etc., the wind being measured at 1,500 ft. Foggy occasions have been treated separately.

**Midday temperature gradient.**—A survey of the mean results for 1200 G.M.T. showed that almost all conformed to a common pattern. In the lowest layers there was a rapid fall of temperature with height, the magnitude of the lapse rate decreasing with increasing height. At greater heights the temperature can be represented by a linear function of height. The mean temperatures at each height for each of four seasons, three states of sky and three wind-speed groups were plotted (36 curves in all), and it was found that all sets of points except one could be fitted reasonably well by a curve from 4 to 250 ft. and a straight line from 250 to 2,000 ft. Since the main purpose of this note is to describe the temperature structure between 250 and 2,000 ft. Table I accordingly gives the fall of temperature from 4 to 250 ft., the mean temperature gradient from 250 to 2,000 ft. and the number of ascents upon which the figures are based. Eight points were plotted on each curve from 250 to 2,000 ft. inclusive. A quick examination showed that in 35 of the 36 curves the departures of the points from the straight lines were less than 0.3°F. for 261 of the 280 points plotted, never exceeded 0.5°F., and were not systematic. It must be borne in mind, however, that the curves themselves are mean curves.

TABLE I—VERTICAL TEMPERATURE STRUCTURE\* AT 1200 G.M.T.

State of sky	Temperature change between 4 and 250 ft. for wind speeds			Temperature gradient between 250 and 2,000 ft. for wind speeds			Number of ascents with wind speeds		
	0-10 kt.	11-20 kt.	21-30 kt.	0-10 kt.	11-20 kt.	21-30 kt.	0-10 kt.	11-20 kt.	21-30 kt.
oktas	<i>degrees Fahrenheit</i>			<i>degrees Fahrenheit per 1,000 ft.</i>					
				<b>Spring (March-May)</b>					
0, 1	-2.5	-2.7	-2.7	-4.2	-3.9	-3.2	15	11	5
2-6	-2.2	-2.6	-2.2	-4.5	-4.5	-4.1	21	24	3
7, 8	-2.1	-1.7	-1.3	-4.5	-4.3	-3.7	16	25	5
				<b>Summer (June-August)</b>					
0, 1	-3.1	-4.1	-3.0	-4.8	-4.9	-4.5	10	8	5
2-6	-2.7	-3.4	-2.5	-4.7	-4.8	-4.6	34	42	8
7, 8	-2.3	-2.8	-2.1	-4.5	-4.5	-4.1	18	24	6
				<b>Autumn (September-November)</b>					
0, 1	-3.1	-2.2	-1.3	-4.2	-4.1	-3.6	11	9	8
2-6	-2.7	-2.6	-2.0	-4.4	-4.4	-3.6	15	35	10
7, 8	-1.8	-1.6	-1.4	-3.6	-3.9	-3.6	19	42	24
				<b>Winter (December-February)</b>					
0, 1	0.0	-1.1	-1.2	†	-2.9	-3.6	8	21	12
2-6	-1.7	-1.4	-1.0	-4.5	-3.4	-3.1	7	17	17
7, 8	-1.0	-1.1	-0.9	-2.5	-2.9	-2.2	25	31	26

\*An inversion is indicated by a positive sign, a lapse by a negative.  
†Temperature structure in different form.

Table I shows that the variation of temperature gradient with state of sky and wind speed is small and not well defined. The main variation however is seasonal, the mean seasonal values of temperature gradient being 4.1, 4.6, 3.9 and 3.1 °F./1,000 ft. in spring, summer, autumn and winter respectively. The variation of temperature change below 250 ft. with wind speed is small and rather irregular. There are however clear indications that it decreases with increasing cloudiness.

The mean of the ascents made in winter with light winds and clear skies did not conform to the general picture, there being a more or less isothermal region from 4 to 750 ft. surmounted by a lapse rate of about 1.9°F./1,000 ft. Examination of the weather reports for these eight ascents showed that mist was of frequent occurrence and this probably accounts for the rather irregular result.

**Temperature structure at 1800.**—The temperature structure at 1800 G.M.T. is set out in detail in Table II, and follows a fairly coherent pattern. In the summer the lapse from 4 to 250 ft. decreases from the midday value to about 1.0–2.0°F. and at 1800 is not much affected by either cloud amount or wind speed. Above 250 ft. the lapse rate remains approximately the same as at midday irrespective of wind and cloud.

By 1800 in autumn however the surface inversion has become established. Under typical radiation conditions—light winds and clear sky—it reaches a height of about 300 ft. with a temperature there about 5°F. warmer than at 4 ft. Increasing cloud both lowers the height of the inversion and diminishes the magnitude, overcast skies and light winds being associated with an inversion reaching to lower than 100 ft. and with a magnitude less than 1°F. The effect of increasing wind (at 1,500 ft.) is not quite so straightforward. Under clear and cloudy skies an increase from 5 to 15 kt. in the mean wind speed has little effect on the height of the inversion though the magnitude is diminished. A further increase in wind speed both lowers the top of the inversion and again decreases the strength. Under overcast skies the height and strength of the inversion are so small even with 5-kt. winds that one can deduce no more than a weakening of the inversion and lowering of the top with increasing wind speed. In all circumstances the inversion is surmounted by a lapse rate a little smaller than that occurring in the summer.

The winter table seems somewhat irregular. Generally the inversion reaches to 300–500 ft. under clear and cloudy skies and to 100–200 ft. under overcast skies irrespective of wind speed. The magnitude of the inversion tends to diminish with increasing cloud but the variation with wind speed is irregular. In an attempt to clarify the picture the December and January figures were separated from the February values thereby ensuring that all ascents were made after sunset. The irregularities remained. It seems likely that the irregularities are associated with the greater liability to mist in the winter months.

The spring ascents present a comparatively simple picture. The inversion is very weak at 1800 and is restricted to the lowest 100 ft. Above this height the normal lapse rate occurs.

**Temperature structure at 0700.**—In summer Table III shows that a lapse occurs from 4 to 2,000 ft. in all conditions. With clear or cloudy skies and light winds the lapse rate is small, since the inversion established during the night must be broken down before the normal day-time lapse can become established.

TABLE II—VERTICAL TEMPERATURE STRUCTURE\* AT 1800 G.M.T.

Wind at 1,500 ft.	State of sky	Difference between temperatures at 4 ft. and at a height (in feet) of											Number of ascents
		30	50	100	250	500	750	1,000	1,250	1,500	1,750	2,000	
kt.	oktas	degrees Fahrenheit											
Spring (March-May)													
0-10	0, 1	+0.5	+0.5	+0.6	+0.1	-0.9	-2.2	-3.2	-4.4	-5.7	-6.6	-7.6	16
11-20		+0.1	0.0	0.0	-0.4	-1.5	-2.7	-3.7	-4.6	-5.5	-6.4	-7.6	18
21-30		0.0	0.0	-0.1	-0.6	-1.6	-2.5	-3.1	-3.7	-4.5	-5.2	-5.9	8
0-10	2-6	+0.5	+0.5	+0.4	-0.2	-1.4	-2.5	-3.7	-5.0	-6.3	-7.4	-8.7	14
11-20		+0.7	+0.9	+1.0	+0.6	-0.2	-1.3	-2.6	-3.6	-4.9	-6.1	-7.3	18
21-30		+0.3	+0.4	+0.2	-0.2	-1.1	-2.0	-3.2	-4.3	-5.5	-6.5	-7.8	4
0-10	7, 8	+0.8	+0.8	+0.5	-0.1	-1.2	-2.5	-4.1	-5.3	-6.2	-7.3	-8.2	3
11-20		-0.1	-0.1	-0.3	-0.8	-1.8	-2.9	-4.2	-5.4	-6.6	-7.8	-8.9	13
21-30		+0.1	+0.1	-0.2	-0.9	-2.0	-2.8	-3.6	-4.2	-4.9	-5.6	-6.3	8
Summer (June-August)													
0-10	0, 1	-0.2	-0.1	-0.2	-1.0	-2.3	-3.4	-4.8	-5.9	-7.3	-8.6	-9.6	14
11-20		-0.6	-0.9	-1.1	-1.9	-3.2	-4.4	-5.6	-7.1	-8.2	-9.2	-10.3	17
21-30		-0.5	-0.7	-1.1	-1.5	-2.9	-4.3	-5.4	-6.4	-7.6	-8.5	-9.5	4
0-10	2-6	-0.1	-0.3	-0.5	-1.2	-2.2	-3.5	-4.8	-6.1	-7.4	-8.6	-9.9	20
11-20		-0.4	-0.6	-0.9	-1.5	-2.7	-3.8	-5.2	-6.5	-7.6	-8.8	-10.9	26
21-30		-0.5	-0.7	-0.9	-1.5	-2.4	-3.6	-4.8	-6.0	-7.3	-8.5	-9.6	7
0-10	7, 8	-0.3	-0.6	-0.8	-1.4	-2.5	-3.8	-4.9	-6.0	-7.2	-8.3	-9.3	18
11-20		-0.3	-0.2	-0.6	-1.3	-2.4	-3.4	-4.6	-5.9	-7.0	-8.1	-9.3	15
21-30		-0.3	-0.6	-1.0	-1.7	-2.8	-4.2	-5.3	-6.5	-7.4	-8.5	-9.5	8
Autumn (September-November)													
0-10	0, 1	+2.2	+3.0	+3.9	+4.9	+4.6	+3.6	+2.6	+1.7	+0.6	-0.2	-1.2	18
11-20		+1.6	+2.2	+3.0	+3.5	+3.5	+2.8	+1.8	+0.8	-0.3	-1.2	-2.2	23
21-30		+1.3	+1.9	+2.2	+2.6	+2.5	+2.0	+1.2	+0.3	-0.8	-1.8	-1.8	16
31-40		+1.0	+1.5	+1.5	+1.4	+0.8	+0.3	-0.3	-1.0	-1.7	-2.4	-2.9	7
0-10	2-6	+1.0	+1.5	+2.4	+2.7	+2.2	+1.5	+0.4	-0.7	-1.9	-3.1	-4.2	10
11-20		+0.8	+1.5	+1.8	+1.9	+1.5	+0.5	-0.6	-1.7	-2.8	-3.9	-4.7	18
21-30		+0.5	+0.6	+0.8	+0.5	-0.1	-1.0	-2.0	-3.2	-4.4	-5.3	-6.4	9
31-40		+0.4	+0.4	+0.6	+0.6	+0.5	+0.3	0.0	-0.4	-1.0	-1.4	-2.0	2
0-10	7, 8	+0.5	+0.7	+0.7	+0.3	-0.5	-1.3	-2.3	-3.2	-4.2	-5.1	-5.9	15
11-20		+0.1	+0.1	0.0	-0.3	-0.9	-1.8	-2.7	-3.6	-4.5	-5.5	-6.4	18
21-30		+0.2	+0.3	+0.3	-0.1	-0.8	-1.7	-2.5	-3.4	-4.3	-4.9	-5.6	19
31-40		-0.1	-0.3	-0.2	-0.6	-1.3	-2.3	-3.0	-3.7	-4.0	-4.9	-5.6	3
Winter (December-February)													
0-10	0, 1	+1.5	+2.1	+2.8	+3.3	+3.2	+2.9	+2.1	+1.5	+0.5	-0.7	-1.6	10
11-20		+1.3	+1.7	+2.2	+2.6	+2.4	+2.0	+1.3	+0.4	-0.4	-1.4	-1.9	17
21-30		+1.0	+1.4	+1.9	+2.5	+2.9	+2.6	+2.0	+1.1	+0.1	-0.9	-1.7	21
31-40		+2.1	+2.4	+2.6	+2.8	+2.8	+2.6	+2.2	+1.6	+1.3	+0.9	+1.0	5
0-10	2-6	+0.7	+1.1	+1.6	+1.7	+1.0	0.0	-0.8	-2.0	-2.7	-3.7	-4.7	5
11-20		+1.1	+1.7	+2.6	+2.9	+2.8	+2.2	+1.5	+0.7	-0.1	-0.8	-1.6	10
21-30		+1.7	+2.3	+2.7	+3.0	+3.6	+3.3	+2.6	+2.0	+1.1	-0.1	-0.8	4
31-40		... ..	... ..	... ..	... ..	... ..	... ..	... ..	... ..	... ..	... ..	... ..	0
0-10	7, 8	+0.5	+0.6	+0.7	+0.7	+0.1	-0.8	-1.6	-2.6	-3.6	-4.6	-4.9	13
11-20		+0.4	+0.6	+0.7	+0.7	+0.4	-0.3	-0.8	-1.3	-2.0	-2.8	-3.7	19
21-30		+0.2	+0.4	+0.3	0.0	-0.5	-1.3	-2.0	-2.7	-3.4	-3.8	-4.5	21
31-40		+0.2	+0.6	+0.6	+0.5	0.0	-0.6	-1.2	-1.3	-1.4	-1.7	-2.4	2

\*An inversion is indicated by a positive sign, a lapse by a negative.

The figures for autumn reflect the conditions shortly after sunrise following 10-15 hr. of darkness. With light winds and a clear sky the inversion extends up to 1,000 ft. with a magnitude exceeding 9°F. A cloudy sky reduces the height to about 700 ft. without greatly affecting the magnitude of the inversion, but an overcast sky has a marked effect, bringing the inversion top down to 250 ft. and the magnitude of the inversion to 0.6°F. In passing it may be noted that an overcast sky probably has a greater effect than indicated here since the number of ascents made in November for the three lines of this part of the table referring to 0-10 kt. were 0, 1 and 6 respectively. The figures for an overcast sky are thus more nearly representative of sunrise conditions than the values for clear and cloudy skies. The effect of increasing wind speed is to diminish the magnitude of the inversion, but under clear or cloudy skies the height is not affected until the wind at 1,500 ft. exceeds 30 kt.

TABLE III—VERTICAL TEMPERATURE STRUCTURE\* AT 0700 G.M.T.

Wind at 1,500 ft.	State of sky	Difference between temperatures at 4 ft. and a height (in feet) of											Number of ascents
		30	50	100	250	500	750	1,000	1,250	1,500	1,750	2,000	
kt.	oktas	degrees Fahrenheit											
Spring (March-May)													
0-10	0, 1	-0.3	-0.1	-0.2	-0.3	+0.3	+0.7	+1.2	+1.2	+0.9	+0.3	-0.6	17
11-20		+0.2	+0.3	+0.3	+0.4	+0.4	+0.4	+0.5	+0.3	+0.1	-0.5	-1.2	19
21-30		-0.1	0.0	-0.2	-0.7	-1.4	-1.7	-2.0	-2.2	-2.3	-2.9	-3.3	20
0-10	2-6	-0.4	-0.5	-0.8	-1.2	-2.3	-2.6	-3.0	-3.3	-4.2	-5.0	-5.8	6
11-20		-0.2	-0.4	-0.5	-0.9	-1.8	-2.4	-2.6	-2.8	-3.5	-3.8	-4.2	9
21-30		-0.3	-0.1	-0.5	-1.0	-1.8	-2.4	-3.5	-4.4	-5.0	-5.8	-6.7	11
0-10	7, 8	0.0	-0.1	-0.2	-0.5	-1.2	-1.7	-2.3	-3.0	-3.6	-4.5	-5.4	16
11-20		-0.2	-0.2	-0.5	-0.8	-1.7	-2.2	-2.8	-3.1	-3.2	-3.7	-4.3	21
21-30		-0.2	-0.1	-0.3	-0.7	-1.5	-2.2	-2.5	-2.8	-2.8	-3.1	-3.6	26
Summer (June-August)													
0-10	0, 1	-0.2	-0.3	-0.5	-0.9	-1.0	-1.1	-1.3	-1.8	-2.5	-3.1	-3.7	33
11-20		-0.8	-0.9	-1.2	-1.5	-2.1	-2.5	-2.7	-3.0	-3.5	-4.0	-4.4	28
21-30		-0.5	-0.6	-0.8	-1.4	-2.5	-3.2	-3.5	-3.4	-3.8	-4.5	-5.0	14
0-10	2-6	0.0	-0.2	-0.3	-0.4	-1.0	-1.4	-2.0	-2.5	-3.2	-3.7	-4.1	14
11-20		-0.6	-0.9	-1.2	-1.9	-3.0	-4.1	-4.9	-5.7	-6.5	-7.2	-7.9	23
21-30		-0.5	-0.7	-1.0	-1.6	-2.7	-3.5	-4.2	-4.9	-5.8	-6.6	-7.0	11
0-10	7, 8	-0.2	-0.4	-0.7	-1.2	-2.1	-2.9	-3.8	-4.3	-4.9	-4.9	-5.4	18
11-20		-0.5	-0.6	-0.8	-1.7	-2.2	-2.7	-2.8	-2.9	-3.5	-4.2	-4.8	17
21-30		-0.2	-0.4	-0.5	-1.3	-2.3	-3.1	-3.6	-4.2	-4.8	-5.4	-6.2	20
Autumn (September-November)													
0-10	0, 1	+0.6	+1.1	+2.5	+4.4	+7.9	+9.0	+9.3	+8.7	+8.2	+7.9	+7.4	8
11-20		+0.5	+0.9	+1.6	+2.3	+4.6	+5.8	+5.9	+5.6	+4.9	+4.1	+3.3	11
21-30		+0.3	+0.7	+0.7	+0.7	+1.1	+1.7	+2.3	+1.8	+1.4	+0.8	+0.1	11
31-40		+0.1	+0.2	+0.3	+0.4	-0.1	-0.3	-0.7	-0.4	-0.7	-0.9	-1.5	4
0-10	2-6	+2.5	+3.0	+4.1	+6.2	+8.3	+8.3	+7.7	+6.9	+6.2	+5.2	+4.5	6
11-20		+0.3	+0.5	+0.7	+1.0	+1.3	+1.5	+1.6	+1.1	+0.4	-0.5	-1.3	21
21-30		+0.3	+0.6	+0.8	+0.9	+1.5	+1.4	+1.5	+1.0	+0.4	-0.4	-1.2	20
31-40		+0.4	+0.3	+0.4	+0.1	0.0	-0.5	-0.9	-1.1	-1.1	-1.2	-1.8	4
0-10	7, 8	+0.1	+0.4	+0.4	+0.6	+0.5	+0.4	+0.1	-0.6	-1.3	-2.3	-2.4	12
11-20		0.0	0.0	0.0	-0.1	-0.1	-0.2	-0.5	-0.9	-1.4	-2.1	-2.8	30
21-30		+0.1	+0.1	-0.1	-0.5	-1.2	-1.9	-2.4	-2.9	-3.6	-4.2	-4.7	40
31-40		-0.3	-0.2	-0.3	-0.4	-1.3	-2.0	-2.4	-2.3	-2.0	-2.4	-2.3	4
Winter (December-February)													
0-10	0, 1	+0.7	+1.2	+1.7	+2.7	+5.0	+6.5	+6.9	+6.4	+5.5	+4.5	+3.8	12
11-20		+1.0	+1.4	+1.8	+2.3	+3.2	+3.9	+3.7	+2.8	+2.0	+1.0	+0.2	15
21-30		+1.0	+1.4	+1.6	+2.0	+2.5	+3.4	+3.5	+2.9	+2.1	+1.1	+0.2	19
31-40		+1.2	+1.5	+1.6	+1.5	+1.4	+1.5	+1.5	+1.1	+0.8	+0.2	-0.6	11
0-10	2-6	+0.3	+0.8	+1.3	+2.3	+3.8	+4.6	+3.9	+3.2	+2.3	+1.8	+1.7	4
11-20		+1.1	+1.4	+2.0	+2.3	+3.2	+3.9	+3.7	+3.0	+2.4	+1.6	+0.7	10
21-30		+0.2	+0.5	+0.6	+0.4	-0.1	-0.5	-1.1	-2.0	-2.5	-3.4	-4.3	9
31-40		+0.3	+0.7	+0.7	0.0	0.0	-0.7	-1.3	-2.0	-2.7	-3.4	-4.3	7
0-10	7, 8	+0.3	+0.5	+0.9	+1.5	+1.8	+1.4	+0.9	+0.3	-0.7	-1.4	-2.0	15
11-20		+0.3	+0.3	+0.3	+0.4	+0.6	+0.5	+0.2	-0.6	-1.3	-2.1	-2.7	35
21-30		+0.2	+0.4	+0.3	+0.1	-0.5	-0.9	-1.4	-1.9	-2.0	-2.2	-2.7	29
31-40		0.0	+0.2	+0.1	-0.1	-0.5	-0.9	-1.3	-1.5	-2.3	-2.8	-3.1	7

\*An inversion is indicated by a positive sign, a lapse by a negative.

The picture in winter is generally similar to that in autumn though the inversions under radiation conditions do not attain the same magnitude as in autumn. The reason may well be the prevalence of mist as mentioned in connexion with the temperature structure at 1800. The 76 ascents contributing to the clear sky, wind 0-30 kt., parts of the table for autumn and winter were examined individually and the height of the inversion determined. The distribution of the heights was as follows:—

250 ft. or below	12 ascents	1,000 ft.	...	27 ascents
500 ft.	... 2 ascents	1,250 ft.	...	7 ascents
750 ft.	... 28 ascents			

Winter contributed 9 of the 12 low heights and both the 500 ft. inversions but otherwise there was very little difference between the two seasons.

The figures for clear skies and light winds in spring are interesting for showing that by 0700 the early morning sun has established a weak lapse in the lowest layer, but that the inversion still persists at higher levels. With 11–20-kt. winds at 1,500 ft. the greater turbulence has caused greater mixing and the atmosphere is practically isothermal up to 1,500 ft. The 21–30-kt. winds were probably associated with weaker and lower inversions during the preceding night and the early morning sun is thus able to build a lapse throughout the whole layer. The figures for cloudy and overcast skies call for little comment other than to say that the lapses shown probably follow comparatively weak and shallow inversions during the night.

**Temperature structure through early morning fog.**—The inversion of temperature which is found in the lower layer of the atmosphere following a clear calm night results from the cooling of the earth's surface by outgoing radiation. If fog forms in this layer the passage of radiation through the layer is hindered but the fog itself radiates. Provided the fog is sufficiently dense there will then be very little net loss of radiation from the surface of the earth but considerable cooling will occur at the upper surface of the fog. Within the fog mixing will be promoted by the sinking of air which has been cooled by radiation from the upper surface. The vertical temperature profile would therefore be expected to consist of a region with a lapse rate between the isothermal and saturated-adiabatic in the fog, and an inversion above the fog top. The inversion should be limited to a depth comparable with the depth of the inversion above the surface after a clear night and the temperature gradient should then change first to isothermal and then to a lapse with increasing height. Such a structure has in fact been discussed in *Geophysical Memoirs* No. 89<sup>1</sup> in relation to observations made on a tower extending to 350 ft. above the surface, but, apart from an isolated meteorograph ascent in fog by L. H. G. Dines (reported by Capt. F. Entwistle<sup>2</sup>), there are little published data supporting this theoretical structure for greater heights.

A preliminary inspection showed that on many occasions when fog was reported at the time of the early morning ascent at Cardington the vertical temperature structure did conform to the pattern outlined. However, even after discarding a few occasions when there were indications of cloud above the fog, there were some occasions when the observations did not fit this picture. In passing it may be emphasized here that the data available did not allow certainty regarding the state of sky above fog. Accordingly the following analysis was carried out. For each occasion on which fog was reported at the time of the early morning ascent and there was no definite evidence of low cloud the temperature profile was examined to see whether it conformed to the pattern described above. Out of the 45 ascents made in fog in the early morning (and with no definite evidence of cloud above the fog) 33 profiles were of the shape expected and 12 were not. On these latter 12 occasions there was an isothermal layer near the surface but no well marked inversion at greater heights. The 33 profiles which fitted the pattern were then further examined, and an assessment made of the height of the top of the surface isothermal layer and of the height at which the temperature ceased to rise steeply. These assessments were based solely on the dry-bulb temperature. Naturally there were minor irregularities in the temperature profiles and to some extent these assessments were necessarily subjective, particularly with respect to the second height mentioned. In order to reduce the subjective element as much as possible



the assessments were all made in terms of the actual heights at which observations were made. The total temperature increase between the first and second heights was also noted. A typical ascent is shown in Fig. 1. The results of this analysis are shown in Tables IV and V in terms of the height of the surface isothermal layer, the depth of the layer over which the temperature increased rapidly with height and the temperature increase through the inversion layer.

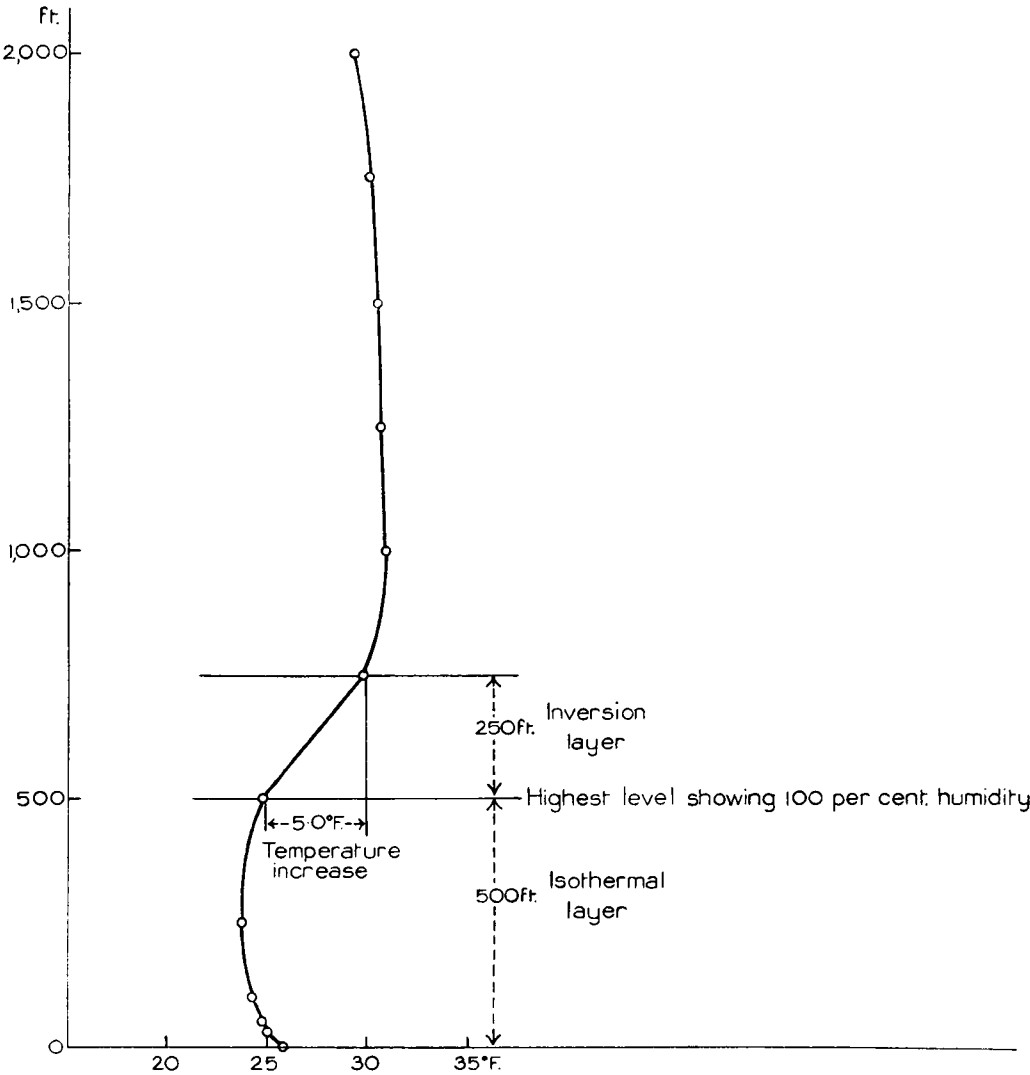


FIG. 1—TYPICAL BALLOON ASCENT THROUGH FOG, JANUARY 30, 1951  
Surface visibility 250 yd.

Too much emphasis should not be placed on the details of these tables since, as already explained, the analysis was to some extent subjective and the assessments were restricted to heights at which observations were actually made. Nevertheless it does appear that in autumn the height of the isothermal layer tends to be smaller, and the thickness of the inversion layer greater, than in the other two seasons. There is little significance in the low frequency with inversion temperature increase less than 5°F. Small inversions would imply that the pattern is not easily recognizable, and may well have occurred in the 12 ascents which did not fit the pattern.

TABLE IV—FREQUENCY OF DEPTHS OF ISOTHERMAL AND INVERSION  
LAYERS ASSOCIATED WITH EARLY MORNING FOG

			Frequency of layers of depth			Mean depth	Number of ascents
			50-200 ft.	250-500 ft.	600-750 ft.		
			<i>number of occasions</i>			ft.	
			<b>Surface isothermal layer</b>				
Spring	...	...	3	6	5	430	14
Autumn	...	...	9	4	1	210	14
Winter	...	...	1	4	0	320	5
			<b>Inversion layer</b>				
Spring	...	...	2	11	1	390	14
Autumn	...	...	0	7	7	540	14
Winter	...	...	0	5	0	380	5

TABLE V—FREQUENCY OF INVERSIONS OF VARIOUS MAGNITUDES ABOVE  
FOG AT 0700 G.M.T.

			Frequency of inversion with increase of temperature				Mean	Number of ascents
			< 5°F.	5-10°F.	10-15°F.	15-20°F.		
			<i>number of occasions</i>				°F.	
Spring	...	...	0	10	3	1	8.3	14
Autumn	...	...	1	8	5	0	9.5	14
Winter	...	...	0	4	1	0	7.8	5

The humidity observations for the 33 ascents were next examined. Naturally the lowest heights showed 100 per cent. relative humidity. The greatest height at which saturation was reported was noted for each occasion. On 19 of the ascents this coincided with the height of the isothermal layer; on 12 ascents saturation was reported above the top of the isothermal layer; on 1 occasion only the top of the isothermal layer had relative humidity less than 100 per cent. and on 1 occasion the humidity observations were missing. It seems a reasonable conclusion that what has so far been described as the isothermal layer is in fact the fog layer but that 100 per cent. relative humidity does occur above the top of the fog.

Reference was made on p. 238 to the necessity for the fog to be sufficiently dense if the temperature profile is to fit the simple pattern discussed. This suggests a reason for 12 of the profiles failing to fit the pattern. To test this the frequency distribution of visibilities for both the 33 cases which do fit and the 12 cases which do not was determined. The results are given in Table VI.

TABLE VI—FREQUENCY DISTRIBUTION OF VISIBILITIES IN THE  
EARLY MORNING FOGS

		Visibility (yd.)						
		< 101	101-200	201-300	301-400	401-500	501-600	601-700 701-800
Well marked inversion	...	17	11	3	1	1	...	...
No well marked inversion	...	1	2	3	...	3	...	1 2

We may conclude from this table that if the visibility is less than 200 yd. the temperature profile will probably contain a well marked inversion above the fog (this refers to early morning and radiation fogs only of course) but that if the visibility exceeds 300 yd. the inversion is not likely to be well marked. It is tempting to conclude that there might be a relation between the strength of the inversion and the visibility, but the observations do not show this. It is true

that the greatest visibility noted which was associated with an inversion (440 yd.) accompanied the smallest inversion (temperature increase  $2.1^{\circ}\text{F.}$ ) noted in the 33 cases, but the second greatest visibility in this class (400 yd.) was associated with an inversion temperature increase of  $13.9^{\circ}\text{F.}$

The data available were tested for several other possible relations but without success. This is not surprising since the temperature profile through fog in the early morning is the result of the operation of several factors during the whole of the preceding night.

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## SPEED OF MOVEMENT OF WARM FRONTS ON THE ATLANTIC

By C. H. HINKEL, B.Sc. and W. E. SAUNDERS, B.Sc.

**Introduction.**—One of the present writers, in the course of weather-forecasting duties, noted a tendency for warm fronts to move faster over the ocean than would be expected from empirical relations deduced from the movements of fronts over Great Britain. The relation of the motion of warm fronts to the geostrophic wind speed has been studied by Matthewman<sup>1</sup> for fronts over the British Isles, and it was decided to make a similar study of the motion of warm fronts on the eastern Atlantic. This note describes the results.

**Data.**—Surface working charts covering the period from January 1, 1951, to June 30, 1953, were examined for examples of warm fronts approaching the British Isles from the west or south-west which would satisfy the following conditions:—

- (i) front well marked on the surface chart
- (ii) both western and eastern positions of front fixed with reasonable accuracy from ships' observations and coastal stations of west Ireland, using the normal surface properties of warm fronts
- (iii) network of observations such that the isobars were reliably determined
- (iv) small isobaric curvature.

During the period considered 52 such examples occurred. The selected fronts were examined by measuring the distance moved by the front from its western to its eastern position. From this the mean speed of the front ( $u_f$ ) was calculated. Next, the components of the geostrophic wind normal to the front at the initial and final positions were measured, and the mean of these two values was assumed to be the mean geostrophic component perpendicular to the front ( $u_j$ ) during the period considered. Finally this last set of measurements was repeated using the normal component of the geostrophic wind 75–100 nautical miles ahead of the front and the mean of the two values ( $u_j'$ ) was obtained as before.

**Method.**—The regression equation of  $u_f$  on  $u_j$  (both measured in knots) was calculated to be

$$u_f = 0.75 u_j + 3.7 \quad \dots\dots\dots (1)$$

with a root-mean-square residual of 5.9 kt. The correlation coefficient between  $u_f$  and  $u_j$  was found to be 0.87 and the regression line is illustrated in Fig. 1.

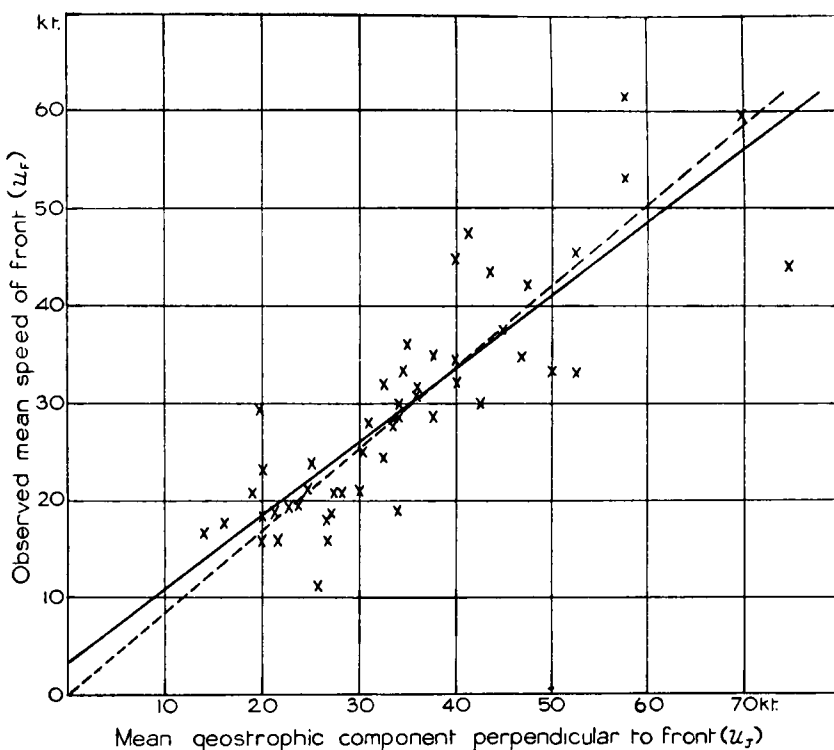


FIG. 1—RELATION BETWEEN SPEED OF FRONT AND GEOSTROPHIC WIND  
ACROSS THE FRONT

Full line represents regression line  $u_f = 0.75u_g + 3.7$   
Broken line represents best fit through the origin  $u_f = 0.84u_g$

The range of values of  $u_g$  in the 52 cases was from 11 to 70 kt., and as the constant term in the regression equation is small compared with such speeds, one would suppose that for practical purposes the use of a simple proportion of the geostrophic speed would be justified by the added convenience. The line of best fit through the origin was, therefore, calculated and found to be

$$u_f = 0.84 u_g. \quad \dots\dots\dots (2)$$

Following the procedure adopted by Matthewman, the above analysis was repeated using  $u_g'$  instead of  $u_g$  and the regression equation was found to be

$$u_f = 0.91 u_g' + 2.6 \quad \dots\dots\dots (3)$$

with a root-mean-square residual of 4.6 kt. Fig. 2 shows the fit between this regression line and the data. The improved correlation (0.92) can be seen in the reduced scatter of the points about the line, and in this connexion it is worth noting that Matthewman obtained a similar improvement by using the geostrophic flow 75–100 miles ahead of the warm front.

The line of best fit through the origin was found to be

$$u_f = 0.99 u_g'. \quad \dots\dots\dots (4)$$

The main statistical results are summarized in Table I.

A comparison between the regression coefficients of equations (1)–(4) and the corresponding values obtained by Matthewman (see Table I) shows that the warm fronts over the Atlantic tended to move with a greater fraction of the geostrophic wind speed than those over land. In order to determine whether

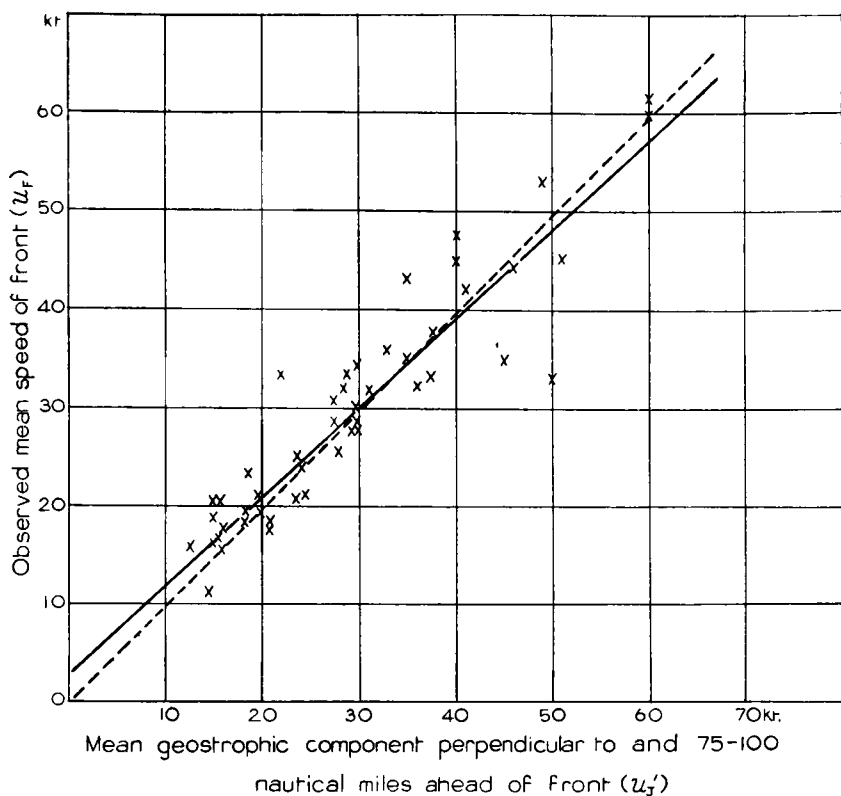


FIG. 2—RELATION BETWEEN SPEED OF FRONT AND GEOSTROPHIC WIND  
75-100 MILES AHEAD OF FRONT

Full line represents the regression line  $u_F = 0.91 u_J' + 2.6$

Broken line represents the best fit through the origin  $u_F = 0.99 u_J'$

this difference is significant, the differences between corresponding members of the four pairs of regression coefficients given in Table I were tested using "Student's"  $t$ -test and were found to be significant at the levels indicated in the third column of Table I. These levels vary from 4 to 12 per cent. and can be regarded as strong, but not conclusive evidence in favour of the contention stated above. It is, however, possible that the differences between the regression coefficients arose as a result of the method of selection of the data. In this

TABLE I—RELATIONS BETWEEN  $u_F$  AND  $u_J$  OR  $u_J'$

	Relations found in this note	Relations found by Matthewman	$t$ -test significance level
Number of cases ... ..	52	37	%
Correlation coefficients:			...
$u_F$ on $u_J$ ... ..	0.87	0.82	...
$u_F$ on $u_J'$ ... ..	0.92	0.85	...
Regression lines:	<i>knots</i>		
$u_F$ on $u_J$ ... ..	$u_F = 0.75u_J + 3.7$	$u_F = 0.60u_J + 2.1$	12
$u_F$ on $u_J'$ ... ..	$u_F = 0.91u_J' + 2.6$	$u_F = 0.70u_J' + 2.3$	4
Root-mean-square residuals			
$u_F$ on $u_J$ ... ..	5.9	5.2	...
$u_F$ on $u_J'$ ... ..	4.6	4.7	...
Line of best fit through origin			
$u_F$ on $u_J$ ... ..	$u_F = 0.84u_J$	$u_F = 0.67u_J$	8
$u_F$ on $u_J'$ ... ..	$u_F = 0.99u_J'$	$u_F = 0.79u_J'$	5

connexion condition (iv), small isobaric curvature, is the only one which might conceivably affect the results. This condition was introduced in order that the geostrophic winds derived from the charts might approximate more closely to the actual winds. Matthewman's original data were therefore examined for examples of warm fronts which would have been excluded from the present analysis on these grounds, and nine cases falling into the category were found. The statistical relations previously obtained were recalculated using this revised data. The values obtained from this determination did not differ appreciably from the original set. However, it was thought desirable to apply the significance test to the new set of regression coefficients; the significance levels were not found to be materially changed. It is, therefore, justifiable to assume that the differences between the pairs of regression coefficients are genuine and did not arise as a result of either sampling or the selection conditions imposed. No attempt is made here to put forward a rigorous explanation for the increased speed of warm fronts over the Atlantic compared with speeds over land. We confine ourselves to suggesting that the result merely reflects the differences in frictional drag over the two types of surface.

**Conclusion.**—It would appear that for warm fronts moving over the ocean, the “two-thirds geostrophic speed” rule commonly used over the land may on most occasions be replaced by “five-sixths geostrophic speed”. A better estimate is given by the full value of the geostrophic wind component perpendicular to the front measured 75–100 nautical miles ahead of the front.

#### REFERENCE

1. MATTHEWMAN, A. G.; Speed of warm fronts. *Met. Mag., London*, **81**, 1952, p. 266.

## EFFECTS OF A WIND-BREAK ON THE SPEED AND DIRECTION OF WIND

By E. N. LAWRENCE, B.Sc.

**Summary.**—The following note describes the wind speed and direction to leeward of a wind-break, first in the horizontal plane at a height of about 6 ft. (referred to as ground level), and secondly in the vertical plane which passes at right angles through the centre of the barrier. The wind field at the end of the wind-break is also examined.

Two types of wind barrier are considered, one of which has a greater density than the other in the upper part of the screen.

The degree of shelter and the effect on wind direction were measured for a range of wind velocities and angles of incidence to the barrier. The wind speeds in the sheltered area have been calculated in terms of the speed of the “undisturbed” or “free” wind at the corresponding level for two types of atmospheric temperature lapse rate, which may be described as “large lapse rate” (referred to as unstable or lapse conditions) and “zero or small lapse rate” (referred to as stable or near neutral conditions).

**Introduction.**—During the period August 1937 to January 1938, a series of observations was made at Manby, Lincolnshire, to explore the suitability of wind screens for the reduction of the wind across runways<sup>1</sup>. The influence on wind of the two artificial barriers examined may be compared with that of natural shelter-belts of trees and shrubs of similar density, the use of which in agricultural work has commanded considerable attention in recent years. In conjunction with the Manby field experiment, wind-tunnel investigations were carried out at South Farnborough in August 1936 and October 1938; the results therefrom are summarized in the Appendix.

**Method.**—The wind-breaks were approximately 50 ft. high, 1,600 ft. long and 10 ft. wide and are shown in the photographs in the centre of this magazine. Details of the structure of the two barriers, given in Fig. 1, show that they

consisted of three parallel frames, the two external frames being similar. The modified barrier was constructed by adding slats (shown by shading in Fig. 1) to the upper parts of the frames of the original barrier.

Wind speeds were measured by cup anemometers mounted on tripods for ground-level winds (at 6 ft.), and by cup anemometers mounted on a telescopic ladder (see photograph in the centre of this magazine) for winds at 30–55 ft. above ground. Each speed was obtained by averaging two or three runs, each run taking 3 min. For heights greater than those reached by the ladder (60 ft. upwards) winds were measured with zero-lift balloons. Flow conditions around the barrier were studied by means of balloons and smoke candles, the latter being observed every 10 sec. for several minutes. Wind directions were estimated by means of light tape fixed at one end to a cup anemometer. These observations were aided by ground markings, consisting of white lines, parallel to the barrier. The mean direction was obtained from observations every 5 sec. over a period of 1 min. Wind observations by cup anemometer were made at a height

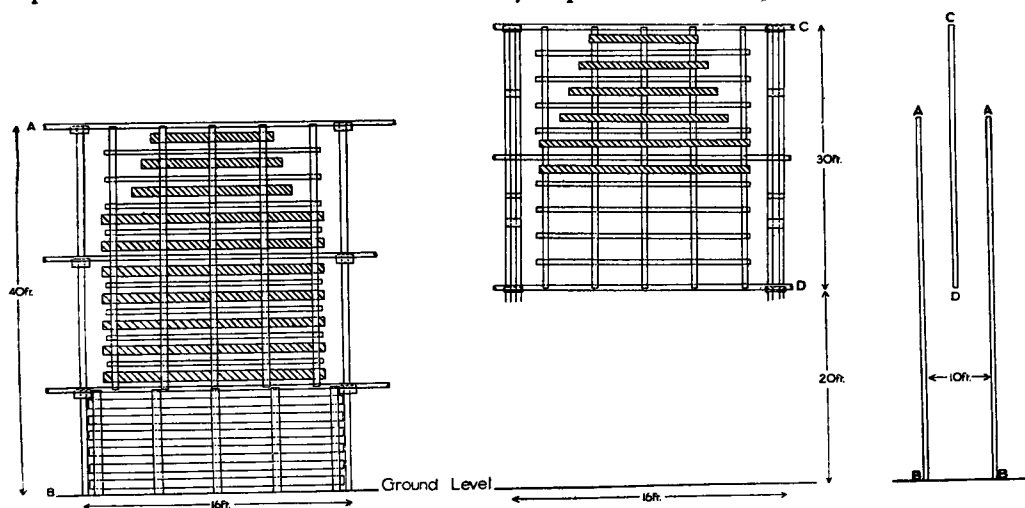


FIG. 1—DETAILED CONSTRUCTION OF THE WIND-BREAK  
 AB = external frame                      CD = internal frame  
 The additional slats of the modified wind-break are shown shaded.

of 6 ft. and at intervals of 5 ft. from 30 ft. to 55 ft. inclusive. In a horizontal plane, observations were made at 150-ft. intervals up to 450 ft. to leeward of the barrier and at 150-ft. intervals parallel to the barrier; at the “sheltered” end of the barrier, on the leeward side, the observation network was denser and generally on a 30-ft. or 60-ft. basis over the area in which the lines of equal “shelter” showed great curvature. Only one telescopic ladder was in use and observations were not simultaneous. It was not the general rule to “average” values for each point, although on occasions, two or more sets of observations were obtained for different values of the magnitude of the “free” wind. The speed and direction of the “free” wind were measured by a pressure-tube anemometer erected at the centre of the barrier-top. This instrument was suitably time marked against a stop-watch, so that observations of “free” wind could be compared with observations to leeward of the barrier.

Undisturbed winds below 9 m.p.h. were not sufficiently strong to give any definite results and the range of free speeds used in the calculations was 9–30 m.p.h. The wind directions were those corresponding to angles of incidence

with the barrier of 0°, 15°, 30°, 45° and 60° for horizontal gradients and 15°, 30° and 45° for vertical gradients and 15° only for the examination of "end effect" of the wind field near the barrier end.

**Calculation and representation of results.**—Let  $v$  be the pressure-tube anemometer reading and assume\* that this is the speed of the "free" wind at 50 ft.

Using Sutton's velocity-profile formula<sup>2</sup>, we obtain

$$v_z = v \left( \frac{z}{50} \right)^{n/(2-n)}$$

where  $v_z$  is the free wind at the height  $z$ . According to Sutton<sup>3</sup>, in lapse conditions  $n = 1/5$ , and in near neutral conditions  $n = 1/4$ , giving respectively

$$v_z = v \left( \frac{z}{50} \right)^{1/9}$$

and 
$$v_z = v \left( \frac{z}{50} \right)^{1/7}.$$

Let  $u_z$  be the observed wind to leeward of the barrier at a height  $z$  and let  $u_z = kv_z$ . Then

$$u_z = kv \left( \frac{z}{50} \right)^{1/9} = k'v \text{ say (lapse conditions)}$$

and

$$u_z = kv \left( \frac{z}{50} \right)^{1/7} = k''v \text{ (near neutral conditions).}$$

Now the available data give the values of  $k'$  and  $k''$  at different points. The corresponding values of  $k$  are given by:—

$$k = k' \left( \frac{50}{z} \right)^{1/9} \quad (\text{lapse conditions}) \quad \dots\dots\dots (1)$$

and

$$k = k'' \left( \frac{50}{z} \right)^{1/7} \quad (\text{near neutral conditions}). \quad \dots\dots\dots (2)$$

All the observations were made during the day-time and not normally under inversion conditions. If we assume a high lapse rate (lapse conditions), then,

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\*The assumption that  $v$  is the speed in the open at 50 ft. appears to be reasonable in view of the vertical cross-section obtained by Bates and Stoeckeler of the United States Forest Service<sup>4</sup>. For a half-solid, 16-ft. barrier, the speed at a short distance above the top was found to be near to 100 per cent. of the speed at a corresponding height in the open. In the following results the degree of shelter would be over-estimated if the speed at the barrier top were under-estimated or if the height in the free air corresponding to this speed were under-estimated. For example, if the pressure-tube anemometer were actually recording 110 per cent. of  $v_{50}$ ,

$$\begin{aligned} v &= (11/10)v_{50} \\ &= (11/10)v_z(50/z)^{1/9} \text{ or } (11/10)v_z(50/z)^{1/7} \end{aligned}$$

using Sutton's formula<sup>2</sup>. If the true value of  $k$  is  $k_T$ , then

$$\begin{aligned} k_T &= u_z/v_z \\ &= (11/10) (u_z/v) (50/z)^{1/9} \text{ or } (11/10) (u_z/v) (50/z)^{1/7} \\ &= 11k/10. \end{aligned}$$

Thus if  $v$  were actually 110 per cent. of the unobstructed wind at 50 ft. all values of  $k$  would have to be increased by 10 per cent.



using equation (1) and substituting the values of  $k'$  and  $k''$  for different points, we obtain a set of curves on which  $k = 0.2, 0.4, 0.6$ , etc. Similarly, using equation (2) we obtain a set of curves for small lapse rates or near neutral conditions. These two sets of curves are a measure of the bounding positions of the lines of equal "shelter" or lines along which the ratio of the sheltered wind speed to the free wind speed at the corresponding height is constant. On a horizontal section, these lines would be lines of equal speed.

The results are shown in Figs. 2-8, speed of the wind being given by isopleths of the distribution of  $k$  and wind direction by means of arrows. Figs. 2-5 apply to the unmodified wind-break; Figs. 6-8 apply to the modified wind-break. It should be noted that the wind direction is within  $5^\circ$  of the angle of incidence quoted.

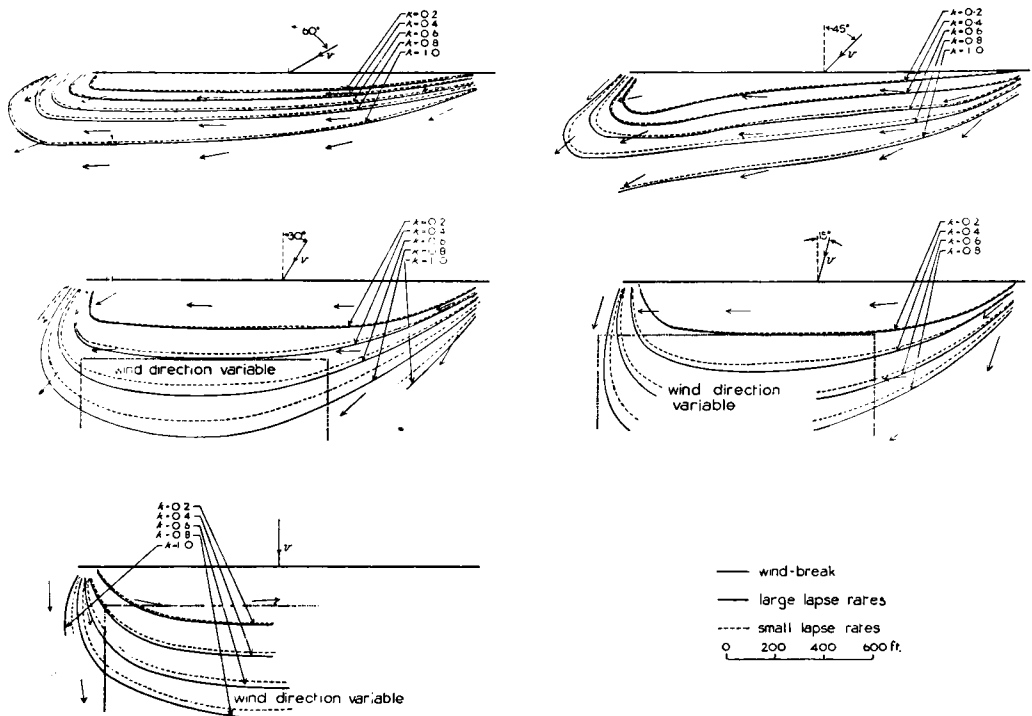


FIG. 2—HORIZONTAL DISTRIBUTION OF  $k$  AT GROUND LEVEL BEHIND THE ORIGINAL WIND-BREAK

**Conclusions.**—As the observations were carried out with a wind-break of height 50 ft. and length 1,600 ft. approximately, the conclusions apply primarily to a barrier with dimensions of this order. The same results cannot be expected with a barrier in which the aspect ratio (i.e. ratio of length to height) is much smaller.

*Original wind-break.*—The general form of the isopleths of  $k$  at ground level is similar for all wind directions. The shielded area decreases as the angle of incidence of the wind to the barrier increases, and the direction of the wind is altered so that the flow becomes approximately parallel to the screen and is smooth. The extent of the area in which the flow is parallel to the screen varies greatly with the angle of the wind. At the leeward end of the screen the flow is not smooth.

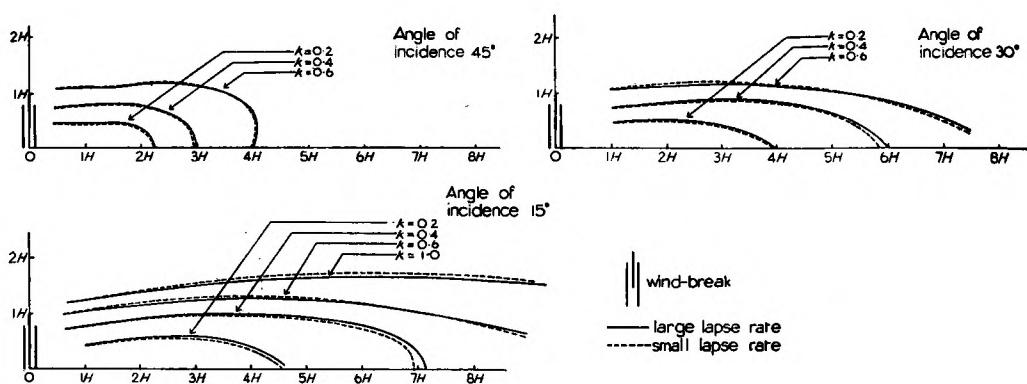


FIG. 3—VERTICAL DISTRIBUTION OF  $k$  BEHIND THE CENTRE OF THE ORIGINAL WIND-BREAK

The vertical cross-sections through the centre of the screen and at right angles to it are very similar for different wind directions and at a distance  $H$  from the screen are almost identical where  $H$  is the height of the screen. Up to a height of about  $0.7H$ , there is a tendency for the flow to become parallel to the wind-break, but above this height the direction of flow is approximately that of the “undisturbed” wind.

At distances down wind greater than  $4\frac{1}{2}H$  from the wind-break, the wind direction at “ground level” was very variable for angles of incidence smaller than  $20^\circ$ . With an angle of incidence of about  $25^\circ$ , at a distance from the screen between  $4\frac{1}{2}H$  and  $9H$ , the flow near the ground was generally along the direction of the barrier, but gusts were observed towards and less frequently away from the screen. With a wind nearly perpendicular to the barrier the flow near the ground at distances greater than about  $4\frac{1}{2}H$  from the barrier consisted of a series of weak gusts in almost every direction, the average speed at  $6H$  being approximately  $0.25v_{50}$ .

With the wind nearly perpendicular, smoke released from the top of the barrier showed a steady stream with small eddies rising to about  $1.2H$  above the ground at  $3H$  from the barrier. Almost all the smoke reached the ground at distances greater than  $6H$  from the barrier. Occasionally some smoke was brought down to the ground by large slow eddies at distances as near as  $1\frac{1}{2}H$  from the barrier. The general flow is illustrated in Fig. 5 and photographic observations of eddies are shown facing p. 249. Occasionally a balloon with no lift and floating a few feet above the ground to leeward of the barrier would be

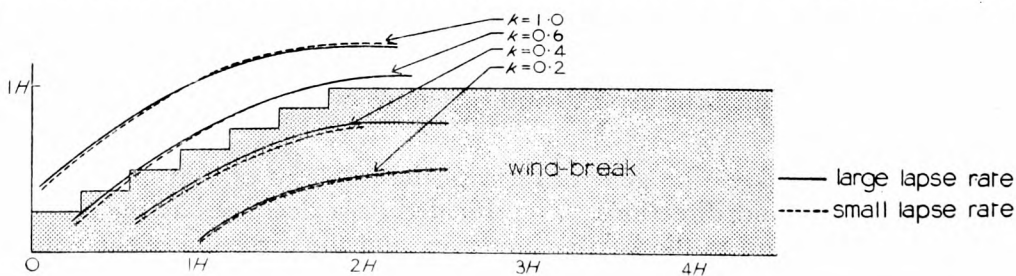
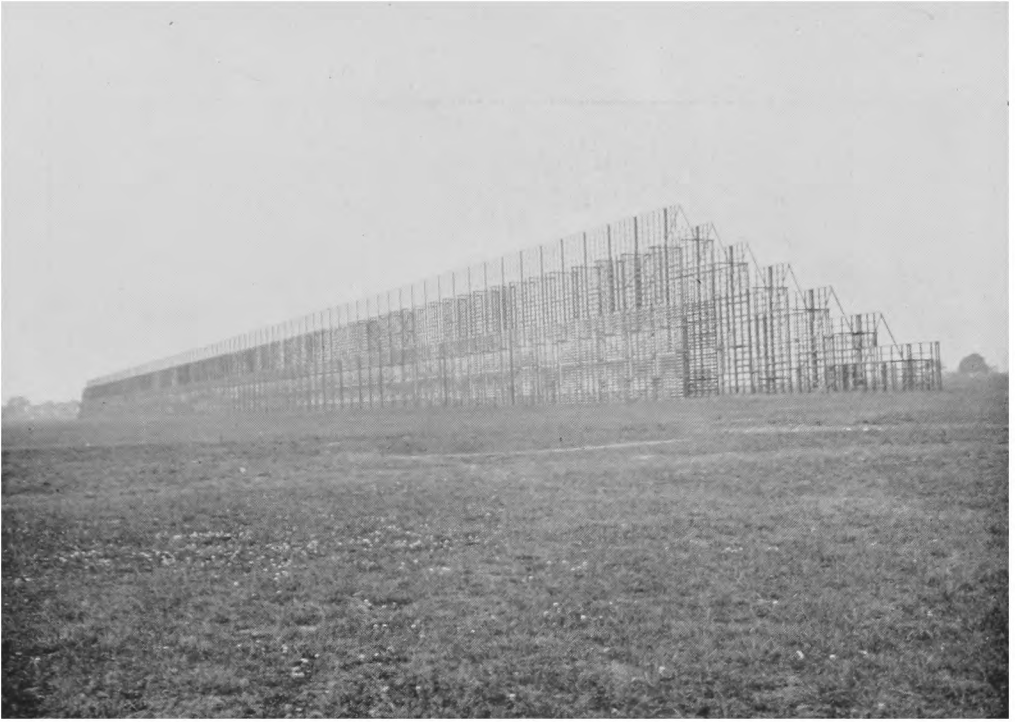
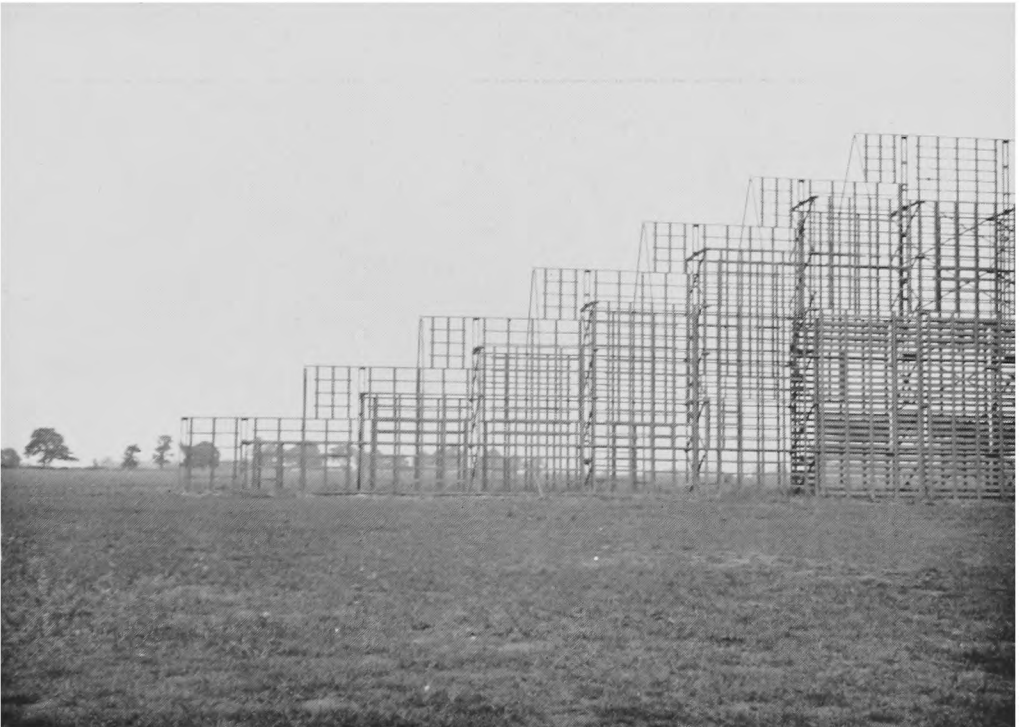


FIG. 4—VERTICAL DISTRIBUTION OF  $k$  NEAR THE END OF THE ORIGINAL WIND-BREAK, 60 FT. DOWN WIND  
Angle of incidence of wind  $15^\circ$

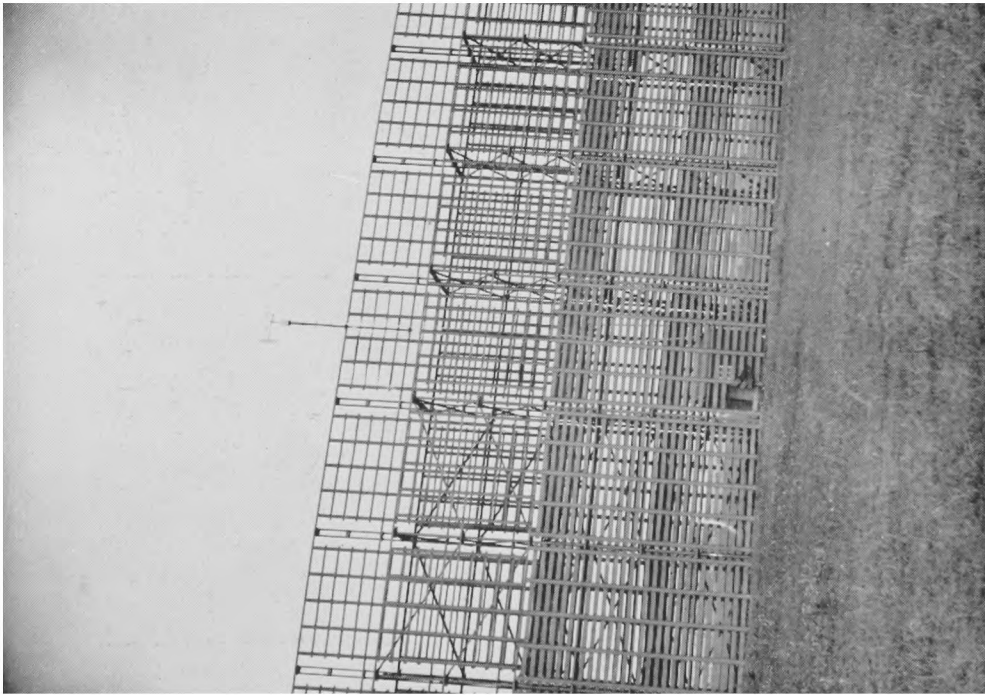


GENERAL VIEW OF THE ORIGINAL WIND-BREAK

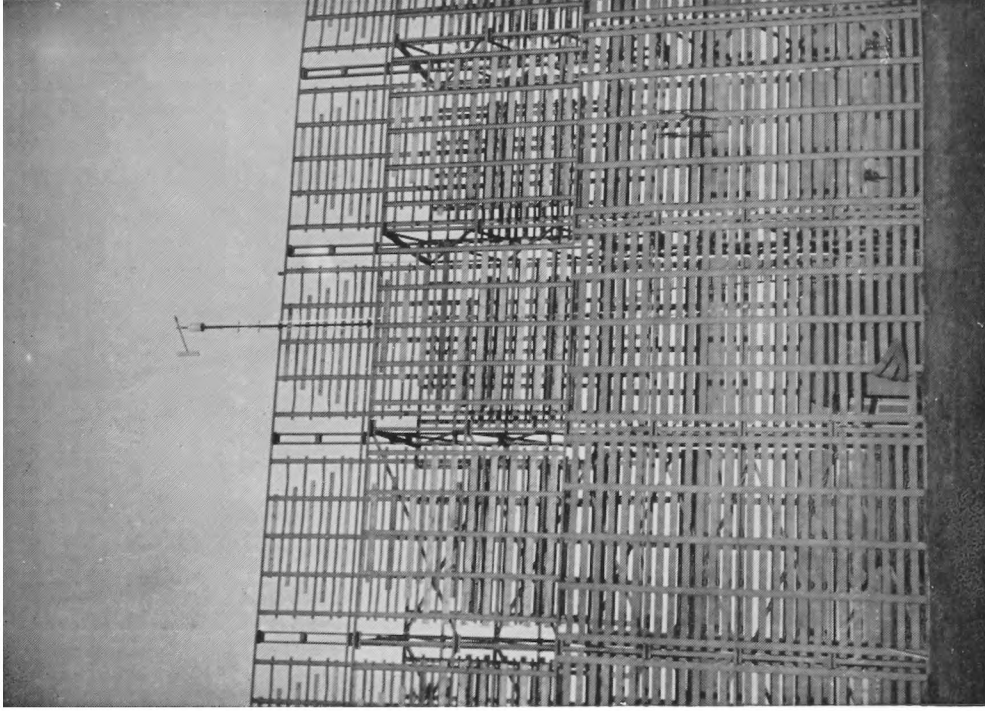


END OF THE WIND-BREAK SHOWING THE TAPER AND GRADUAL  
REDUCTION IN DENSITY

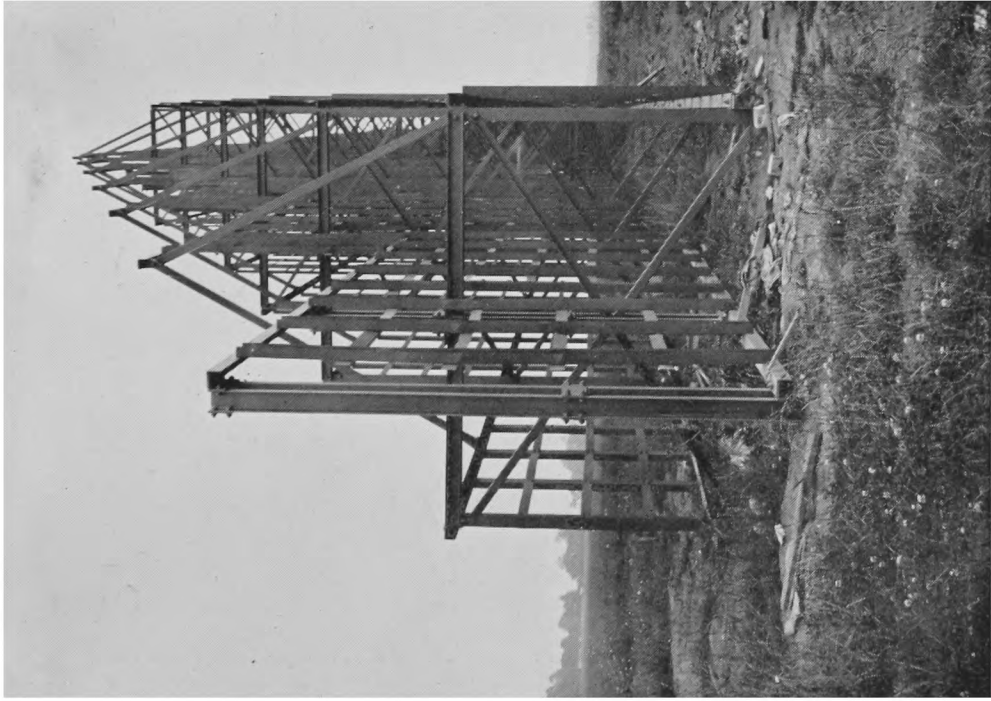
ARTIFICIAL WIND-BREAK AT MANBY, LINCOLNSHIRE  
(see p. 244)



CENTRAL PORTION OF ORIGINAL WIND-BREAK SHOWING PRESSURE-TUBE ANEMOGRAPH

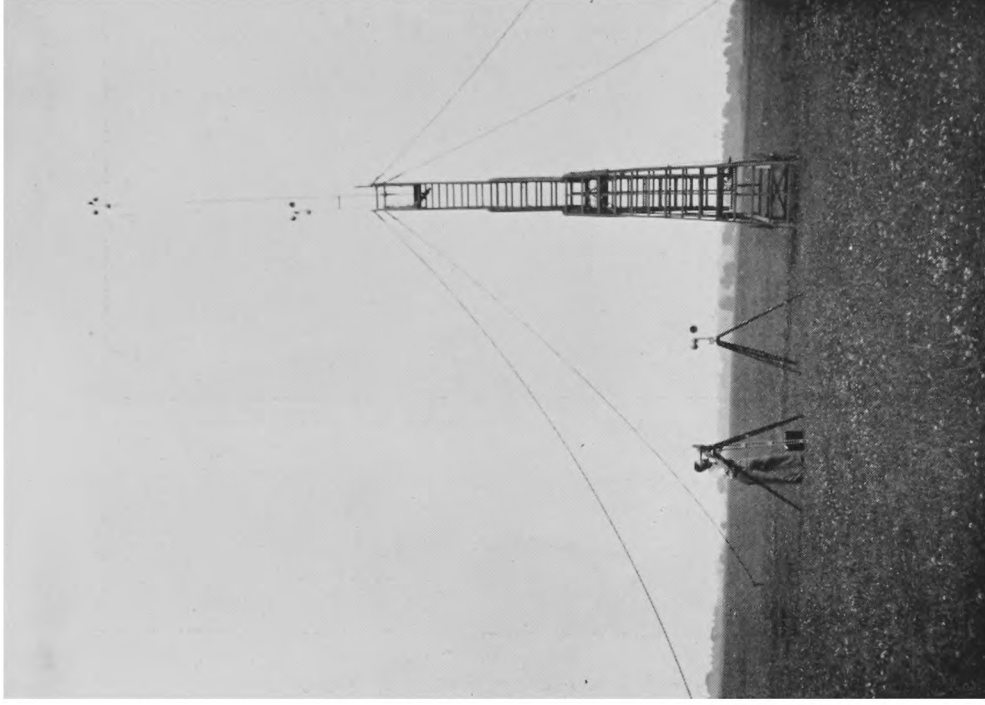


CENTRAL PORTION OF MODIFIED WIND-BREAK

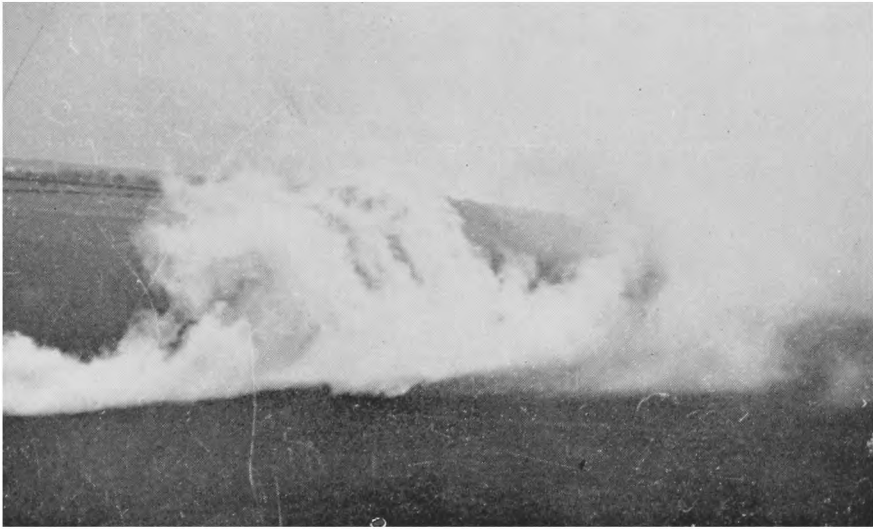


END VIEW OF THE ORIGINAL WIND-BREAK

ARTIFICIAL WIND-BREAK AT MANBY, LINCOLNSHIRE  
(see p. 244)

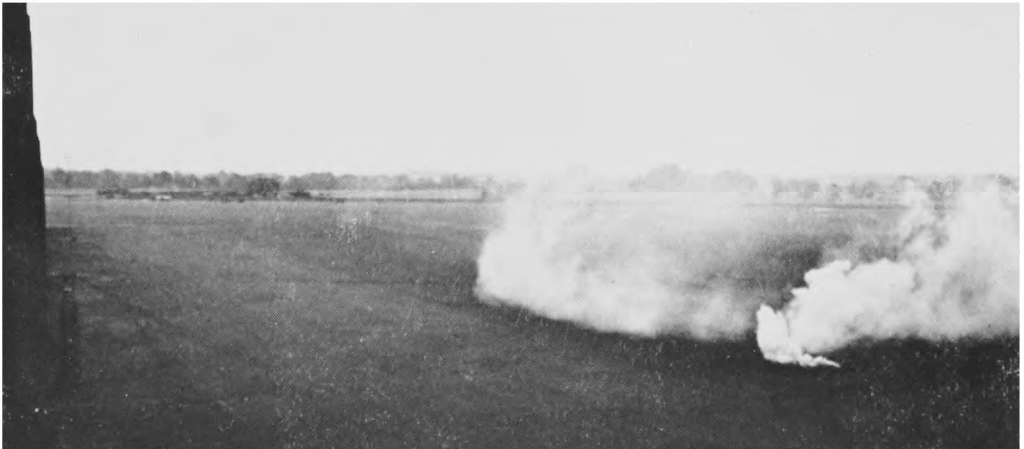


CUP ANEMOMETERS MOUNTED ON TELESCOPIC LADDER  
The theodolite is used for reading the anemometers



VIEW LOOKING AT RIGHT ANGLES FROM THE WIND-BREAK

The source of the smoke is just to the left of the picture; the undisturbed wind direction is from the left  $15^\circ$  from the perpendicular to the wind-break which is behind the camera.



VIEW FROM NEAR THE WIND-BREAK

The wind is almost at right angles to the wind-break seen on the left of the photograph. The smoke flows parallel to the wind-break at first before lifting and eddying at right angles.



VARIABILITY OF WIND DIRECTION

The source of the smoke is shown by the small arrow; it will be seen that sometimes the smoke is blown towards and sometimes away from the wind-break which is just off the picture to the left.

DEMONSTRATION OF EDDIES NEAR THE WIND-BREAK BY SMOKE CANDLES

(see p. 244)



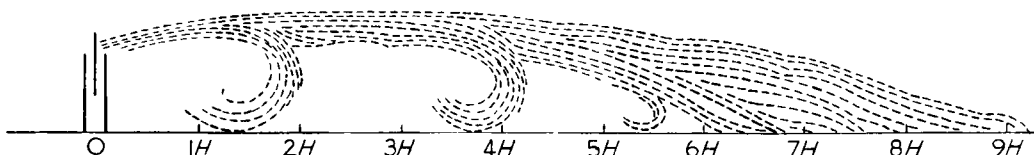


FIG. 5—LARGE EDDIES OBSERVED BEHIND THE CENTRE OF THE ORIGINAL WIND-BREAK WITH WIND ALMOST AT RIGHT ANGLES TO THE WIND-BREAK

caught in a rapid up-draught until it was carried away by the main stream over the top of the wind-break.

*Modified wind-break.*—The isopleths near the ground have the same general form as with the original barrier, but the shielded area is rather less than the previous area for angles of incidence of  $15^\circ$  and  $30^\circ$  and slightly greater for angles of incidence of  $45^\circ$  and  $60^\circ$ .

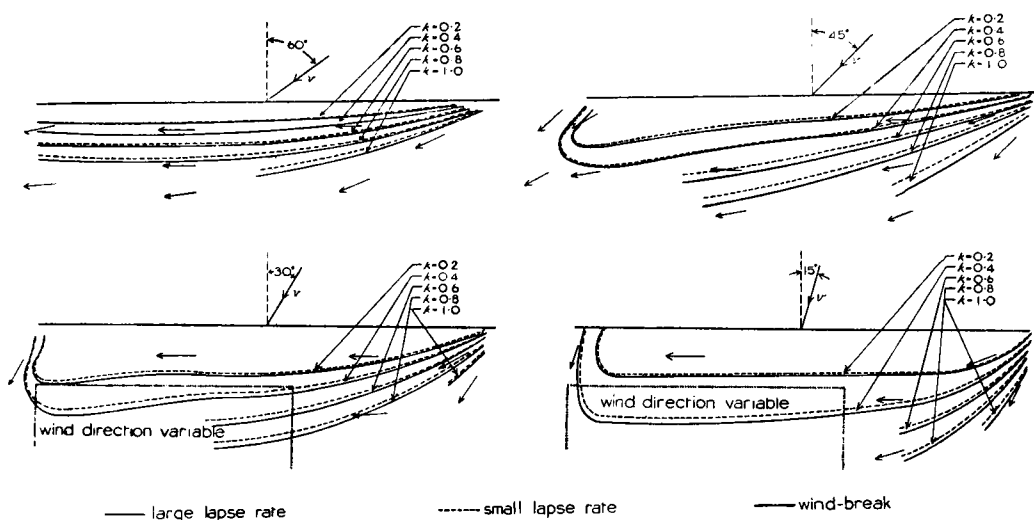


FIG. 6—HORIZONTAL DISTRIBUTION OF  $k$  AT GROUND LEVEL BEHIND THE MODIFIED WIND-BREAK

Similar isopleths are a few feet higher in the vertical plane than the corresponding isopleths with the original barrier up to a distance of about  $6H$  from the wind-break.

The eddying conditions in the sheltered region are more disturbed than with the original barrier. As in the case of the latter, with a wind at right angles

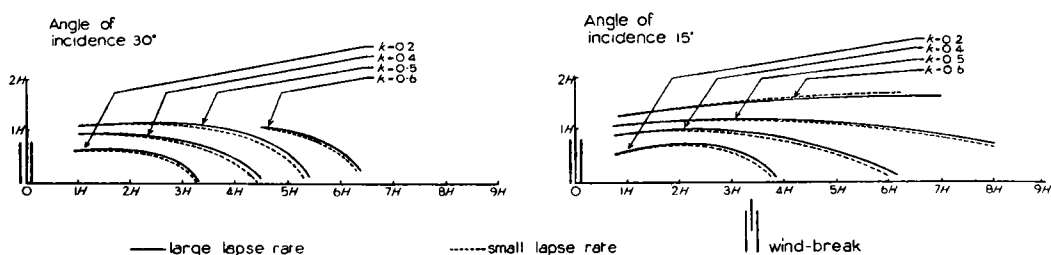


FIG. 7—VERTICAL DISTRIBUTION OF  $k$  BEHIND THE CENTRE OF THE MODIFIED WIND-BREAK

most of the smoke reached the ground at distances of more than  $6H$  from the barrier. Large eddies which carried the smoke down to the ground were more frequent and more violent than those observed with the original barrier.

With angles of incidence of wind between  $0^\circ$  and  $20^\circ$ , the wind direction on the ground at distances of  $3.6H$  to  $6H$  was very variable with fairly strong frequent gusts towards the barrier. Smoke released in this area was carried towards the barrier and generally at about  $3.6H$  distance rose rapidly to a height of  $1.2H$ . These gusts did not often penetrate to within a distance of  $3H$  from the wind-break. The wind roses in Fig. 8 illustrate this. At a distance of  $3H$ , the most frequent wind direction is approximately parallel to the screen.

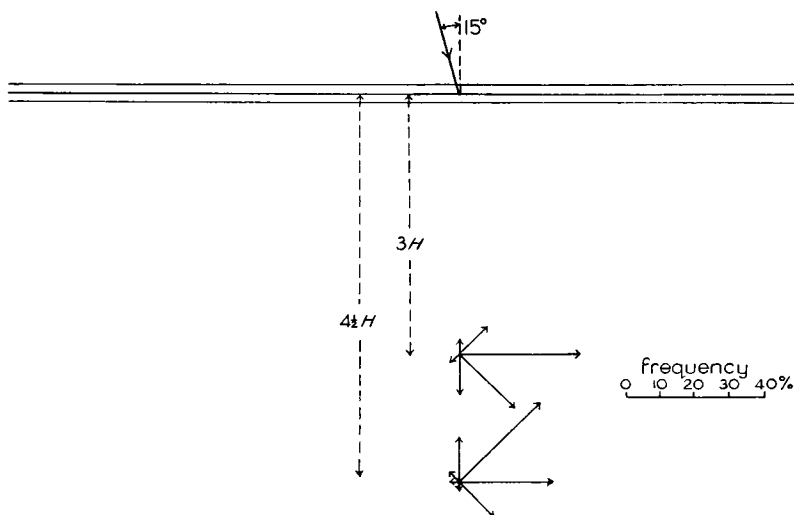


FIG. 8—WIND ROSES AT TWO FIXED POINTS BEHIND THE CENTRE OF THE MODIFIED WIND-BREAK WITH ANGLE OF INCIDENCE OF THE WIND  $15^\circ$   
 $H$  = height of the wind-break

*Both wind-breaks.*—The effect of lapse-rate differences (for positive lapse rates) is very small except below a height of approximately  $\frac{1}{2}H$  and at distances from the barrier between about  $2H$  and  $8H$ , especially for angles of incidence of about  $30^\circ$  or less.

The effective reduction of wind is normally greater for unstable than for stable lapse rates up to height  $H$ .

The shelter or velocity isopleths of these artificial barriers may be compared with those obtained by Nægeli<sup>5</sup> for a gap in a hedge. As might be expected, the shelter gradient becomes much greater near the gap and presumably the narrower the gap in the barrier, the greater will be this gradient. Also, the shelter near a gap does not extend so far beyond the “ends” of the hedge as with the single end of the artificial barriers described. The general run of the isopleths is otherwise similar.

## Appendix

### Wind-tunnel experiments

These experiments were originally devised to obtain, by means of a wind-break, a sufficiently extensive area of shelter without severe speed gradients (that is, variations of wind speed with distance) or eddying conditions in the boundary zone. A solid screen was known to cause a very disturbed eddy and to give only a relatively small extent of protected area. The experiments<sup>6</sup> in 1936 were therefore directed towards the development of a perforated barrier.



In the Manby (full-scale) experiments, flat slats were used instead of the gauze of the model tests. As the drag on flat plates is greater, this was compensated for by using a smaller wind-break density in the full-scale experiments. In spite of this, the full-scale experiments did not produce proportionally so large a sheltered area as the models.

Further model experiments<sup>7</sup> were carried out in 1938, using copper ribbon soldered to steel brackets and arranged to give the same density as in the full-scale experiments. The sheltered area was considerably less than in the earlier model tests but again greater than on the full scale. The differences between the two sets of wind-tunnel experiments were attributed to differences in screen design and to tunnel-boundary effects. The differences between the 1938 model tests and the full-scale experiments increased with distance from the barrier, and were accounted for partly by the constriction of the main stream by the tunnel walls and partly by the different methods of wind-speed measurement. On the full scale, the mean absolute speed regardless of direction was measured by a cup anemometer. In the model tests the air speed recorded by the pitot-static tube in approximately the mean wind direction would be lower than that shown by a cup anemometer in regions where frequent changes in wind direction occurred.

Concerning the effects of scale and aspect ratio, the available evidence<sup>8</sup> on the drag of plates of infinite aspect ratio shows no scale effect above a Reynolds number (based on width normal to wind) of about 4,000. Below this value the drag coefficient decreases to a minimum of 85 per cent. of its steady value with a Reynolds number of 1,500. The Reynolds number of the individual strip in the model tests was about 3,000 at full stream velocity. No evidence was known as to the scale effect on the dimensions of the wake of a flat plate or lattice girder, but it was assumed, on the basis of drag measurements<sup>8</sup>, that the scale effect would be small and would not account for a larger sheltered area at the lower Reynolds number.

To examine end effects in the tunnel, it was found necessary and acceptable to use a much smaller aspect ratio of 11·9.

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## EXAMPLE OF A DOUBLE WARM FRONTAL STRUCTURE OVER NORTH-WEST EUROPE

By W. J. BRUCE

In general forecasters are less ready to accept a double structure of warm fronts than of cold fronts, though it is thought that this is a measure of the difficulty of recognition rather than of frequency of occurrence. Matthewman<sup>1</sup> found that from 55 frontal cross-sections, 12 occasions of double structure were possible, whilst Chappaz<sup>2</sup> gave an interesting example of a double warm front observed from an aircraft over the Lake Constance area. However, in this latter paper it was considered that the double warm front was probably a result of the local topography, the high ground in the region having held back the surface front. It is considered worth while to add to these records some evidence for the existence of a double warm front over north-west Europe on September 3, 1952.

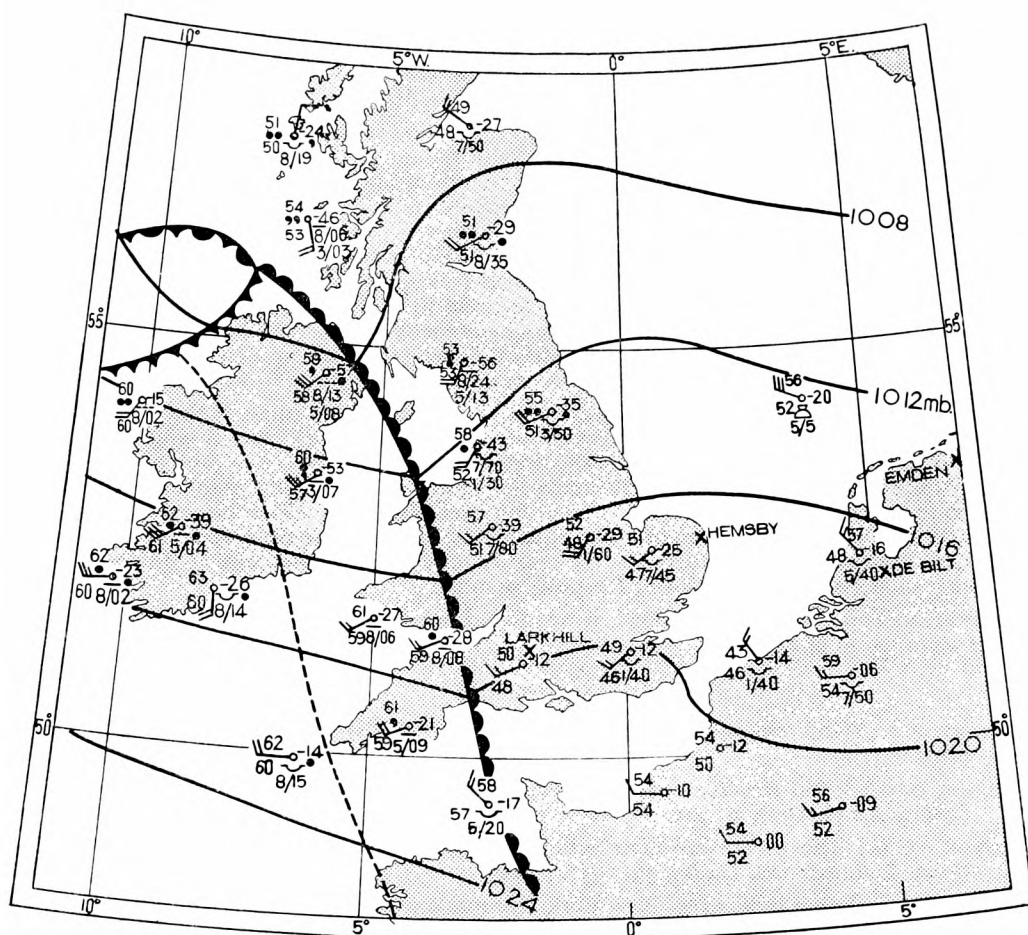


FIG. 1—SYNOPTIC CHART, 0300 G.M.T., SEPTEMBER 3, 1952

**Synoptic situation.**—Figs. 1 and 2 show the synoptic situation at 0300 and 1500 G.M.T. on September 3, 1952. A secondary depression moved eastwards in a strong thermal gradient and deepened somewhat. The rain area extended, and was more intense over Germany than in the same latitudes in England. The following gives some evidence for the existence of a second warm front intersecting the earth's surface at approximately the position of the pecked lines, though the surface front was not readily recognizable on the charts until 1500 G.M.T.

**Weather.**—The weather experienced at Wahn during the afternoon (see Table I) was consistent with the existence of a double warm front. Light to moderate rainfall occurred during the afternoon ceasing about 1600. The upper cloud then broke and became thinner whilst the low cloud tended to disperse temporarily. Later there was a general thickening and increase of cloud followed by moderate rainfall. The rain stopped at about 1900 which was approximately the time at which the second warm front should have passed the area. Subsequently there were typical warm-sector conditions with occasional light rain or drizzle. More detailed synoptic charts for 1500 G.M.T. covering northern Germany and the Low Countries showed two separate well defined belts of heavier rainfall, these belts being partially recognizable in Fig. 2.

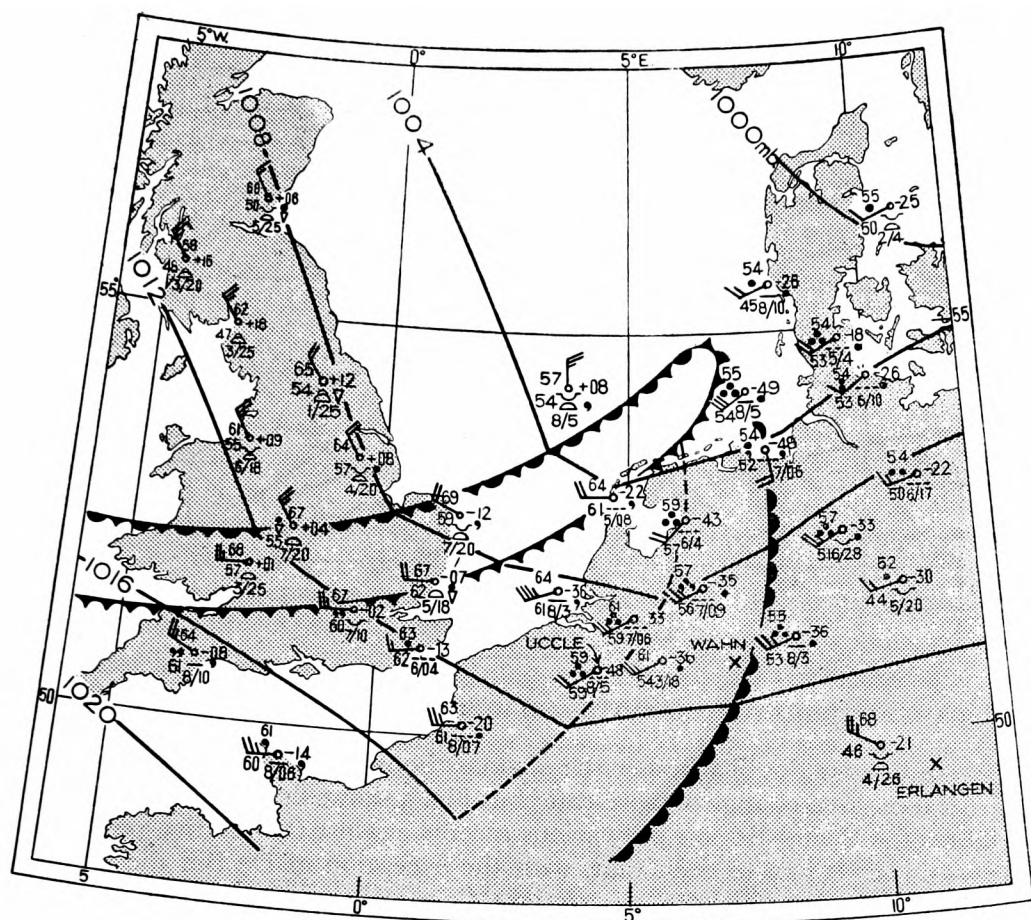


FIG. 2—SYNOPTIC CHART, 1500 G.M.T., SEPTEMBER 3, 1952

TABLE I—HOURLY WEATHER TAKEN FROM THE OBSERVATION BOOK  
AT WAHN, SEPTEMBER 3, 1952

G.M.T.	Dew point	Weather	Tendency	Surface wind	Cloud
°F.			mb.	° kt.	
1400	51	c	-3.1	250 9	8 oktas As at 8,000 ft., 5 oktas Sc at 2,000 ft.
1500	52	cr <sub>0</sub> r <sub>0</sub>	-3.0	250 7	8 oktas As at 8,000 ft., 5 oktas Sc at 2,000 ft.
1600	52	c/r	-3.0	270 9	7 oktas As at 9,000 ft., 4 oktas Sc at 2,600 ft.
<i>First warm front</i>					
1700	55	cir <sub>0</sub>	-2.6	250 11	7 oktas Sc at 2,000 ft., 1 okta St at 1,800 ft.
1800	56	crr	-2.6	250 8	8 oktas St at 900 ft.
1900	57	cir <sub>0</sub>	-1.7	250 7	8 oktas St at 1,500 ft.
<i>Second warm front</i>					
2000	59	c/r	-0.8	270 9	8 oktas Sc at 2,500 ft., 5 oktas Sc at 1,300 ft.
2100	59	c	-0.5	270 8	7 oktas Sc at 2,000 ft.
2200	59	cir <sub>0</sub>	-0.6	270 7	8 oktas Sc at 2,000 ft., 5 oktas St at 1,500 ft.
2300	60	cir <sub>0</sub>	-0.9	250 13	8 oktas Sc at 2,000 ft., 5 oktas St at 1,400 ft.
<i>Cold front or cold occlusion</i>					
2400	55	c/r	-0.9	310 3	5 oktas Sc at 2,000 ft.

**Upper air ascents.**—Figs. 3 and 4 show the 0200 G.M.T. tephigrams for Larkhill, Hemsby, De Bilt and Emden, these stations lying approximately on a straight line normal to the warm front. The boundaries of both warm and cold air are shown in these diagrams at AA' and BB'.

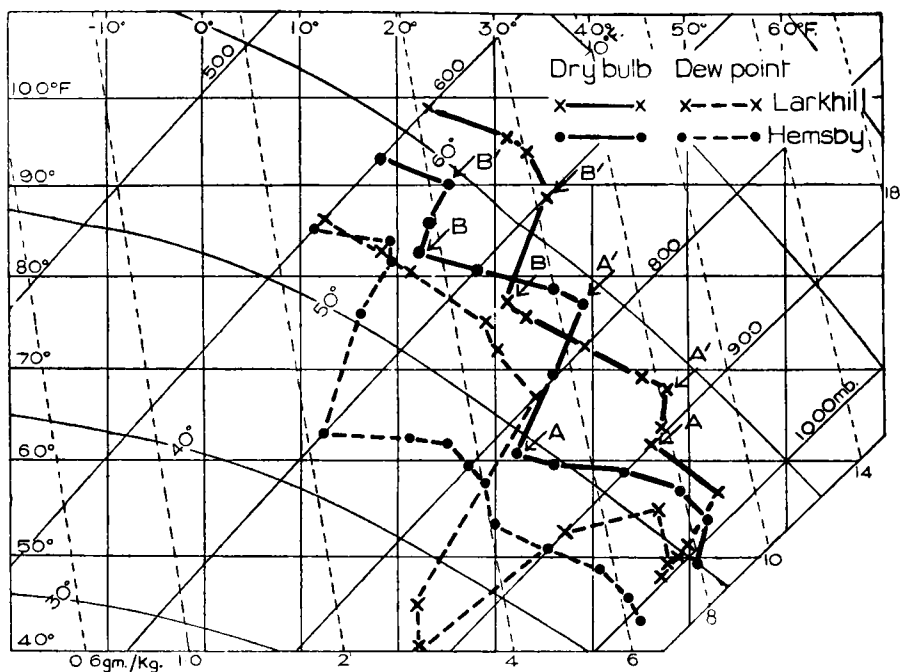


FIG. 3—TEPHIGRAMS FOR LARKHILL AND HEMSBY 0200 G.M.T., SEPTEMBER 3, 1952

There is some doubt whether the air-mass boundaries occur precisely where there is a marked change of lapse-rate<sup>3</sup> but Fig. 5 shows the result of plotting the heights of AA' and BB' on the various ascents against the relative positions of the stations. It can be seen that, with the exception of De Bilt the points so obtained lay approximately on straight lines, these being indicated by the pecked lines on the diagram. The poor fit of De Bilt may be explained by this station being almost 100 miles out of line to the south. It can be seen that the

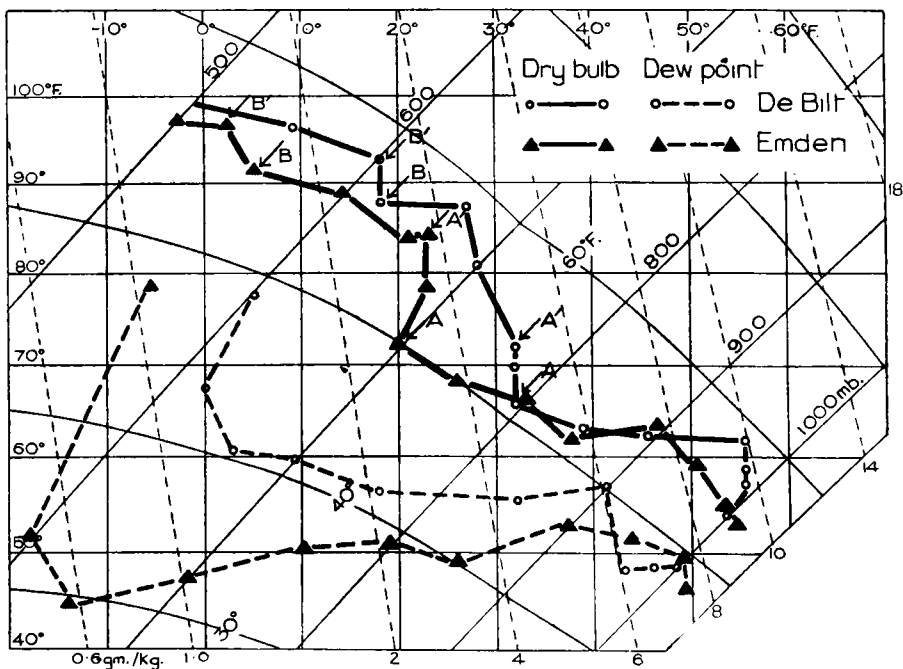


FIG. 4—TEPHIGRAMS FOR EMDEN AND DE BILT 0200 G.M.T., SEPTEMBER 3, 1952

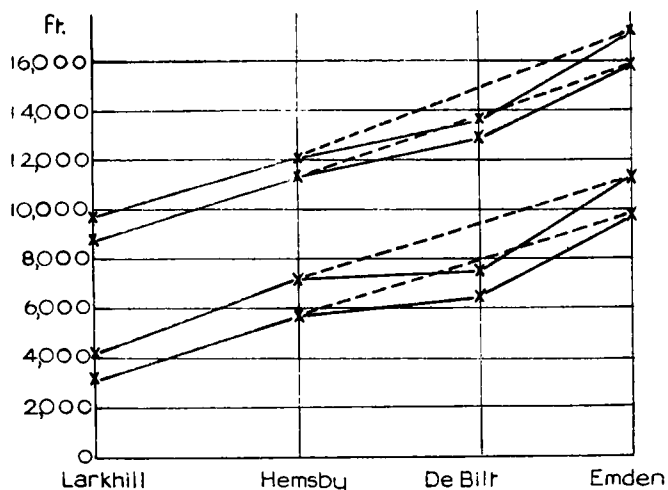


FIG. 5—HEIGHTS OF BASES AND TOPS OF INVERSIONS SHOWN ON TEPHIGRAMS

mixing zones were remarkably constant in depth on all the ascents. The slopes of the frontal surfaces were calculated to be 1 : 120 to 1 : 180.

In order to discount the possibility that one of the changes of lapse-rate might be due to subsidence, Table II shows the wet-bulb potential temperature taken from the various ascents on the day in question. The figures show that there were more than two air masses involved, the boundaries being indicated by dotted lines.

TABLE II—WET-BULB POTENTIAL-TEMPERATURE DISCONTINUITIES

Larkhill 0200		Hemsby 0200		De Bilt 0200		Uccle 0800		Erlangen 1400	
Pres- sure	Wet-bulb potential tempera- ture	Pres- sure	Wet-bulb potential tempera- ture	Pres- sure	Wet-bulb potential tempera- ture	Pres- sure	Wet-bulb potential tempera- ture	Pres- sure	Wet-bulb potential tempera- ture
mb.	°F.	mb.	°F.	mb.	°F.	mb.	°F.	mb.	°F.
500	58	500	57	500	54			500	60
550	57½	550	56					550	59
600	58	600	56½	605	53½	610	57		
650	58	640	54	620	52	650	57	630	57½
670	58					675	56	700	57
700	58	670	54½	670	49				
730	55	700	51	700	50	720	55	720	57
750	55	750	52½	760	48	770	54	770	55
800	54½	800	50½	795	51	820	50½	780	54
850	47½	820	47	850	49½	850	50½	850	57
870	47	850	47						
900	49	900	48	920	51				
910	49½								
950	52½	950	49½						
980	52	980	49	985	52				

As regards later ascents, the only relevant one at 0800 G.M.T. was that of Uccle (Fig. 6). The positions of the mixing zones were found to be consistent with the probable positions of the warm fronts and the slope of the frontal surface agreed with that found on the 0200 G.M.T. ascents. By 1400 G.M.T. the

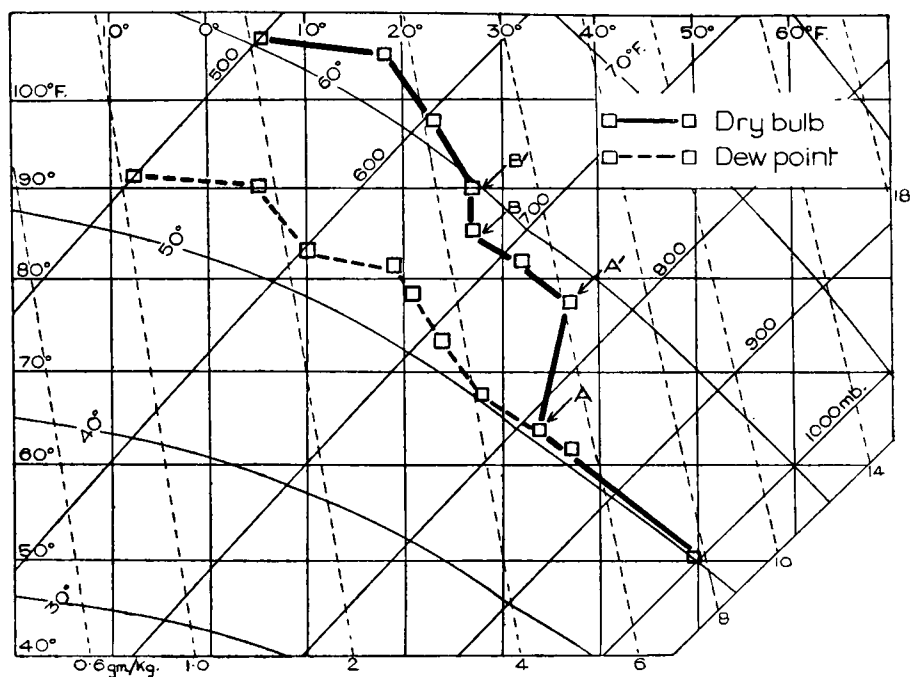


FIG. 6—TEPHIGRAM FOR UCCLE, 0800 G.M.T., SEPTEMBER 3, 1952

Erlangen ascent (Fig. 7) was showing both mixing zones at heights in reasonable agreement with the positions of the warm fronts on the surface chart.

**Conclusion.**—It appears probable that there were two warm fronts involved in the situation on September 3, 1952, the second one becoming more active and more readily recognizable at the surface as time progressed. The early recognition of such double structures through upper air ascents might be of some importance in the framing of accurate short-range forecasts for some localities.

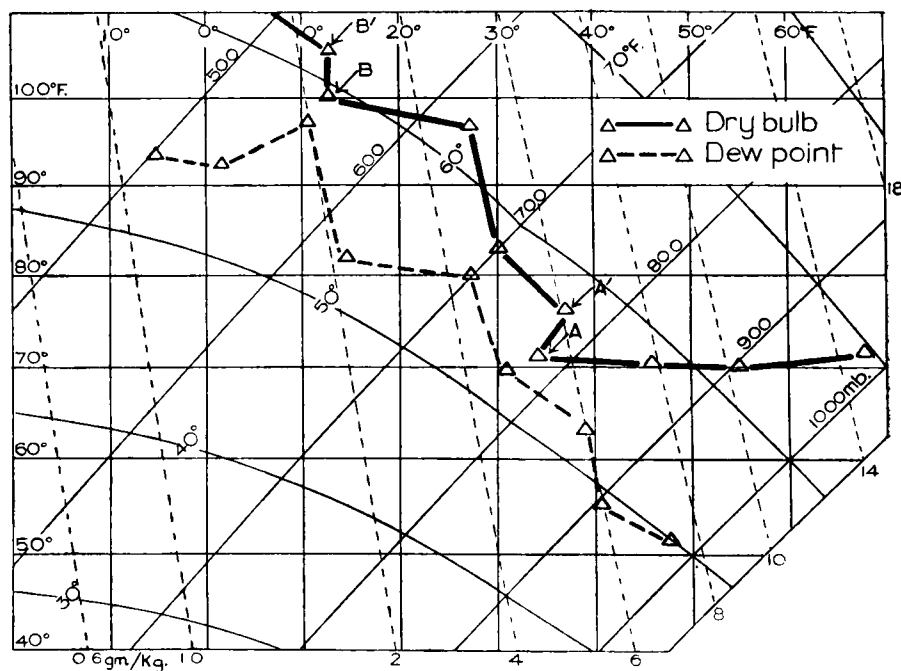


FIG. 7—TEPHIGRAM FOR ERLANGEN, 1400 G.M.T., SEPTEMBER 3, 1952

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## OFFICIAL PUBLICATION

The following publication has recently been issued:—

### PROFESSIONAL NOTES

*No. 113—Depressions crossing Labrador and the St. Lawrence Basin.* By A. G. Forsdyke, Ph.D.

Depressions which traverse the eastern part of North America may be divided into two main classes according to their subsequent behaviour; they may either move out into the Atlantic or become slow moving somewhere to the west of Greenland. The relation between the behaviour of these depressions and the synoptic situation over western Europe is examined with a view to its possible use in extended forecasting for the British Isles. The corresponding hemispherical 500-mb. contour patterns are studied but they appear to afford little indication of the subsequent surface developments.

The development and movement of individual depressions is examined in relation to the 1000–500-mb. thickness pattern, but no simple connexion which would be useful in forecasting is found.

## ROYAL METEOROLOGICAL SOCIETY

### Symons Memorial Lecture

The 1955 Symons Memorial Lecture was delivered in the Royal Meteorological Society's rooms by Prof. A. C. B. Lovell, Director of the Jodrell Bank Experimental Station, University of Manchester, on April 27, 1955. The title of the lecture was "Radio astronomy and the fringe of the atmosphere". This was the first time for many years that the outer atmosphere had been the topic of one of these lectures, and the hope was expressed that this would lead to more attention being paid to the outer layers by meteorologists in this country.

The ignorance of the subject on the part of many of those present was matched by the very small amount of observational knowledge of atmospheric flow at very great heights so far available. By intricate processes of deduction, however, the Jodrell Bank workers, and others, have now obtained an interesting collection of self-consistent evidence on air movements at very great heights which require interpretation.

Prof. Lovell's lucid account was largely taken up with various techniques evolved by the radio astronomers, such as measuring the drift of meteorites and interstellar dust within the earth's atmosphere, to deduce the motion of the atmosphere at the 80–100-Km. level and around 300 Km. The winds at 300 Km. over England included speeds of 100–200 m./sec. and twice daily reversals of direction. Other observing techniques yielded information about pressure and air density at various heights, which were in very fair agreement with the V2 rocket observations over Nevada.

Many present must have been groping for a connexion between this realm of radio-astronomical exploration and the layers to which our attention as meteorologists has been usually confined. Bowen's proposed association between meteor showers and rainfall 30 days later in Australia came in for mention. Unfortunately the proposed rainfall responses to the Bielid and Giacobinid showers also occur in epochs when these meteor groups are, or were, far from the earth and undetectable by astronomical observation. Perhaps the lesson here is twofold: first that calendar-bound weather singularities may have more elusive origins within the system earth-atmosphere; secondly that any linkages between the circulations in the inner and outer atmospheric layers may be altogether more subtle and perhaps limited to occasional trigger effects.

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The meeting of the Society held on June 15, 1955, with Prof. P. A. Sheppard, Vice-President, in the Chair, opened with the election of Dr. R. C. Sutcliffe as President for the next session and the election of the other members of the new Council.

The technical part of the meeting was a joint discussion with the Challenger Society on "Wind and waves". The papers read were mainly concerned with the interaction between the wind and the sea.

*Longuet-Higgins, M. S.—On the statistical distribution of the heights of sea waves\**

The author began by reviewing several simple ways in which wave heights could be defined, such as the mean height of all waves, the mean height of the highest one-third waves, etc., and explaining the relation between them after pointing out how difficult it is to describe the state of the sea because the heights of waves vary so greatly. From a consideration of all the wave-generating areas off a coast, each of which contributes to the wave height at a point, he deduced that the probability-distribution of such a sum of contributions resembled the "random-walk" distribution found by Rayleigh, and thence arrived at a theoretical frequency distribution of the maximum wave height and the highest 30 per cent. of the waves. In conclusion the author showed that comparisons of the ratios of the mean values of these quantities to the mean height of all the waves as derived from the theory given in this paper, gave satisfactory agreement with the values found for these quantities in practice by Munk, Putz and other workers.

*Darlington, C. R.—The distribution of wave heights and periods in ocean waves†*

In this paper, which was also presented by Mr. Longuet-Higgins, the first experimental records of waves in the deep ocean have been analysed. These records were obtained from a new wave recorder, due to Tucker, which has been installed in a British ocean weather ship. The profiles of the waves are recorded automatically by this instrument, which eliminates the effect of the ship's own vertical motion and responds to waves of all periods between 5 and 25 sec. The results show a close agreement with the theoretically deduced results of Longuet-Higgins, just described.

Mr. D. E. Cartwright was next asked to present some work of his extending that of Longuet-Higgins. Assuming a frequency distribution for the height of sea waves the same as that found by Rice in a mathematical investigation in acoustic theory, and using a rather different measure for wave height, he found a method of correlating mean wave-crest height above mean sea level with the statistical properties of the wave sample used.

*Hay, J. S.—Air flow over the sea‡*

Mr. Hay measured wind velocity profiles from a large platform moored about 800 m. east of a coastline of the United Kingdom, by using sensitive electric contact anemometers at heights of 0.5, 1, 2, 4 and 8 m. above the windward edge of the platform. He found that the flow was aerodynamically rough at all mean wind speeds ranging from 5 to 10 m./sec. used in his experiments. The profiles showed a wind increasing with the logarithm of the height above the sea and from them the stresses were inferred. He also concluded from the scanty data available that in inversion conditions the variation of wind speed with height departed from the logarithmic a few metres above the surface. Gustiness measurements were made but were considered to have been affected by the presence of the coastline and cliff 60–90 m. high on the up-wind shore.

In his invited contribution Dr. H. U. Roll (Hamburg) discussed Mr. Hay's values of the shear-stress coefficient and drew attention to the similar results of other workers some of which showed a minimum value of the shear-stress coefficient with a wind speed between 4 and 6 m./sec. He considered this result was real, and that a search should be made for a physical cause. Wave steepness might well be an important factor. Dr. Roll then described work he had carried out on the relation between wind speed at various heights and air-sea temperature difference.

Dr. H. Arakawa, who was also invited to contribute, then gave an interesting account of his investigations into interference between complicated wave patterns at sea. As examples he cited tidal waves on the inland Sea of Japan, and an occasion when pyramidal waves seriously damaged the Japanese fleet while a fast-moving typhoon passed through the area where it was carrying out manoeuvres. Finally, Mr. Darbyshire presented some wind-stress measurements made on Lough Neagh in conditions of low-level stability and instability. The level of the water surface was measured by water-level gauges at four stations located in representative positions and winds taken from an anemometer at Aldergrove. A surprising result found from this work was that the stress coefficient increased with the fetch or distance down wind under all conditions.

In the discussion which followed Mr. Gold wanted more information about the shape of the nearby coast and its influence on the wind profiles described by Mr. Hay. He also found the small value of the roughness parameter rather surprising and wanted to hear more from Dr. Roll about the relation between the Beaufort scale and wind near the sea surface. Dr. Roll said his measurements of Beaufort force were made by anemometer at the top of the ship's mast. Finally, Mr. Francis thought Mr. Hay's values of the stress coefficient were on the high side, and that a possible reason for this might be the formation of "standing waves" in the sea by reflection from the sides of the floating platform.

\**J. Mar. Res., New Haven Conn.*, **11**, 1952, p. 245.

†*Quart. J. R. met. Soc., London*, **86**, 1954, p. 619.

‡*Quart. J. R. met. Soc., London*, **81**, 1955, p. 307.



## LETTER TO THE EDITOR

### Glazed frost

The occurrence of glazed frost is quite an uncommon phenomenon anywhere in this country and yet I have had the opportunity of witnessing it on four occasions in three successive years—three times at my station at Habergham Eaves near Burnley, and once in Burnley,  $1\frac{1}{2}$  miles away. The occurrences were all in January: January 5, 1953, January 6 and 8, 1954, and January 15, 1955.

On January 5, 1953, there was snow in the morning, freezing rain in the afternoon, and dense fog at night. When the rain was falling in the afternoon, the temperature was about  $29^{\circ}\text{F}$ . All objects exposed to the wind and rain were coated with layers of ice, and on the steep Manchester Road in Burnley a long line of vehicles could not move owing to the glassy surface.

Thick fog occurred on January 6, 1954 at 0900 G.M.T., and at 0930 it began to rain with the temperature at  $32^{\circ}\text{F}$ . Everything was instantly coated with ice, but the rain gradually turned into snow later in the morning as it became colder, with a cold N. wind blowing at night. I was astonished to find only two days later, glazed frost occurring again, but this time only in Burnley. It came just before noon, when the temperature was  $31^{\circ}\text{F}$ ., and motorists complained of their windscreens being completely “iced up”. There was keen frost in the early morning but it became milder during the day.

On January 15, this year, there had been steady snow falling during the afternoon with an easterly wind blowing, but later on at 1600 G.M.T. it turned to drizzle and rain with the temperature at  $30^{\circ}\text{F}$ . These conditions persisted for about two hours, and in that period everything exposed to the rain was covered with ice. It was peculiar to hear the “swish-swish” of the rain and drizzle as it made contact with objects. Branches of trees were bending under the heavy weight of accumulated ice, and the whole sides of houses were like sheets of glass. As sub-freezing temperatures prevailed for a time after this, the ice on trees, houses and telephone wires persisted for five days.

The latter glazed frost was most probably due to supercooled rain falling from the warmer moist air of the depression which was passing over southern England at the time, overriding the colder surface air that had prevailed for a fortnight.

I do not know if glazed frosts occurred anywhere else on the given dates, but it does seem noteworthy that this district should be particularly subject to this supposedly “uncommon” phenomenon on so many occasions in such a short time!

R. MICHAEL SMITH

*87 Glen View Road, Habergham Eaves, near Burnley, Lancashire. April 23, 1955*

### REVIEWS

*Further outlook.* By F. H. Ludlam and R. S. Scorer.  $8\frac{3}{4}$  in.  $\times$   $5\frac{1}{2}$  in., pp. 174, *Illus.*, Allan Wingate (Publishers) Ltd, London, 1954. Price: 15s. 6d.

The term “further outlook” has been absorbed in the vocabulary of the weather forecaster, and in its more general meaning is tending to disappear from common usage. In choosing a title for their book, Mr. Ludlam and Dr. Scorer have disregarded any restriction, for among the interesting aspects of meteorology they deal with, the subject of forecasting occupies less than a quarter of

their pages. They apparently set out to write about what interests them most, for many meteorologists in this country could identify the authors from the contents of this book. The picture on the jacket is appropriate; it depicts a stratospheric glider of the future above mother-of-pearl clouds over Norway. The pilot, one feels sure, is a somewhat older Dr. Scorer checking that the air goes up and down in the right places while, in the passenger's seat behind him, Mr. Ludlam engages in a little surreptitious cloud seeding.

The first two chapters are a rather ordinary account of necessary fundamentals such as sequences of observed weather, the formation of the main cloud types, and permanent and transient circulations. If these pages were written with enthusiasm it is not imparted to the reader. Indeed he is likely to be discouraged by the inadequacy of the explanations. He is repeatedly told, for example, that cloud forms by the cooling of rising air, but the process must remain obscure to him.

The writers warm to their task in Chapter III where atmospheric turbulence is introduced in homely and effective language. Beginning with a chimney emitting smoke with "lumps all over its outside", this chapter develops a stimulating picture of eddies up to the scale of those constituting the general circulation. The reader may be left in some doubt as to what he has learnt, for the treatment is free and discursive, but he should have no difficulty in keeping in step with the writer. The next chapter, "Exploiting the atmosphere", deals with thermals and the pastime of soaring, with fascinating examples from the behaviour of locusts, which we are told fly "for the fun of it" and gravitate to regions where thermals produce the surface moisture needed to maintain life; and we learn of the habits of the vulture and the albatross.

Chapter V brings us back to earth with eight pages allotted—somewhat grudgingly, one feels—to "The art of forecasting", and a dismal art it appears, consisting largely of extrapolation based on the experience of years and guided by "some scientific knowledge". On the dictionary definition of art as "the practical application of any science" we cannot cavil at this title, but it is quite another thing to accept that there is such a chasm between the science of meteorology and the practice of forecasting. This chapter is in contrast to the next, on "The science of forecasting", which presents a somewhat optimistic picture of the machine age of forecasting. While rightly giving prominence to the greatest forecasting development of today, the writers recognize that the machine cannot replace the forecaster but will result in still greater demands being made on his skill. Greater emphasis might indeed have been given to the inability of a machine to handle any problem which cannot be solved by a meteorologist with unlimited time and labour at his disposal.

The pages on "Weather control" are bound to appeal to the general reader because human interference with the course of nature provides the most impressive demonstration that nature's secrets have been revealed. The authors are to be commended, however, on concluding with a strong reminder that the effects of cloud seeding are difficult to establish with certainty, particularly in a country where this activity is commercialized and unco-ordinated. The final chapter, "Uncertainties", is written in a philosophical vein, and discusses the pitfalls in assessing the significance of observations or the degree of success attained in forecasts. It constitutes an unusual and interesting addition to a book on meteorology.

C. J. BOYDEN

*Plant climate and irrigation.* Edited by S. A. Searle. 8½ in. × 5½ in., pp. xii + 155, *Illus.*, Chichester Press Ltd., Chichester, 1954. Price: 20s. od.

This book consists of a series of articles by four contributors on plant climate, the term plant climate being used in its broadest sense to cover the climate from the lower limit of the root zone to the top of the vegetation and thus including the soil. Its aim is essentially practical, to provide growers with sufficient background knowledge to enable them to modify the plant climate to their own advantage by controlling the temperature, light and water supply of the plants. It does, incidentally, provide a great deal of interesting information to meteorologists.

Mr. Searle has contributed the first two chapters on "Plant climate" and "Environmental factors in the glasshouse". The second chapter gives a generally sound account of a difficult subject, but there is one statement which will cause surprise to climatologists; on p. 14 it is stated that tomato plants need a difference of 10°F. between day and night temperatures during the early stages of growth, and that the range between average day and night temperatures in the British Isles is less than half this value in the winter months. This statement arises from the faulty interpretation of hourly means of temperature which have apparently been used to give the range. This chapter ends with a most clear and concise account of photoperiodism. Chapter III by F. R. Frampton has the rather surprising title "Growing in a microclimate" and is an essentially practical account of a system of heat distribution in glasshouses. Chapter IV by Eastwell and Searle deals with the measurement of soil moisture and concludes that above  $pF$  2.8 (a moisture tension of about 50 cm. of mercury) soil moisture is best measured by electrical methods, and below  $pF$  2.8 by a tensiometer. The following chapter gives a summary of the "balance-sheet" method of calculating the water needs of a crop.

Chapter VI is by P. J. Salter and is entitled "The effects of different water régimes on the growth and yield of tomatoes". It occupies almost half the book and is part of a thesis. It is an account of a valuable piece of horticultural research but, to the reviewer's mind, it is quite out of place in this publication. Naturally, the chapter deals with such topics as experimental details and significance of results which can hardly interest most growers. A short summary of the work could have been more valuable and would have resulted in a more balanced publication. The last chapter by Mr. Searle reverts to practice, particularly in relation to the tomato crop.

The appendices include a short account of Penman's work on the physics of irrigation control and some useful conversion tables. The book is well documented and illustrated and has good author and subject indexes.

W. H. HOGG

### METEOROLOGICAL OFFICE NEWS

**Retirement.**—Mr. R. P. Batty, O.B.E., Senior Principal Scientific Officer, retired on June 27, 1955. After serving in the Royal Welch Fusiliers from 1915 to 1918 he was commissioned in the Meteorological Section, Royal Engineers. He joined the Office on demobilization in November 1919 and served at West Lavington, Calshot and Larkhill. In 1925 he was seconded for duty with the Royal Air Force in India. He returned to the Office in 1931 and after a short period at Headquarters in the Aviation Services Division he was posted to Iraq.

On his return in 1934 he served for two years at Cranwell. In 1936 Mr. Batty was posted to Heliopolis and during the Second World War 1939-45 was Chief Meteorological Officer at the Royal Air Force Headquarters in Cairo. On his return from the Middle East in 1946 he was appointed Head of the R.A.F. Overseas Branch and from 1948 until his retirement he was Assistant Director (Military Services). Mr. Batty was "Mentioned in Despatches" in 1943 and was awarded the O.B.E. in 1950.

At a ceremony in the Conference Room in Victory House on June 30 Dr. A. C. Best presented Mr. Batty with a cheque subscribed by his colleagues. In expressing his thanks Mr. Batty recounted some interesting recollections of his experiences in the Office and events with which he had been associated.

Mr. Batty has accepted a temporary appointment in the Meteorological Office.

**Sports activities.**—The Air Ministry Annual Sports were held at the White City Stadium on June 29 and marked the end of the year for the competition for the Bishop Shield. The Meteorological Office retained the Shield for the seventh successive year. The Office also won the W. S. Jones Memorial Cup for the aggregate of points gained on Sports Day and the Halahan Shield for the Tug of War. The Office won both the Men's and Ladies' Relay Championships and several other events. The Ladies' Relay team by finishing in 55·6 sec. broke the record for the event which had stood since 1939 and Mr. B. L. Woolcott with 5 ft. 6 in. broke the record for the High Jump in addition to winning the Quarter Mile Championship.

The Meteorological Office Centenary Sports Meeting was held on Wednesday, June 22, at the Headstone Manor Ground. The weather was appropriately ideal and several hundreds of present and past members of the staff including many from the Headquarters branches of the Office at Harrow, London and Dunstable were able to spend a most enjoyable afternoon. Among many former members of the staff who attended were Sir George Simpson, Mr. Gold and Mr. Lempfert, accompanied by Lady Simpson, Mrs. Gold and Miss Lempfert. There was a large programme of track and field events and a number of less serious items were also included. Some of the better performances, which were attained on a loose track, were:—

Mr. K. Garrard won the two miles in 10 min. 11·5 sec.

Mr. B. L. Woolcott won the 440 yards in 55·1 sec.

Mr. M. Bibb won the 100 yards in 11·0 sec.

Miss K. Newman won the ladies' 100 yards in 12·8 sec.

In the field events Mr. G. L. Whitworth jumped 19 ft. 2 in., a new record for the Sports organized by the Harrow Social and Sports Committee, and Mr. Woolcott won the high jump at 5 ft. 4 in. Lady Sutton presented the prizes, though unfortunately owing to illness Sir Graham Sutton himself was unable to be present. After the prize-giving the Chairman of the Meteorological Office Social and Sports Committee, Mr. N. H. Smith, thanked Lady Sutton, and, on behalf of the spectators, asked her to convey to Sir Graham the sincere wishes of all present for his speedy recovery to health. A considerable number of those present then moved on to a Social Gathering which was held at Kodak Hall by kind permission of the Factory Manager. Refreshments were available as well as facilities for dancing for those who wished, and a pleasant evening came to an end all too quickly.

## WEATHER OF JUNE 1955

The weather was marked by below-normal pressure near Novaya Zemlya and the White Sea, thence in a zone across Siberia east-south-east to the Okhotsk Sea, and from there in another zone stretching north-east to the maximum anomaly of  $-5$  to  $-6$  mb. over extreme north-west Canada. This whole zone of lowered pressure was followed by travelling depressions. The disturbances continued south-east to southern Quebec and later combined with Atlantic depressions to give another region of pressure 5 mb. below normal in  $50-55^{\circ}\text{N.}$  over the eastern Atlantic. The depressional activity was farther north than usual over Alaska and north-west Canada and was displaced south-eastwards over the eastern Atlantic (lowest monthly mean pressure 1008 mb. near  $55^{\circ}\text{N. } 30^{\circ}\text{W.}$ ). The polar anticyclone was rather weaker than usual but displaced towards the Atlantic sector (centre 1019 mb. over north-west Greenland). Pressure was a little above normal over most of Europe.

Temperature was generally a little below normal over Europe, except over France, Spain and the Balkans. Most of the United States was also rather cool, but Canada was generally warmer than usual, culminating in an anomaly of  $+6^{\circ}\text{C.}$  over northern Alberta.

Precipitation was above normal over north Spain, France, Germany, the Alps, England and Ireland, also in north Norway and along the Atlas Mountains. Stations round the Bay of Biscay, also in Alaska and in parts of the southern Rockies had over double the normal June rainfall.

In the British Isles a south-easterly type of weather prevailed during the first week, but on the 7th a colder air stream swept southward from the Greenland region and northerly winds were maintained over the country until the 10th. A period of milder south-westerlies followed as depressions moved eastward from the Atlantic, until an anticyclone became established over the North Sea from the 16th to the 19th, with a renewal over England of mainly south-easterly winds. During the remainder of the month the weather was of a generally westerly type.

The fine weather experienced at the end of May continued during the first two days of the month. On the 3rd, a secondary to the main Atlantic depression formed in the Bay of Biscay and moved northward, giving widespread and in places heavy rain, particularly in the west country, where nearly  $2\frac{1}{2}$  in. of rain fell at Abergavenny, Monmouthshire in 24 hr.; there were frequent thunderstorms the following day as the depression passed over Ireland. Thunderstorms and outbreaks of heavy rain also occurred on the 6th, 7th and 8th, especially in the southern half of England. The 6th was the warmest day of the year at many places so far; London Airport and Holyhead both recorded  $76^{\circ}\text{F.}$  The next day an anticyclone near Greenland increased in intensity; troughs in the north became retrograde, and were brought south again over the country by the cold north-easterly air stream flowing round the east side of the anticyclone; widespread rain accompanied their passage. Maximum temperatures at many places in the north were  $20^{\circ}\text{F.}$  below the previous day's highest temperatures. During the early hours of the 10th temperature at Kew Observatory fell to  $40\cdot2^{\circ}\text{F.}$ , the lowest screen temperature recorded there in June for 32 yr. The cold weather was short-lived, however, for the following evening a depression from the Atlantic moved eastward across northern England, giving nearly 1 in. of rain in many places and fairly widespread thunderstorms in eastern England. As pressure rose behind the depression an anticyclone developed over northern France, and the resulting circulation brought subtropical air from near the coast of Spain to our south-western districts with considerable drizzle, low cloud and sea fog. The high pressure over Greenland joined with that over France and settled as an anticyclone over the North Sea from the 16th to the 19th. During this period the weather was cool near the east coast and mainly dry, but there were thundery outbreaks in Cornwall on the 18th, and on the following day weak low-pressure systems moving north from France brought some rain to most of England and Wales, but thereafter a westerly type of weather set in, and persisted for the rest of the month. Weather was fairly dry and sunny over most of the country, but rain was more prolonged in the west and north, notably on the 23rd when nearly 1 in. of rain in 12 hr. was recorded at Benbecula in the Hebrides. More than twice the average amount of rain for the month was recorded over most of south and central Wales, the south-west Midlands and Exmoor; the duration of sunshine at several places was the lowest on record for June.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	$^{\circ}\text{F.}$	$^{\circ}\text{F.}$	$^{\circ}\text{F.}$	%		%
England and Wales ...	79	24	$-1\cdot1$	143	+1	81
Scotland ...	76	22	$-0\cdot3$	87	-2	103
Northern Ireland ...	70	33	$-1\cdot0$	154	+4	63

# RAINFALL OF JUNE 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	2·29	113	<i>Glam.</i>	Cardiff, Penylan ...	4·19	167
<i>Kent</i>	Dover ...	1·51	79	<i>Pemb.</i>	Tenby ...	4·64	193
<i>„</i>	Edenbridge, Falconhurst	2·43	110	<i>Radnor</i>	Tyrmynydd ...	6·89	211
<i>Sussex</i>	Compton, Compton Ho.	3·09	124	<i>Mont.</i>	Lake Vyrnwy ...	5·77	179
<i>„</i>	Worthing, Beach Ho. Pk.	2·33	133	<i>Mer.</i>	Blaenau Festiniog ...	12·81	197
<i>Hants.</i>	St. Catherine's L'thouse	3·22	181	<i>„</i>	Aberdovey ...	5·66	208
<i>„</i>	Southampton (East Pk.)	2·73	136	<i>Carn.</i>	Llandudno ...	3·21	169
<i>„</i>	South Farnborough ...	2·74	142	<i>Angl.</i>	Llanerchymedd ...	4·59	194
<i>Herts.</i>	Harpenden, Rothamsted	2·00	89	<i>I. Man</i>	Douglas, Borough Cem.	4·80	198
<i>Bucks.</i>	Slough, Upton ...	2·20	107	<i>Wigtown</i>	Newton Stewart ...	3·69	140
<i>Oxford</i>	Oxford, Radcliffe ...	4·22	188	<i>Dumf.</i>	Dumfries, Crichton R.I.	2·57	102
<i>N'hants.</i>	Wellingboro' Swanspool	2·15	102	<i>„</i>	Eskdalemuir Obsy. ...	3·07	97
<i>Essex</i>	Southend, W. W. ...	1·84	99	<i>Roxb.</i>	Crailing ...	0·89	40
<i>Suffolk</i>	Felixstowe ...	1·93	113	<i>Peebles</i>	Stobo Castle ...	1·42	61
<i>„</i>	Lowestoft Sec. School ...	2·08	115	<i>Berwick</i>	Marchmont House ...	1·34	58
<i>„</i>	Bury St. Ed., Westley H.	2·42	115	<i>E. Loth.</i>	North Berwick Gas Wks.	0·93	57
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·29	106	<i>Midl'n.</i>	Edinburgh, Blackf'd. H.	0·74	37
<i>Wilts.</i>	Aldbourne ...	3·55	144	<i>Lanark</i>	Hamilton W. W., T'nhill	1·08	49
<i>Dorset</i>	Creech Grange ...	2·88	125	<i>Ayr</i>	Prestwick ...	2·81	146
<i>„</i>	Beaminster, East St. ...	2·86	124	<i>„</i>	Glen Afton, Ayr San. ...	3·09	103
<i>Devon</i>	Teignmouth, Den Gdns.	3·18	166	<i>Renfrew</i>	Greenock, Prospect Hill	3·25	104
<i>„</i>	Ilfracombe ...	4·66	215	<i>Bute</i>	Rothesay, Ardenraig ...	3·91	127
<i>„</i>	Princetown ...	4·88	121	<i>Argyll</i>	Morven, Drimnin ...	4·21	136
<i>Cornwall</i>	Bude, School House ...	2·46	122	<i>„</i>	Poltalloch ...	3·82	125
<i>„</i>	Penzance ...	3·73	168	<i>„</i>	Inveraray Castle ...	6·11	154
<i>„</i>	St. Austell ...	3·82	147	<i>„</i>	Islay, Eallabus ...	3·74	143
<i>„</i>	Scilly, Tresco Abbey ...	4·30	249	<i>„</i>	Tiree ...	3·39	133
<i>Somerset</i>	Taunton ...	2·72	155	<i>Kinross</i>	Loch Leven Sluice ...	1·73	79
<i>Glos.</i>	Cirencester ...	3·69	148	<i>Fife</i>	Leuchars Airfield ...	0·92	55
<i>Salop</i>	Church Stretton ...	4·04	159	<i>Perth</i>	Loch Dhu ...	3·82	92
<i>„</i>	Shrewsbury, Monkmere	2·38	114	<i>„</i>	Crieff, Strathearn Hyd.	1·39	53
<i>Worcs.</i>	Malvern, Free Library...	5·15	222	<i>„</i>	Pitlochry, Fincastle ...	1·50	72
<i>Warwick</i>	Birmingham, Edgbaston	2·93	114	<i>Angus</i>	Montrose, Sunnyside ...	0·77	46
<i>Leics.</i>	Thornton Reservoir ...	2·86	132	<i>Aberd.</i>	Braemar ...	1·02	52
<i>Lincs.</i>	Boston, Skirbeck ...	2·77	152	<i>„</i>	Dyce, Craibstone ...	1·96	105
<i>„</i>	Skegness, Marine Gdns.	3·82	212	<i>„</i>	New Deer School House	1·19	60
<i>Notts.</i>	Mansfield, Carr Bank ...	3·28	145	<i>Moray</i>	Gordon Castle ...	1·53	75
<i>Derby</i>	Buxton, Terrace Slopes	3·76	117	<i>Nairn</i>	Nairn, Achareidh ...	1·03	88
<i>Ches.</i>	Bidston Observatory ...	3·09	140	<i>Inverness</i>	Loch Ness, Garthbeg ...	1·28	56
<i>„</i>	Manchester, Ringway...	3·13	129	<i>„</i>	Glenquoich ...	4·89	100
<i>Lancs.</i>	Stonyhurst College ...	3·44	112	<i>„</i>	Fort William, Teviot ...	4·00	113
<i>„</i>	Squires Gate ...	3·54	170	<i>„</i>	Skye, Broadford ...	5·02	128
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·60	74	<i>„</i>	Skye, Duntuilin ...	5·82	224
<i>„</i>	Hull, Pearson Park ...	2·09	101	<i>R. &amp; C.</i>	Tain, Mayfield... ..	0·98	53
<i>„</i>	Felixkirk, Mt. St. John...	2·45	112	<i>„</i>	Inverbroom, Glackour...	1·90	67
<i>„</i>	York Museum ...	2·37	114	<i>„</i>	Achnashellach ...	4·78	127
<i>„</i>	Scarborough ...	1·30	71	<i>Suth.</i>	Lochinver, Bank Ho. ...	2·46	115
<i>„</i>	Middlesbrough... ..	2·46	130	<i>Caith.</i>	Wick Airfield ...	0·57	32
<i>„</i>	Baldersdale, Hury Res.	2·23	102	<i>Shetland</i>	Lerwick Observatory ...	1·85	103
<i>Norl'd.</i>	Newcastle, Leazes Pk....	3·00	142	<i>Ferm.</i>	Crom Castle ...	4·08	151
<i>„</i>	Bellingham, High Green	1·97	86	<i>Armagh</i>	Armagh Observatory ...	4·30	171
<i>„</i>	Lilburn Tower Gdns. ...	1·19	57	<i>Down</i>	Seaford ...	5·13	186
<i>Cumb.</i>	Geltsdale ...	3·49	129	<i>Antrim</i>	Aldergrove Airfield ...	3·85	160
<i>„</i>	Keswick, High Hill ...	3·24	111	<i>„</i>	Ballymena, Harryville...	3·95	136
<i>„</i>	Ravenglass, The Grove	4·11	157	<i>L'derry</i>	Garvagh, Moneydig ...	2·98	117
<i>Mon.</i>	A'gavenny, Plás Derwen	5·93	221	<i>„</i>	Londonderry, Creggan	3·51	124
<i>Glam.</i>	Ystalyfera, Wern House	9·66	256	<i>Tyrone</i>	Omagh, Edenfel ...	5·35	190

METEOROLOGICAL OFFICE

# THE METEOROLOGICAL MAGAZINE

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## SECOND CONGRESS OF THE WORLD METEOROLOGICAL ORGANIZATION

By J. DURWARD, M.A.

The Second Congress of the World Meteorological Organization was held in Geneva from April 14, 1955 to May 13, 1955, inclusive, under the Chairmanship of Dr. F. W. Reichelderfer, President of the Organization. It was attended by representatives of 83 member countries or territories, 7 non-member countries and 11 international organizations. The total number of persons present in the capacity of delegates, advisers or observers was about 215. The United Kingdom delegation was led by Sir Graham Sutton, Director of the Meteorological Office.

In the *Meteorological Magazine* for June 1951 a short account is given of the first Congress of the World Meteorological Organization describing how the semi-official International Meteorological Organization was replaced by the World Meteorological Organization and the problems which had to be faced by the First Congress. Naturally the problems of the Second Congress were different. It was now not necessary to create measures to ensure the smooth functioning of the Organization but more necessary to improve upon the procedures which had already been tried out over the first financial period. The review of the basic administrative procedures was made by the Administrative Committee and the Legal Committee. In addition the technical programme for the second financial period was handled by the Programme Committee.

It would be impossible to set out all the matters discussed and results achieved within the compass of a short article. Attention will therefore be confined to items likely to be of most interest to readers of this Magazine.

**Officers of the Organization.**—The following were elected to hold office until the Third Congress: President, Mr. A. Viaut (France); First Vice-President, Dr. Barnett (New Zealand); Second Vice-President, Prof. Ferreira (Portugal).

**Executive Committee.**—Dr. Reichelderfer was elected unanimously and with acclamation. Voting for the other five vacancies for elected members resulted in the following appointments: Mr. A. A. Solotoukhine (U.S.S.R.), Sir Graham Sutton (United Kingdom), Mr. L. de Ascarraga (Spain), Dr. A. Nyberg (Sweden), Mr. M. F. Taha (Egypt).

**Secretariat.**—Mr. D. A. Davies, Director of the British East Africa Meteorological Service, was elected as Secretary-General of the Organization. Other changes approved for the Secretariat were: increases in salary for the Secretary-General and Deputy Secretary-General; increases in the number of persons

employed; a rise in grade of the professional officers employed; the addition to the staff of a radio technologist; and the employment when necessary of a legal expert as a consultant.

**Work of the Legal Committee.**—One of the main tasks of this Committee was to review the general regulations of the organizations and make the necessary amendments, additions or deletions to make the regulations as clear as possible. It will be appreciated that one source of difficulty is that of language—translation too often alters the sense. In no language have words the same delicate shades of meaning as in English.

**Work of the Administrative Committee.**—*Contributions.*—Naturally a great deal of the time of the Administrative Committee was taken up in discussing a basis for contributions to the Organization. The proposals ranged from (a) adoption of the present scale, (b) adoption of the United Nations scale, (c) adoption of the International Telecommunications Union scale or a compromise between (a) and (b). The compromise ultimately adopted was to take 75 per cent. of the existing scale and 25 per cent. of the United Nations scale—a solution which resulted in the United Kingdom's contribution being reduced by one unit.

*Budget.*—The total budget of the Organization for the next four yearly period was fixed at \$1,700,000. This is somewhat less than the maximum figure to which the United Kingdom was prepared to go and resulted in a curtailment of the technical programme.

*International Meteorological Organization funds.*—It was decided to invest \$50,000 of the surplus funds of the International Meteorological Organization, and to devote part of the income from this investment to the award of an International Meteorological Organization Prize for outstanding work in the field of meteorology. The first award is to be made to Dr Hesselberg who is retiring shortly from his appointment as Director of the Meteorological Service of Norway.

*Assistance by Secretariat during and between sessions of constituent bodies.*—A sum was included in the budget for the second financial period to cover assistance to constituent bodies during and between sessions. This sum included travelling expenses of Secretariat staff at meetings of Regional Associations and Technical Commissions and of Presidents of Technical Commissions; also it included partial financing of meetings of working groups.

*New Headquarters building.*—No decision was reached regarding the provision of a new Headquarters building for the World Meteorological Organization, but a sum was included in the budget to allow for the renting of accommodation additional to that already occupied.

**Work of the Programme Committee.**—*Adoption of technical regulations.*—There was a great deal of controversy about the adoption of technical regulations. In particular the registering with the Organization of “deviations” from a standard practice was not favoured by some delegates on the grounds that such a procedure savoured too much of “rack and screw methods”.

It was decided that Chapter XII of “Technical regulations” which deals with “Meteorological service for international air navigation” should be published separately, and come into force on January 1, 1956; Chapters I–XI will come into force six months later.



*Programme for the second financial period.*—Twenty-two items for inclusion in the programme were listed in a Congress resolution. Some of the more important of these are meteorological telecommunications, World Meteorological Organization participation in the International Geophysical Year, preparation of meteorological guides and technical notes and comparison of instruments, in particular of radio-sondes and barometers.

*Technical assistance.*—There was criticism of the manner in which the benefits of the United Nations Expanded Programme of Technical Assistance were distributed. It was felt that the World Meteorological Organization, through its regional associations and Executive Committee, ought to play a greater part in deciding which countries should be assisted and which projects supported. The difficulty is that the country and not an outside body must ask for assistance in various fields and allot priorities to the various projects. It was left that the existing arrangements be continued, modified in the light of experience and development.

There was discussion as to whether the World Meteorological Organization should operate a regular Technical Assistance programme with funds under its own control. Objection was taken to the title of such a programme, and to avoid confusion and possible competition with the expanded programme, it was decided to recommend that the World Meteorological Organization include in its budget provision for the creation of an “Operational and Technical Development Fund”—a fund which would be devoted to remedying deficiencies in the pattern of world-wide and regional meteorology by encouraging the development of reliable meteorological services in areas of meteorological importance.

*Items on the technical programme for the second financial period.*—There was detailed discussion on some of the 22 items which were left on the technical programme for the second financial period—the arid zone, humid tropics and water-resource development projects of other specialized agencies, the preparation of a world climatological atlas, of a world meteorological bibliography, international meteorological guides and the formation of a film lending library.

As regards the International Geophysical Year, Congress decided that the World Meteorological Organization should accept the responsibility of becoming the collecting centre for essential meteorological records of the International Geophysical Year, and should prepare standard forms for the recording of meteorological data.

There was a good deal of discussion on the terms of reference of the Technical Commissions. It was generally agreed that some radical changes in the existing structure would have to be made in the interests of efficiency, but there was insufficient time during Congress to formulate the problem clearly. The existing Commission structure will therefore remain during the next financial period and plans for re-organization will be submitted to the next Congress.

## **CONFERENCE OF COMMONWEALTH METEOROLOGISTS, MAY 1955**

By J. DURWARD, M.A.

The fifth Conference of Commonwealth Meteorologists was held in the Air Ministry, Whitehall Gardens, from May 23 to 26, 1955. The Conference was attended by delegates from all Commonwealth territories, by an observer (Dr. Doporto) from the Republic of Ireland, by representatives of the Naval

Weather Service, Colonial Office, Commonwealth Relations Office, and, for certain items on the agenda, by representatives of the Royal Society (Sir David Brunt), Ministry of Transport and Civil Aviation, and Ministry of Supply, in addition to various members of the staff of the Meteorological Office.

The Conference was opened by Lord De L'Isle and Dudley, V.C., Secretary of State for Air, who, in the absence of Sir Graham Sutton, because of illness, was introduced by Dr. J. M. Stagg. In his remarks the Secretary of State referred to the contributions made by Commonwealth meteorologists in the advancement of their science. He welcomed the appointment of Mr. D. A. Davies as Secretary-General of the World Meteorological Organization and Dr. Barnett of New Zealand as its first Vice-President. He continued, "As with rapidity of communications in the modern world, so we need rapidity in the exchange of ideas if we are to keep pace in meteorology with advances in other branches of science and knowledge. I believe that you will have this in the forefront of your minds as you meet in Conference." In lighter vein, he referred to some words from the voyage to Laputa by Jonathan Swift, "'He had been eight years upon a project for extracting sunbeams from cucumbers which were to be put into vials, hermetically sealed and let out to warm the air in raw inclement summers.' But I recognize that your task like that of Socrates in his basket is with 'higher things'".

Dr. J. M. Stagg was elected Chairman, and, before beginning the business of the meeting, he suggested that a message should be sent to Dr. J. Patterson former Controller of the Canadian Meteorological Service in view of his association with the Commonwealth Conferences over the years. The following telegram was accordingly despatched to Dr. Patterson.

"Weather Toronto for Patterson. At the opening session of the fifth Conference of Directors of Commonwealth Meteorological Services it was unanimously agreed to send greetings to you Dr. Patterson in recognition of your long and valued association with Commonwealth Meteorology and your work in connexion with earlier Conferences. The assembled Directors wish you continued good health and strength in the future and all success in your present work."

The formal business of the session consisted either in the examination of certain papers which had been prepared as congress documents or of an opening statement by an expert from the Meteorological Office.

**Review of the resolutions of the 1946 Conference.**—Many of these resolutions have by now been implemented and are in the main only of historical interest. Reference was, however, made to the paucity of ships' reports from certain areas. This shortage arises in many cases from the failure of the receiving country to disseminate the reports as quickly as possible.

It was also considered necessary to confirm a resolution of the 1946 Conference regarding the "Interchange of meteorologists between Commonwealth countries".

Dr. Sutcliffe, having stressed the desirability of frost-point hygrometer observations by aircraft at high levels, was asked to circulate information to Canada, Australia and New Zealand on the fitting of such instruments to aircraft. This action might enable those countries to overcome the difficulties of making such observations.

**Discussion on marine meteorology** (opener: Cmdr Frankcom).—The most important question discussed was the improvement of the network of voluntary observing ships. The Commonwealth with 23 per cent. of the world's tonnage provide 34 per cent. of the "selected" ships. There was thus ample justification for the members of the Commonwealth planning their programme so that they benefit themselves in the first instance. An offer was made by Mr. Thomson (Canada) proposing to have on the Canadian "selected" ships' list, ships of British registry not on the British list. A general resolution to this effect was adopted.

**Recruitment and training in the Meteorological Office** (opener: Mr. H. L. Wright).—The main points brought out were the difficulty in getting recruits, the unattractiveness of forecasting as a career, difficulties in overseas territories of getting staff on "approved terms" and the added difficulty in some colonies because of impermanence of employment.

A resolution was finally adopted emphasizing the importance of co-operation between Commonwealth territories in training meteorologists and recommending that full use should be made by the smaller territories of the training facilities available in the larger territories.

**Meteorology and aviation** (opener: Dr. A. C. Best).—The discussion on Dr. Best's opening remarks was centred mainly on the accuracy and availability of aircraft reports, the best methods of using the observational data for the construction of upper air charts, the need for speeding up the collection of data and the need for increased accuracy in aerodrome forecasts.

Reference was made to the panel set up by the Institute of Navigation to discuss the problem of improving navigational techniques so that more accurate estimates of the wind could be made.

The construction of contour charts came in for some criticism especially from the representatives from tropical territories who rightly represented that the contour-chart technique was of no value in these areas, and thought that the only possible way of estimating upper winds was the statistical method weighted as necessary by any actual recent measurement available.

Mr. Ockenden remarked that the use of facsimile transmissions would help considerably for distributing processed data but not basic data. Mr. Thomson (Canada) described the coast-to-coast wire and radio facsimile network established in Canada which was working well.

As regards accuracy of aerodrome forecasts, Mr. Sellick thought that it was quite unrealistic to express cloud heights and visibilities to any high degree of accuracy 12 hr. or more in advance—a point of view shared by many others.

**Gusts and turbulence** (opener: Mr. J. K. Bannon).—This subject was included at the request of the Commonwealth Air Research Council. Mr. Grimes of the Ministry of Supply said that what was wanted was information on the maximum gust likely to be encountered, the shape of gusts and the frequency of occurrence.

It was decided that the prime responsibility was on aircraft pilots to report occurrences of severe turbulence so that Meteorological Services could make synoptic investigations into the really outstanding cases.

**Numerical forecasting** (opener: Mr. J. S. Sawyer).—Mr. Sawyer's opening statement, which was illustrated by lantern slides, evoked a great deal

of interest, and the ensuing discussion was mostly in the form of questions to the opener: How long did the complete process take? Was any smoothing of the data required? Were more than two parameters necessary? Could one improve on the geostrophic relation? What hope was there for tropical regions where the geostrophic relation did not hold?

Dr. Sutcliffe summed up the tropical problem by saying that before numerical forecasting could be thought of in these regions, one had to know a great deal more of the tropical weather systems. There did not seem to be much real knowledge about this except that, according to Mr. Sellick, few systems (except some cyclones) extend to any great height.

**Meteorological research including artificial control of rain** (opener: Dr. R. C. Sutcliffe).—Dr. Sutcliffe described the main research activities of the Meteorological Office under the main branches, climatological, forecasting, physical, instrument development and special investigations. In answer to Mr. Thomson (Canada) he described how the research and operational staff were brought together by colloquia at Dunstable and Harrow and by discussions in London. Co-ordination between the Office and the universities was effected largely through membership of the Meteorological Research Committee.

A desire was expressed that progress reports on research projects should be circulated amongst Commonwealth Meteorological Services. It was not enough to see only the finished product.

Dr. Schumann (South Africa) made a strong plea for the publication of world maps of temperature and wind at different levels for each month of the year. He regarded this as a project of the utmost importance.

On the problem of artificial control of rain, the principal speakers were Dr. Sutcliffe, Mr. Thomson (Canada), Dr. Naqvi (Pakistan), Mr. Davies (East Africa) and Dr. Basu (India). Mr. Thomson said that seeding by means of silver iodide generators had, according to a statistical analysis, caused a decrease of 14 per cent. of rain over the target area, a result which Dr. Naqvi explained might be because silver iodide discharged from the ground had lost its effectiveness as a nucleating agent before it had reached the freezing level. Dr. Basu stressed the importance of carrying out experimental work over several years. An increase of 15 per cent. in one year of the rainfall in an area of very low rainfall was of no significance.

**Current methods of forecasting** (opener: Mr. S. P. Peters).—Mr. Peters described the data now available, and how it was handled. The main “products” of the forecasters’ skill were prebaratics and forecast thickness isopleths. The great problem, however, remains that the derivation of a forecast from a prebaratic does not lend itself to computation and increased accuracy is hard to come by.

Mr. Sellick spoke to a paper he had submitted as a conference document on forecasting in Rhodesia and Nyasaland. The subsequent discussion showed that it was difficult to make any progress with the problem of tropical forecasting until the nature of the weather system had been established. A pattern was required to which the Services could work. Some Services had tried to work on waves in the easterlies or on the intertropical convergence zone but with little success. It was felt that the drawing of and forecasting the movement of stream lines were very important but they would necessitate a good network of radar wind stations.

There was discussion on the setting up of an institute of tropical meteorology. The idea was abandoned, but a resolution was agreed for the setting up of a small research team working in a tropical Commonwealth territory, but looked after by the Meteorological Service of one of the major Commonwealth countries. The United Kingdom was regarded as the best sponsor for such a project.

**Commonwealth participation in the International Geophysical Year** (opener: Mr. H. W. L. Absalom).—Sir David Brunt, on behalf of the Royal Society, attended the meeting at which the programme was discussed. Most territories indicated the extent of their programme, some suggesting additional items such as measurements of hygroscopic nuclei and others indicating that in low latitudes the number of radio-sonde observations could very well be reduced from four a day.

It was reported by several Colonial delegates that they were not being kept in the picture regarding the International Geophysical Year, and Sir David Brunt agreed to raise the matter at the next meeting of the National Committee for the International Geophysical Year.

**Meteorological instruments and instrument supply** (opener: Dr. F. J. Scrase).—Dr. Barnett (New Zealand) also spoke to the document submitted by him on the M.E.7 (radar wind equipment). The general discussion is summed up in the resolution passed that

The Conference, considering the desirability of

- (i) lowering the cost of meteorological instruments through steps towards standardization,
- (ii) reduction in the number of designs required for particular requirements,
- (iii) stating the specifications of particular instruments so as to cover as wide a field of requirements as is practicable,

resolved that the Meteorological Services of the British Commonwealth should co-operate in the development of standardized instruments by exchanging promptly all specifications which they develop and inviting comment on the principles or details of the design.

The detailed discussion centred around the development of

- a simple radar wind-measuring equipment
- a replacement for the Dines anemograph
- a low-level (2,000–5,000 ft.) radio-sonde balloon
- an instrument to give a measure of the evaporation from a free surface
- precision aneroids.

On the social side the Conference enjoyed the hospitality of the Air Council, The Royal Meteorological Society and Messrs Muirhead, Messrs Decca Radar and Messrs Mullard.

The Conference was a great success owing to the able chairmanship, to the friendly atmosphere, the eagerness of delegates to learn about the latest developments and to ventilate the problems peculiar to their own territory. There is no doubt that the opportunity to get together in this way and get to know one another's personal characteristics is of a definite personal and official advantage.

## SOME EFFECTS OF SHELTER-BELTS AND WIND-BREAKS\*

By R. W. GLOYNE, B.Sc.

**Introduction.**—Considerable information is available concerning the physical and biological effects of wind-breaks and shelter-belts, although, owing to the difficulties inherent in field work and to the complexities of the interactions involved, the accuracy and reliability of this information varies widely.

Most of the pioneer work has been carried out in hot arid regions of the world, and this, together with the fact that the action of a given belt is decisively affected by its physiographical and climatic setting, makes necessary a very critical examination of the conditions under which any results were obtained before they can be applied to the British Isles.

**Physical effects of shelter-belts and wind-breaks.**—A barrier will alter the air flow (mean flow, and vertical and horizontal gradients of flow) and the flux of radiation (direct and diffuse) towards and from surfaces within the “zone of influence” of the barrier.

These basic changes, acting singly or in combination and in conjunction with the properties of the surface (slope, aspect, roughness etc.), will effect consequential changes in:—

- (i) Air and soil temperature—absolute values, vertical and horizontal gradients (in practice we are also concerned with the temperature of exposed surfaces).
- (ii) Heat balance and exchange—heat changes, at natural and artificial surfaces (both wet and dry), by forced and free convection and by radiation.
- (iii) Moisture content of the air—absolute and relative values, horizontal and vertical gradients.
- (iv) Evaporation (i.e. water loss)—from open water surfaces, soil, evaporimeters, and through the plant (i.e. by transpiration).
- (v) Erosion, transport and deposition of small particles—generally soil or snow, but also insects, spores, bacteria and pollution.
- (vi) Properties of the soil—affecting the soil moisture by the influence on the amount of precipitation reaching the ground and on the subsequent loss by evaporation, run-off and percolation; affecting the soil freezing through the influence on snow-cover and shading; and affecting the mechanical properties related to cultivation and “trafficability”.

An essential prerequisite for an estimate of the effects due to a barrier in any given case, is an adequate appreciation of the interaction between the sheltering from the wind and the shading from sun and sky. The data which follow have been selected as being appropriate to conditions in the British Isles. Consequently relatively recent work from Denmark, Holland, Germany and Switzerland has been drawn upon, in preference to the older and more widely known results obtained in Russia, the United States and elsewhere.

When considering the results of field work in this subject, it is particularly important to consider critically the instruments used and techniques adopted for the measurement and analysis of the meteorological factors. The limitations so revealed have been given due weight in the presentation of the results to follow.

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\*This paper is based upon one presented to the Committee on Hedgerow and Farm Timber of the Forestry Commission, and is published with their permission.

**Reduction in mean speed of the wind.**—For convenience barriers may be classified into open barriers (density or “blockage-ratio” less than 40 per cent.), medium dense barriers (density 40–80 per cent.), and dense barriers (density 80–100 per cent.). It is assumed that the density is uniform over the face of the barrier.

Wind speeds in the protected area are normally expressed as a percentage of the simultaneous wind speed in the “open”, the measurements being made at some convenient reference height less than the height of the barrier and generally between 4 and 6 ft. (see Table I). If, in addition, horizontal distances are measured in terms of the height *h* of the barrier, scale effects are, for practical purposes, eliminated. Although some effects can be detected certainly at 6*oh*, and possibly to greater distances, for most purposes effects beyond 30*h* or 40*h* may be ignored. These percentage figures are valid for “free” wind speeds of between about 5 and 20 m.p.h., and for many purposes hold sufficiently well for higher speeds, say 25 m.p.h.

TABLE I—TYPICAL VALUES OF THE HORIZONTAL WIND SPEED EXPERIENCED  
BEHIND BARRIERS OF DIFFERENT DENSITIES

Down-wind distances measured in terms of the height *h* of the barrier

Type of barrier	Wind speed at distance down wind of								
	0 <i>h</i>	2 <i>h</i>	5 <i>h</i>	10 <i>h</i>	15 <i>h</i>	20 <i>h</i>	25 <i>h</i>	30 <i>h</i>	40 <i>h</i>
	<i>percentage of “free” wind speed</i>								
Open (density about 30 %) ... ..	90	80	70	75	85	90	95	100	100
Medium dense (density about 50 %) ...	40	25	20	25	50	60	75	90	100
Dense (density about 100 %) ... ..	0	20	40	65	80	85	95	100	100

Typically, the dense barrier gives rise to a region of still air immediately to its lee, followed by a rapid recovery in speed, giving but little reduction beyond 20*h*.

The medium dense barrier (a barrier of density 60 per cent. is found to give the best results) allows air to filter through, thus avoiding complete stagnation, and producing a minimum speed equal to about 20 per cent. of the “free” speed at 3*h*–5*h* down wind with a relatively slow recovery to 60 per cent. at 20*h*, and to about 100 per cent. at 40*h*.

With a very open barrier (such as is presented by close-mesh wire fencing) the wind speed is reduced to perhaps 70 per cent. of the free value at 5*h*, but usually beyond 10*h* there is hardly any reduction. The absolute height of the barrier, the wind speed and the stability of the air modify the results, but not to an extent sufficient to prejudice the general applicability of the figures quoted.

It is generally agreed that straightforward cumulative effects do not arise with a succession of simple barriers set 40*h* or more apart.

**Eddies and turbulence.**—Eddies form in an air stream when a barrier is encountered, and behind an impermeable barrier such eddies cause damage to crops. Indeed, the benefit to certain easily bruised crops (e.g. tulips, citrus fruits), expected from the reduction in wind speed caused by an impermeable barrier, may be completely cancelled out by the damage caused by eddies.

It is found that an eddying type of flow is mainly confined to a zone 10*h* or 15*h* down wind from the barrier, and the motion in the remainder of the wake

(recognizable at any rate to  $40h$ ) can in practice be regarded as a mean horizontal flow with relatively small-scale turbulence superimposed upon it.

An eddying region can be identified until the density of the barrier becomes as low as 20–30 per cent., although little damage to crops appears to occur with barriers of density less than 50 or 60 per cent. (this is the density of the most efficient barrier regarded from the point of view of evenness of wind reduction over a wide strip).

**Modifications in air flow induced by barriers of limited cross-wind length and of considerable thickness.**—Even if the wind approaches a barrier at right angles, it will “cut-in” around the ends so reducing the area effectively protected, and when the wind blows obliquely to the barrier, the protected area is further reduced. It must be remembered that only at particular sites will the wind always approach from one or two very limited ranges of direction, and only in special circumstances will it be winds from only one direction against which protection is desirable. To obtain the full benefit from a barrier of height  $h$  it must have sufficient cross-wind length—one of length about  $20h$  is hardly sufficient.

The protective effect of a dense barrier formed by a thick belt of trees (at least 40–60 yd. thick) is much as is given in Table I, but the vigorous eddying inseparable from a narrow dense barrier seems to be much reduced with a wide barrier such as that formed by a plantation of trees whose canopy presents an extensive and very rough surface to the air stream. If the tree belt is very deep (of the order of miles) then the protective effect in the lee margins exceeds the values quoted in Table I (e.g. 100 per cent. at  $60h$ – $70h$  instead of  $40h$ )<sup>16</sup>.

Although, as mentioned earlier, there is no indisputably convincing evidence of a cumulative influence exerted by a succession of narrow barriers set  $40h$  or more apart, a succession of large plantations does appear to exert such an effect. This, however, is as likely to be due to a progressive reduction of the general wind (which reduction is very difficult to determine in such circumstances), as to a straightforward cumulative shelter effect. There is evidence, however, that the decrease of protected area due to “end-effects” is reduced by a succession of parallel barriers, and indeed that the protected zone extends laterally to a further  $7h$ – $12h$ , and in this sense some cumulative protection is achieved<sup>34</sup>.

**Shading.**—The extent of the shadow will depend on the orientation of the barrier, but its importance will depend upon the amount of sunshine—especially in the six months October–March—and near a dense belt the loss of light is quite sufficient to depress growth in the spring.

As well as the direct effect upon illumination, the shading will affect soil and air temperatures (including the extent and intensity of freezing), water loss and soil moisture.

Little investigational work has been done on the influence of various types of barrier upon illumination reaching the surface. Bates’s work<sup>18</sup> almost stands alone, but his results are not directly applicable to conditions in the British Isles as he was working in the presence of continuous, rather than intermittent, sunshine.

**Soil temperature.**—Temperature at or near the ground surface fluctuates markedly in response to sunshine and to direct shading, but the contrast between temperatures in shaded and unshaded areas decreases with depth.



The Dutch workers Van der Linde and Woudenberg<sup>31</sup> report an occasion when temperatures at a depth of 4 in. in parts of a wind-sheltered area exceeded those in the open by up to 6°F.; such an excess was transitory and rather greater than the values reported by other workers. In the immediate shadow the corresponding temperatures were at times 2–4°F. lower than in the open. Differences tend to disappear at night, in overcast weather, or when winds are strong.

**Air temperature.**—In conditions of light wind, temperature in the protected area exceeds that in the open during those parts of the day when there is a net gain of radiation at the surface, and falls below it when the surface is, on balance, losing heat<sup>20</sup>. In regions subject to long spells of clear skies the mean temperature over a 24-hr. period differs little between sheltered and unsheltered areas. In our conditions of intermittent sunshine there is a small net gain over the 24 hr. unless the barrier is so sited as to form a frost “pocket” on still nights, when the net effect may be negative<sup>31</sup>.

In the Dutch investigations the highest day temperature occurred in the protected zone just beyond the limit of the shadow<sup>31</sup>. The largest temperature increases were of the order of 2–3°F. at 4 ft. from the ground and about twice that amount at 4 in.; these differences occurred within a strip 5*h* or less from the barrier. At night the position of the minimum temperature appeared to be closely linked with that of the minimum wind (a secondary minimum was also identified immediately behind a live barrier<sup>31</sup>). At 1–2 ft. above the surface, minimum temperatures were of the order of 1°F. lower in the sheltered than in the unsheltered areas, little difference being reported at 4 ft. The same workers<sup>31</sup> report anomalously high maximum temperatures in unshaded but sheltered margins.

Recently Kreutz<sup>25</sup> has published results showing an increase of 4½°F. in maximum and a decrease of 2½°F. in minimum temperatures a foot or so from the surface within the close network of artificial and natural screens.

With “free” wind speeds between about 5 and 12 m.p.h. temperature differences become insignificant beyond about 10*h*; with stronger winds both the temperature differences and the area affected decrease.

**Heat balance.**—The heat exchange of a body exposed to the elements, besides being a function of the physical and geometrical properties of the body, is affected by wind, humidity, direct and diffuse radiation as well as by the air temperature measured in the meteorological screen.

These considerations are particularly important with livestock, and, in practice, every case must be considered on its merits. The potential benefits of a shelter-belt to livestock must not be judged with respect to the changes caused in air temperature alone.

As regards buildings it is reported<sup>34</sup> that the heat loss from a house is about doubled with an increase of wind from 5 to 20 m.p.h., and that in the central regions of the United States the fuel bill can be reduced by up to 40 per cent. by exploiting the protective effect of shelter-belts.

**Humidity.**—Within a zone extending down wind for about 10*h* to 15*h* from the shelter, absolute and relative humidities in the middle of the day are generally higher than in the open. The differences are, however, small beyond about 5*h*. Within the narrower zone, typical values<sup>31</sup> for the increases a foot or two from

the surface are 5–10 per cent. for relative humidity and 1–3 mb. for absolute humidity in conditions when the general level is about 10–16 mb.

In the very disturbed eddying flow behind a dense barrier both absolute and relative humidity may be lower than in the open due to the increased loss of water vapour by eddy diffusion. In the high-temperature zone adjacent to an unshaded but sheltered margin, similar differences occur<sup>31</sup>.

Dew-fall is higher in the protected zone, being appreciably greater near to the belt<sup>25</sup>; this effect extends down wind to 5*h* or 10*h*.

**Evaporation.**—Practically all investigators, and especially the earlier ones, attach great importance to the ability of a shelter-belt to decrease evaporation (or more strictly the water loss from various types of evaporimeters). Evaporation is very difficult to measure in a way free from serious criticism, but there is sufficient qualitative agreement between the various measurements, and ample biological confirmation, that the “evaporative potential” imposed upon the ground and upon plants is reduced by the interposition of a barrier. Results from some recent work<sup>25</sup> at the agricultural-meteorological station at Giessen, Germany, are given in Table II; it is not clear what type of evaporimeter was used. The similarity in trend of the results is of interest. No explanation is given by the author for the rather anomalous result at 2·8*h*—variability of that order is not uncommon in field studies however.

TABLE II—WIND SPEED AND EVAPORATION AT DIFFERENT DISTANCES  
FROM A HEDGE

		Value at distance from hedge of:					April 5, 1949
		0·4 <i>h</i>	1·6 <i>h</i>	2·8 <i>h</i>	4·0 <i>h</i>	5·2 <i>h</i>	6·4 <i>h</i>
		<i>percentage of “open” value</i>					
Wind speed	...	52	59	63	61	74	80
Evaporation	...	70	80	84	80	86	95

Reviewing the mass of the data available it would appear that the effect of a barrier upon water loss:—

- (i) is similar in pattern to that for wind speed but less marked in extent
- (ii) extends to 5*h* or 10*h* and exceptionally to 20*h*
- (iii) is strongly modified by direct shading
- (iv) is a function of the absolute speed of the wind.

**Snow cover, soil moisture.**—Snow will tend to accumulate within, or be confined to, those regions adjacent to a barrier where eddying takes place. The region to leeward extends to about 12*h*–15*h* from a permeable barrier and rather less from a dense barrier, although in the latter case the maximum vertical extent of the region is greater<sup>17</sup>.

Particularly if the snow falls before the ground is frozen, the soil will become saturated under the drifts. Surfaces clear of snow are more liable to freeze.

The differential supply of water to the soil is not, however, regarded as likely to be of importance in the British Isles, where, certainly in the hill areas, the soil in all parts is almost invariably at “field capacity” in the early spring. Under such conditions differences in soil moisture in the summer should be related to evaporation from the surface, or transpiration from plants. There

appears, however, to be no suitable numerical data to quote, and the possible higher moisture content of the soil in sheltered areas can only be inferred from the behaviour of crops and the state of the soil surface. The soil will dry out less readily in sheltered areas which, from an agricultural point of view, may be a disadvantage.

**Erosion, transport and deposition of small particles.**—Wind erosion is a phenomenon of only a few well defined areas in the British Isles. Experience elsewhere<sup>33</sup> has shown the immense value of barriers of all kinds, from forest-like plantations to slat fences and stubble, for stabilizing the soil.

Judging from the behaviour of snow there is a tendency for airborne material to be deposited in the shelter of a barrier. If such material consists of insects, spores and bacteria, the agricultural implications are obvious.

**Some biological consequences of shelter-belts and wind-breaks.**—In semi-arid regions shelter-belts are valued mainly for their ability to reduce the blowing of soil, and to mitigate the effect of strong drying winds; it is to this latter effect that the large increases in the yield of crops are attributed. In the British Isles, however, the areas where blowing is of consequence are limited in extent, and prolonged severe desiccating winds do not often occur. The benefit derived by crops from shelter in these islands is at least as much to be attributed to the reduction in physical damage and to other effects, as directly to the reduction in water loss. With livestock the main benefits can be traced to the reduction in heat loss. It would be out of place in this present survey to consider biological effects to any extent, but sufficient information will be given to enable the reader to judge of the importance of the subject in agricultural meteorology.

Shelter-belts are known to influence the growth, development, activity and productivity of plants and animals. Amongst the effects noted by various observers are the following:—

- (i) Increase in yield of crops—linked with the reduced water loss, reduced physical bruising, slightly higher temperature and humidity in the protected zone. Often, however, shading is detrimental and the root competition from any trees or shrubs forming the barrier is usually disadvantageous.
- (ii) Earlier crops—frequently the direct consequence of protection from the cold dry E. and NE. winds of early spring. An “early bite” of grass can be induced by the use of shelter-belts.
- (iii) Better-quality produce—particularly of the leafy delicate crops and of fruit and flowers readily bruised by the wind.
- (iv) Livestock benefit in many ways from protection afforded by barriers against cold winds (especially when in association with rain), against hot sunshine, and indirectly through the better herbage frequently to be found near shelter-belts.
- (v) The balance of pests and predators is often altered by the interposition of a barrier (whether live or artificial) and this may or may not be an advantage. One advantage is the greater activity of pollinating insects when protected from boisterous conditions.

(vi) With fruit trees, benefit is claimed from the protection during blossoming time against cold winds with or without precipitation, and from the reduced risk of "windfalls" just prior to harvest. Protection against unseasonably warm winds in early spring (when the soil is cold and moisture uptake inhibited) is also beneficial.

(vii) The partial or complete stilling of the air by a shelter-belt can, however, give rise to a damp stagnant atmosphere and damp cold soil which can be detrimental, particularly by virtue of the encouragement to certain diseases of plants and animals.

Amongst the data of relevance to the British Isles, that contained in two important publications from Germany and Denmark by Kreutz<sup>25</sup> and Andersen<sup>33</sup> respectively, may be mentioned. Broadly speaking crop yields are increased by 10–20 per cent., and in certain circumstances by 50 per cent. or even more, within a strip extending 10h–12h down wind. Leafy and delicate crops gain more than do, for example, cereals which are detrimentally affected by shading. There is also risk of a softer growth in the sheltered area which is more vulnerable to insect or disease attack.

Kreutz reports that in the dry and warm season of 1949 there were increases of 57 per cent. in the yield of beans and 18 per cent. in the yield of fodder beet when grown in "cells" 18 m.  $\times$  12 m., having barriers of 1.8 m. high along the shorter sides and maize bordering the longer sides.

Andersen reports from Denmark a progressive decrease in average yield of apples (1922–31) from 627 Kg./hectare in a 36-m.-wide strip beginning at 14 m. from a shelter-belt, to 483 Kg./hectare in a similar strip some 200 m. from the protective belt. On the whole Denmark has a rather windier climate than the British Isles, and equally striking results may not be usual here, although there certainly are areas in the British Isles (e.g. the higher parts of Cornwall) where some shelter from the wind is essential before any reasonable commercial crop of vegetables or flowers can be grown.

In a current series of investigations on the effect of shelter, which are being carried out jointly by the Meteorological Office and the experimental horticultural stations of the Ministry of Agriculture, results of a type confirming the experience on the Continent are being obtained.

The effects on pests and diseases have yet to be studied properly, but some information is given by Schrodter<sup>41</sup>. On balance, in the British Isles, it is thought that the tendency for shelter to increase losses from disease and pests may be a major fact limiting its usefulness.

**Notes on the effects of certain types of natural barriers.**—*Isolated trees.*—These will present to the wind a narrow impermeable barrier for the first few feet, and above, a large semi-permeable canopy. We expect to find, therefore,

- (i) some very limited protection from winds from every direction
- (ii) a localized increase in wind speed around the sides of the trunk
- (iii) vigorous eddying in the lee
- (iv) a relatively large shaded area compared with the limited obstruction to wind near the ground.

That vigorous eddying does occur is confirmed by the frequent observations of "laid" crops near impermeable barriers and around isolated trees. The

denser the canopy and, within limits, the nearer it is to the ground the more vigorous the eddies.

In respect of (ii) Geiger<sup>21</sup> reproduces some observations of Woelfle indicating regions where the wind speed reached 135 per cent. of the "free" wind adjacent to an isolated trunk rather less than a metre in diameter. These areas were displaced slightly down wind and approximately  $1\frac{1}{2}$  m. from the centre of the trunk. In the same paper he quotes an instance<sup>26</sup> in which two rows of poplars bordered a roadway, the trees being 5 m. apart within the rows. Local increases of wind speed up to 120 per cent. of the "free" wind speed were recorded between the trees. The associated eddies would be detrimental on the whole to crops, but the shading provided by the spreading canopy could be of assistance to stock in hot weather. The competition for moisture and plant nutrients between the trees and the surrounding crop may be detrimental to the crop.

*Copses and Spinneys.*—The compact shape of these plantations will give shelter from winds from any direction, but the comparatively small cross-wind dimensions will lead to relatively large losses of shelter due to end effects.

The shelter from a square block 5 acres in area would, however, be appreciable, and such a plantation, even if the trees were widely spaced within it, could not fail to present an efficient barrier against the wind. The shading would be adequate for a large herd of cattle, but allowance must be made for the tendency of cattle to sterilize the area by their droppings.

Often plantations of trees will be used to supplement the protection obtained by farm buildings, in which case the benefit to livestock farming will be much greater than the limited acreage devoted to trees would suggest<sup>36</sup>.

*Roadside trees in belts up to 20-yd. wide.*—This produces the "basic" type of shelter-belt, and if it can be maintained so as to give a medium dense barrier, and particularly if supplemented by a reasonably dense hedge, the effects listed earlier in this paper will be manifest in the most typical form. Even a belt of two or three staggered rows of trees, if properly maintained and accompanied by the shrub layer, can present an adequate barrier to the wind.

**Problems of shelter plantations in hilly areas.**—In hilly and particularly in mountainous areas the climate, the topography, and the characteristics of the soil will often dictate what trees to plant and where this can be done; the lack of choice, in effect, simplifies the problem. In most other respects, however, the problems are rendered more complicated than those encountered when considering the provision of shelter in flat areas.

In the first place a system of hills will control the air flow in a way not yet fully understood, and a realistic estimate of the effectiveness of any given belt demands a knowledge of the relationship between the actual wind experienced and the large-scale wind system. Whilst air flow alone might be studied with profit as an aerodynamic problem in the wind tunnel, no similar technique is available for the investigation of other features of the climate, which must therefore be undertaken in the field. Indeed it should be clear that in any practical case all factors involved and their interactions must be considered, and this will imply that a full appreciation of the broad climatic and topographical features is as essential as is the estimate of the local and microclimatic effects which the shelter-belt is expected to produce.

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TORNADO SEEN AT LUTON AIRPORT, JUNE 8, 1955  
(see p. 289)



**COURSE OF THE TORRENT THROUGH THE WHEATFIELD**  
The ravine is 150 ft. long, 8 ft. wide and 5-6 ft. deep.



**VIEW INSIDE THE RAVINE**  
The stones are slabs of Pennant grit.

#### **RAVINE CUT THROUGH A WHEATFIELD**

The torrent came down the mountain slopes shown in the background from a small valley behind the large tree on the right of the farm buildings (Gelli-hir Farm). The back of one of these buildings was smashed in by hundreds of tons of boulders (see p. 281).





VIEW IN TORRENT BED BEHIND GELLI-HIR FARM  
The torrent scoured a channel 4-5 ft. deep in stratified grits.



GULLY ERODED IN ROAD TO TOR-Y-FRON FARM  
The road had a macadamized surface over consolidated ash.

MORE FLOOD DAMAGE NEAR GELLI-HIR FARM  
(see p. 281)



FLOOD DAMAGE IN FORMER MOUNTAIN STREAM BED BEHIND  
GELLI-HIR FARM  
(see opposite)



MR. P. N. SKELTON, M.B.E.  
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## A SOUTH WALES THUNDERSTORM

By G. MELVYN HOWE

The thunderstorm which raged over a portion of the Llynfi Valley in mid Glamorgan during the afternoon of August 22, 1954 was undoubtedly the worst in living memory. It was of exceptional severity and the extensive flooding of roads and basements of houses and shops in the Garth district of Maesteg, together with the havoc caused by swollen torrents at the nearby Gelli-hir farm made the occasion unique and worthy of investigation. Fortunately such

phenomena are relatively rare in any one area, though they are familiar from press reports. When they occur they invariably cause damage and considerable inconvenience; in this respect the Maesteg thunderstorm was no exception. Largely as a result of culvert blockage the drainage system failed to take the sudden rush of storm water and the inevitable flooding which followed led to traffic dislocation and considerable damage to roads and property.

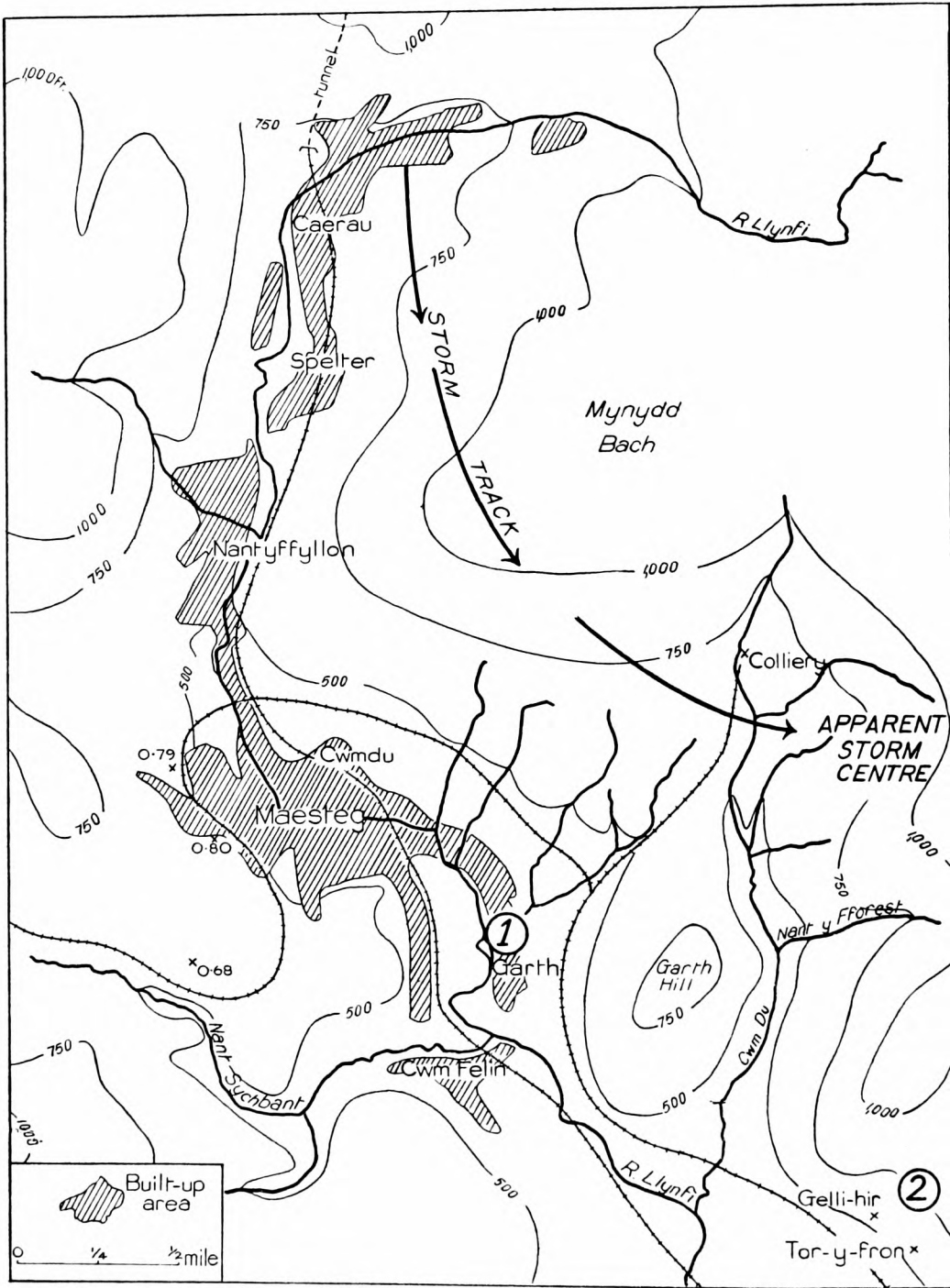


FIG. 1—AREA OF THE STORM  
Rainfall amounts are given in inches.

**The storm.**—On August 22, 1954 the convergence of unstable air in a trough of low pressure provided the explosive situation which was touched off by day-time heating. Thunderstorms were widespread, but that at Maesteg would appear to have been the most violent and spectacular. This storm developed near the head of the Llynfi Valley at Caerau at approximately 3.45 p.m., from whence it followed a half-mile wide track south-eastward (Fig. 1). It skirted Mynydd Bach (1,421 ft.), and then seemed to impinge on the amphitheatre-like area near the St. John's Colliery one mile north-east of Maesteg, and also over the watershed between the Llynfi Valley and the Garw Valley to the east. Here it remained for some 90 min. during which time the district was enshrouded in a dull red pall of cloud. The rainfall, which reached tropical intensity, was preceded by a particularly heavy fall of hailstones, the whole being accompanied by violent thunder and lightning.

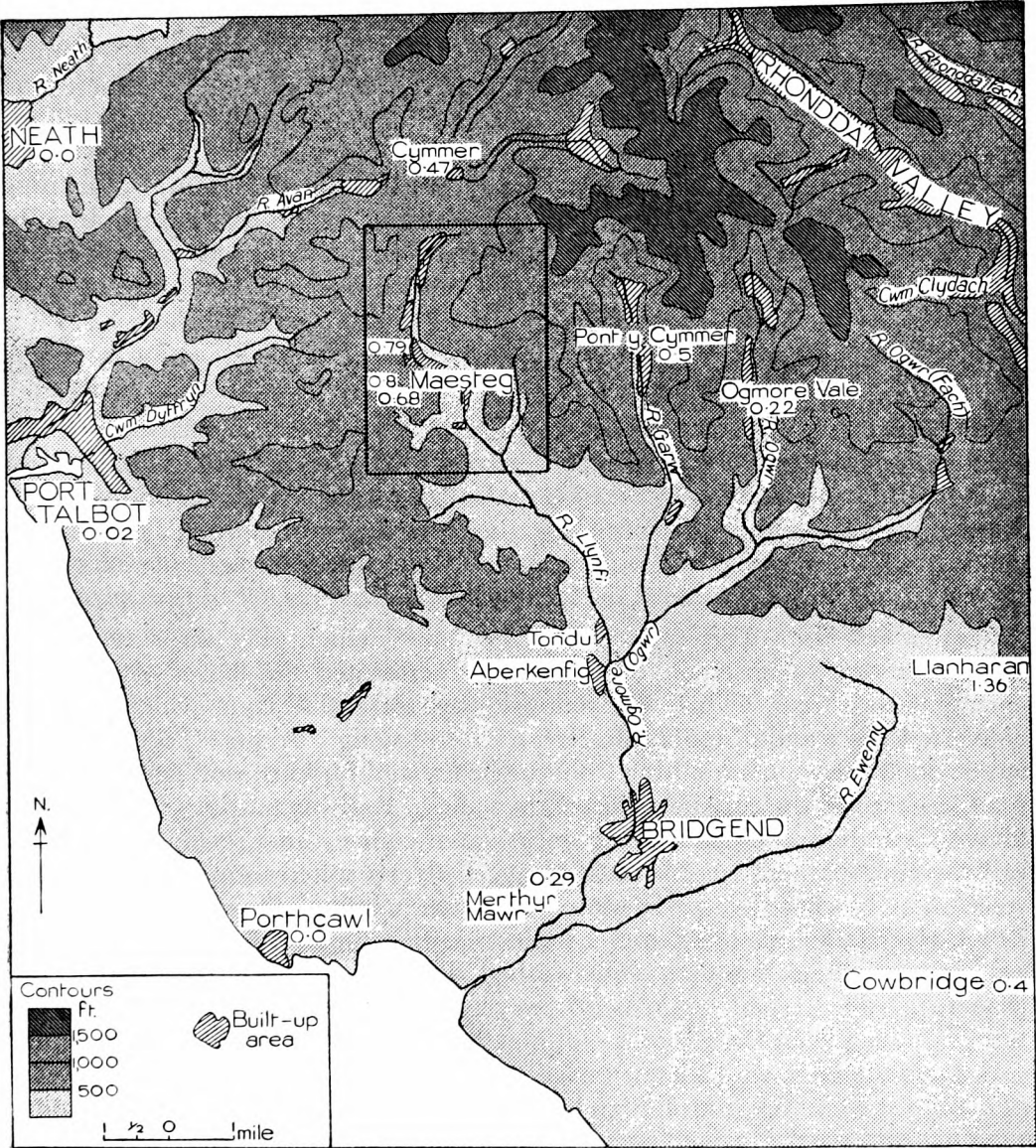


FIG. 2—MID GLAMORGANSHIRE  
The area covered by Fig. 1 is indicated by the rectangle. Rainfall amounts are given in inches.

It is unfortunate that there was no rainfall recording station in the area which experienced the full effects of the storm, while a rain recorder sited in the Welfare Park at Maesteg, on the edge of the storm, was blocked by hailstones and consequently failed to register. A rain-gauge alongside the recorder and two other gauges, all sited on the western side of the valley and on the very fringe of the storm, gave the not unusual falls of 0.79, 0.80 and 0.68 in. respectively. Such falls would not even qualify for the "noteworthy" category<sup>1</sup> even though they occurred in the short space of 90 min. but it is the general opinion of numerous observers, borne out by the spectacular evidence of changes wrought in the land surface, that the rainfall was very much heavier on the eastern side of the valley. National press and B.B.C. reports stated that "nearly 4 in." of rain fell in the area during the storm period of 90 min. Such a fall in so short a time would appear highly improbable, and the claim probably arose from a local press report saying that "it would be no exaggeration to suggest that the rainfall over the Cwmdy (east) side of Maesteg was five times that experienced on the Hospital (west) side" (see Fig. 1). However, ten miles south-east of Maesteg at the village of Llanharan (see Fig. 2), where there was another, though much less severe, cloudburst, a "noteworthy" fall of 1.36 in. in 80 or 90 min. was recorded. Just how much rain and hail actually fell in the centre of the Maesteg thunderstorm during that terrifying and disastrous one-and-a-half hours will never be known, but it probably substantially exceeded 2.5 in. and most likely approximated to 3.0 in. In any case it easily qualified for the "very rare" category which is taken as a minimum of 2.52 in. in 90 min.

Little rain fell on the south Glamorgan coast (see Fig. 2). No rain fell at Porthcawl, 0.02 in. at Port Talbot and 0.28 in. at Rhose (west of Barry). Inland at Schwyll, near Merthyr Mawr, and at Pwllwy, Aberthin, near Cowbridge, only 0.29 and 0.40 in. respectively were recorded. In the valleys eastward of the Llynfi, Pont-y-Cymmer in the Garw Valley received 0.50 in. and Ogmore Vale in the Ogwr Valley received 0.22 in. from the same storm. These aggregates spread over 24 hr. give only reasonably wet days and are not unusual in these parts. They also confirm the extremely localized nature of the downpour.

**Storm effects.**—The initial fall was of hail\* which gave the surrounding hillsides a coat of unseasonable white and perforated the leaves of rhubarb, cabbage and trees. This was followed by torrential rain which rapidly converted the tranquil mountain streams into raging torrents. To these latter were added the waters resulting from the heavy and rapid run-off from artificial road surfaces on the eastern slopes of the valley. Railway cuttings on the slopes above Cwmdy were transformed into water courses and several sections of railway embankment were washed away. Culverts suited to more normal flow were soon blocked by storm water, and the narrow, though swift-flowing, Llynfi river failed to take the greatly increased volume of water. Tons of silt, pebbles and huge boulders were washed down the west side of Garth Hill (849 ft.), colliery spoil heaps were severely gullied and large amounts of soil were removed from the gardens of a new housing estate. The drainage system was unable to cope with the torrential rain and hillside torrents, and the covers of manholes were thrown feet high by the pressure of the exceptional and sudden

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\*It was thought that the covering of storm-water traps by up to 10-in. depth of hail was a contributory factor in the serious flooding that occurred in Maesteg, Tondy and Aberkenfig. Hailstones of up to 1 in. in diameter were observed.



rush of water. Considerable flooding followed, but fortunately, though numerous domestic pets were drowned, no human lives were lost (Area 1 on Fig. 1). On the east side of Garth Hill where the bulk of the storm water was conveyed to the Llynfi via the Cwm Du, the absence of houses meant that the greatly enlarged stream caused no serious damage.

A mile to the south-east of Maesteg at the hill farm known as Gelli-hir (Area 2 on Fig. 1), turbulent storm waters followed the former course of a mountain stream which has been piped away in another direction. The previously shallow and dry water course of gradient 1:4 to 1:5 was filled to overflowing, and scoured to a depth of 4–5 ft. in stratified grits (see photographs in the centre of this Magazine). Yet this exceptional erosion and transportation of rock waste only occurred between about 500 ft. and 700 ft. above sea level. Above that height and towards the source of the dry stream bed and where the gradient was less steep (1:6) evidence of abnormal stream flow was completely lacking. Huge angular blocks of grit were dislodged from the stream bed and transported down the mountain side to crash into certain farm outbuildings. It was estimated that 1,000 tons of waste were deposited on and around these demolished buildings, some of the rocks being heavier than four men could lift. Two bullocks were engulfed in the torrent and crushed to death.

Below the farm buildings and further down the mountain side the turbulent waters scoured a trench through a field of wheat 150 ft. long, up to 8 ft. wide and 6 ft. deep. A typical vertical section in this trench showed 18 in. of top soil and the remainder subsoil derived from the underlying grits. The road leading to a neighbouring farm (Tor-y-fron) built of one foot of consolidated ash overlying heavy clay was scoured by a 2 ft. wide trench to a depth of 2–4 ft. (see photographs in the centre of this Magazine).

**Conclusions.**—The steep side of the Llynfi valley, so typical of all mining valleys in south Wales, undoubtedly aggravated the speed and volume of run-off after this exceptional storm. At the Llynfi power station, for example, down stream from Maesteg, the river was observed to rise 7 ft. within 45 min. while the larger Ogwr River, into which the Llynfi flows, rose 5 ft. at Bridgend. A gauging scheme for the mid-Glamorgan rivers has yet to be introduced, and so volumes of discharge for the various streams and rivers are not available. It has been estimated however that, at the peak of the flood, discharge in the Ogwr at Bridgend was of the order of 7,000 cusecs; it would be very difficult to hazard even a guess for the Llynfi discharge.

The effects of the cloudburst on the landscape have been briefly outlined, and from them one is led to agree with what Prof. Austin Miller wrote in connexion with a 1944 cloudburst in the Mawddach Valley in north-west Wales, "The conclusions justify the belief that rivers do their geological work in sudden spurts; one great flood can achieve more erosion and transportation of rock waste than centuries of normal behaviour"<sup>2</sup>. On the other hand one cannot but speculate on what the human effects would have been had the circumstances been but slightly different. In the first instance the fact that the rain fell in a local thunderstorm was important, for it meant that the downpour was limited in its effects. Had the torrential rainfall been more widespread within this densely populated area or occurred further up the Llynfi Valley in the vicinity of Caerau, or even been displaced slightly to the east or west over the neighbouring and densely populated valleys (see built-up areas in Fig. 2), the effects

of the storm would have been catastrophic. Instead, and unique among the mid and east Glamorgan valleys, the Llynfi Valley opens out into a fairly wide strath below Maesteg. The collieries and close settlement of the narrow, trench-like valley up stream of Maesteg are replaced by a few scattered farms in a typically rural setting. Consequently, when the storm impinged over the mountain side south-east of Maesteg and resulted in an exceptional downpour in a limited area, the greatly enlarged Llynfi overflowed its banks in a relatively sparsely-populated area, and acres of meadowland rather than streets of houses were inundated. Equally significant was the fact that the Ogmore River, which is tidal to the town of Bridgend, was able to convey from the Llynfi the additional flow of storm water and discharge it into the Bristol Channel, a discharge which was possible only because the tide in the Channel during the period of the storm was on the ebb. Had the reverse been true and the incoming tide impounded the rush of flood water, the results in the large urban centre of Bridgend would have been incalculable.

**Acknowledgment.**—I have to acknowledge many valuable observations on the storm and its effects which were made by Mr. Lewis W. Jones, Engineer and Surveyor to the Maesteg Urban District Council, Mr. H. W. Adams, Manager and Clerk to the Mid-Glamorgan Water Board and Mr. W. E. Wright, Clerk and Engineer to the Glamorgan River Board.

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### OFFICIAL PUBLICATION

The following publication has recently been issued:—

#### PROFESSIONAL NOTES

*No. 114—A study of warm fronts.* By A. G. Matthewman, M.A.

Some typical features of the structure of warm fronts with respect to temperature, humidity, wind and cloud are examined. An example of detailed analysis of a well marked warm front illustrates the large-scale and small-scale structures of the temperature, humidity and wind fields. The difficulties presented by the small-scale structure are discussed. The cloud structure is examined statistically in relation to the textbook models, and in relation to various parameters, usually or sometimes available to the forecaster. The best correlation of frontal cloud here achieved is with the difference between the speed of the surface front and the actual wind component normal to the surface front at the upper surface of the frontal zone, but this correlation coefficient is only about 0.5.

### ROYAL SOCIETY

#### Radiative balance in the atmosphere

On Thursday, June 9, 1955, from 11 a.m. to 6 p.m. a discussion on the radiative balance in the atmosphere was held in the apartments of the Royal Society at Burlington House, London. There were 13 principal speakers; the earlier contributions were devoted to the lower atmosphere (troposphere and stratosphere) and the later ones to the region above 30 Km. All layers are meteorologically significant in that they give rise to radiative energy exchanges, one of the most important of which is the selective absorption of the incoming solar beam.

The discussion was opened with a general survey by Prof. H. S. W. Massey. To solve the problem of radiative exchange it was necessary to know, for all levels, the composition of the atmosphere, on which depend the absorption spectra and scattering phenomena. It was also necessary to know the distribution with height of one of the quantities, temperature, pressure or



density, the other two being then deducible from the gas equation and the hydrostatic equation. For levels below about 30 Km. the techniques of measuring these quantities are mainly those employed in modern meteorology; above this level direct measurement using rocket-borne instruments has replaced the former indirect methods such as anomalous sound propagation and the observation of meteorites.

Dr. F. Moller considered the flux of infra-red radiation in the troposphere. In the lower and middle layers the most important factors are water vapour, clouds and haze layers. The radiative exchanges correspond to a general cooling in these layers of the order of  $2^{\circ}\text{C./day}$ . Near the tropopause absorption by carbon dioxide outweighs the emissive losses due to water vapour. Slides were presented showing the net radiative cooling at various levels with various types and amounts of cloud.

Mr. A. R. Curtis said that on the basis of reasonable physical assumptions it would be possible with an electronic computer to integrate the equations of radiative transfer with their variable absorption and emission coefficients over the necessary ranges of wave-length and height.

Dr. M. V. Migeotte described the fine structure of various absorption bands in the approximate range  $3\text{--}24\ \mu$  of the solar spectrum, mostly obtained from spectroscopic observations on the Jungfraujoch. With the aid of slides he demonstrated that these bands are very complex; for example, the absorption band of ozone at  $9.6\mu$  when subjected to a high degree of resolution shows over 300 separate absorption lines.

Dr. G. D. Robinson said that recent work at Kew Observatory had been directed to estimating the atmospheric albedo from observations of the solar radiation received at the ground. This involves measuring the intensity of the direct solar beam and the diffused radiation due to scattering by cloud and other particles. These had to be balanced with the values of the solar constant and the absorption by atmospheric constituents which were known, and values of the absorption by dust and cloud particles which it was necessary to estimate. At Kew, for example, the absorption by atmospheric dust was estimated as between 5 and 10 per cent. of the incoming solar energy.

Dr. F. E. Jones, Dr. J. Yarnell and Mr. J. T. Houghton described various aspects of the work of radiation measurement in the upper air using instruments mounted in aircraft. There are numerous difficulties in instrumental technique not the least of which is to keep the spectroscope always pointed towards the sun when observations of the direct solar beam are required. One of the reasons for high-level work is to reduce the amount of carbon dioxide and water vapour between the observer and the sun, and it is found that the obscuration due to these constituents is much reduced at a height of 5 Km. Mr. Houghton described the measurement of the upward and downward components of infra-red radiation with the Houghton and Brewer radiometer mounted in a Mosquito aircraft of the Meteorological Research Flight. The upward flux of radiation was always greater than the downward but both were in reasonable agreement with the values estimated from radiation charts.

Prof. G. M. B. Dobson emphasized the importance for radiative exchanges of the distribution of water vapour and ozone in the stratosphere and upper troposphere, and he outlined the methods of measuring these quantities; both could be determined with satisfactory accuracy. In general, water vapour diffuses upwards and ozone downwards. The very low values of atmospheric water-vapour content (frost point  $189^{\circ}\text{K.}$ ) found at about 15 Km. in the region of the British Isles are remarkable. It seems that they can only be explained by advection from the cold tropical stratosphere; it is suggested that this advection is an important feature of the general atmospheric circulation. It is difficult, however, to understand why the stratosphere in our latitudes does not gain water vapour by diffusion.

The remainder of the discussion, including contributions from Dr. R. M. Goody, Prof. D. R. Bates, Dr. R. L. F. Boyd, and Prof. R. W. Ditchburn, was concerned mainly with the very high levels of the atmosphere above 50 Km. and was of less direct meteorological interest. At those high levels it seems that Kirchhoff's law of radiative emission and absorption requires modification to account for the probable heat exchanges. There was reason to believe that at 200–300 Km. the temperature is of the order  $700\text{--}800^{\circ}\text{K.}$ , while at the outer fringe of the atmosphere it is necessary to assume a temperature of  $1,500^{\circ}\text{K.}$  to account for the escape of helium.

## LETTER TO THE EDITOR

### Unusual halo phenomena

On February 5, 1955 at Wrexham there was a minor halo complex which was notable for the virtual absence of the halo of  $22^{\circ}$  and the persistence throughout the day of a brilliant arc of contact of the halo of  $22^{\circ}$ .

A period of continuous sleet in the early morning came to an end at 0845; by 0840 the low cloud had all dispersed leaving the sky uniformly covered with grey altostratus, through which the sun was visible, accompanied by a bright

upper arc of contact to the halo of  $22^{\circ}$  and a sun pillar extending right up to that arc. Both these phenomena lasted practically all day afterwards, the former being particularly prominent, and one was able to watch continuously its change of shape with varying solar altitude. The sun pillar became a little shorter after 0930, but an inferior pillar of about  $5^{\circ}$  formed as well; and the upper part persisted until 1500. The arc of contact remained until 1600. The halo of  $22^{\circ}$  was seen on three occasions for a few minutes only, and was fragmentary and very faint. The left parhelion was visible from 0903 to 0920, and the right parhelion briefly at 0950. The upper part of the halo of  $46^{\circ}$  was visible for some time from 1147, and it was brighter than the halo of  $22^{\circ}$  had been.

S. E. ASHMORE

11 Percy Road, Wrexham, February 20, 1955

## NOTES AND NEWS

### Unusually low temperatures in Hong Kong

On the night of January 11–12, 1955 the minimum air temperature at the R.A.F. Station Sek Kong was  $26.5^{\circ}\text{F}$ . This is the lowest temperature recorded in the colony of Hong Kong since records were begun in 1884. The previous lowest was  $32^{\circ}\text{F}$ . in January 1893 at the Royal Observatory in the town of Kowloon. However, meteorological observations have been made at Sek Kong only since April 1951, and it is probable that even lower temperatures have occurred there in the more distant past.

On the morning of the 12th the aerodrome was extensively covered with hoar frost—a very rare sight in Hong Kong.. Unfortunately, no grass minimum thermometer is used at Sek Kong and the temperature near the ground was not measured. The night had been cloudless with little or no surface wind. The minimum temperature at the Royal Observatory on the same night was  $41.3^{\circ}\text{F}$ . On the previous night the minimum at Sek Kong was  $35.6^{\circ}\text{F}$ . and at the Observatory  $37.6^{\circ}\text{F}$ . The latter temperature was the lowest for 55 yr. at the Observatory.

This remarkably cold spell of weather was caused by a strong surge of the winter monsoon on the western side of a depression which had moved eastwards across Japan. Very cold air from western Manchuria swept southwards across the eastern part of China.

Sek Kong is about 30 ft. above M.S.L., situated in a narrow valley about six miles south of the Chinese border. There are hills to 1,800 ft. on its north side, to 3,000 ft. on its east side and to 1,500 ft. on its south side. There is generally low ground to the west.

The latitude of Sek Kong is  $22^{\circ}26'\text{N}$ . The highest temperature recorded there during the last 3 yr. is  $96.8^{\circ}\text{F}$ . This compares with the absolute maximum of  $97^{\circ}\text{F}$ . recorded at the Royal Observatory in 1900.

R. G. HUGHES

### An exceptionally cold day in May

May 17, 1955, will find a place in meteorological history as an exceptionally cold day for the time of year in many southern and central districts of England and Wales, and also as a day of unusually late snowfall.

On May 10 there was a sharp fall of temperature of more than  $10^{\circ}\text{F}$ . over much of the country due to an influx of arctic air around the eastern side of an

anticyclone near Greenland. This cold northerly air stream persisted for more than a week, but was temporarily interrupted on the 17th by a depression which moved from Scilly across southern England to the southern North Sea. Heavy rain fell in south-east England as the depression approached, but after its passage the wind reverted to a northerly direction with renewed strength, frequently reaching gale force, while the rain turned to sleet or snow in many places. There had been fairly extensive ground frost in the north during the night—the minimum air temperature fell to 32°F. at Dyce and to 35°F. at Aldergrove—and this cold surface air was quickly brought southward by the gale-force winds.

The maximum temperature during the day was only 36°F. at Aberystwyth (Llety-evan-hen), Cardiganshire, and was 39°F. or lower at a number of other places in Wales and in the Pennines from Buxton to Moor House. There were many stations where the temperature rose no higher than 40°F., but among the lower-level stations the most notable was Ross-on-Wye where 40°F. was the lowest maximum temperature recorded in May since temperature records were first taken in 1875, and 2°F. lower than the previous lowest on May 13, 1915. During this long period there were only two other days in May—May 13, 1915 and May 3, 1892—when the maximum day temperature was below 45°F.

Over a wide area in Wales, the Midlands and southern England, as the wind backed to north behind the depression and the temperature fell by several degrees, rain turned to sleet or snow. Birmingham experienced its worst May snowstorm for 60 yr.; there were 26½ hr. of continuous precipitation which included a period of 8 hr. of sleet and about 2 hr. of snow. Further north 4 in. of snow fell at Malham Tarn and several roads were blocked by snow drifts in the Peak District, one by a drift 3 ft. deep. In the evening snow and sleet were reported from many places in the south and east, including the London area; snow fell for over an hour at Bournemouth, and in east Yorkshire and the east Midlands it lay extensively to a depth of over 1 in. Parts of Wiltshire and north Dorset had the worst mid-May snowstorm in the memory of the local people; snow fell all day accompanied by a high wind, and in many places snow lay to a depth of 3 in. In south Wales 3 or 4 in. of level snow lay extensively in the Merthyr, Brecon and Neath districts. Snow had not occurred so late in the year since 1902 at Bedford.

R. E. BOOTH

### **Funnel cloud at Luton, June 8, 1955**

We are indebted to Mr. E. Pestell for the photograph of a funnel cloud facing p. 280 which was taken from Luton Airport at about 1430 G.M.T. on June 8, 1955. Notes on the phenomenon have been provided by him and by Mr. C. V. Smith, who observed it from near the Meteorological Office, Dunstable.

The cloud appears to have been over the outskirts of Luton, and both there and at Dunstable it was raining heavily at the time, with some thunder. Mr. Pestell first noticed that about two miles away two clouds were beginning to amalgamate and rotate. Their height was estimated at 800–1,000 ft. and this was later confirmed by aircraft observations. After 3–5 min. the funnel cloud extended apparently down to the ground over a hill about two miles away west-south-west from the airport. It then seemed to Mr. Pestell to recede

as quickly as it had developed, but according to Mr. Smith it took 10–15 min. to dissipate gradually from the ground upwards, during which time it travelled north-east with the main body of cloud, trailing at an angle of about  $45^\circ$  to the vertical. As the decaying funnel cloud passed over Luton Airport black specks which might have been leaves or birds were seen whirling around in it. It was not raining at the airport when the cloud passed overhead, but some minutes afterwards a heavy thunderstorm broke out there and lasted for about two hours.

Weather had been thundery over the southern half of England since June 4. The instability developed ahead of a cold depression which was moving eastwards into the Bay of Biscay. A weak frontal belt extended east-west and may have contributed to the development, but winds were light at all levels in this region.

### **Retirement of Mr. P. N. Skelton, M.B.E.**

Mr. P. N. Skelton, Head of the Instrument Supply Branch of the Meteorological Office, retired on July 9, 1955, after nearly 49 years' service in the Meteorological Office. Mr. Skelton, who was born at East Molesey, Surrey, in 1890, was educated at Alleyn's School, Dulwich and in H.M.S. *Worcester*. Having obtained a Board of Trade First-Class Certificate in Seamanship he was offered an appointment with the British India Steam Navigation Company but had to refuse it because his eyesight was below the acceptable standard.

Mr. Skelton joined the Meteorological Office at 63 Victoria Street as a Probationer in 1906. During his first year he worked in the Library under R. G. K. Lempfert and T. Duncan Bell and also on the *Weekly Weather Report* under A. J. Rigby and C. W. Heinemann. In 1907 he moved into the Instruments Branch under E. Gold and R. F. Wallace, but during the mornings he helped in the "telegraph room" where the *Daily Weather Report* was reproduced by "jellygraph". For the following three years Mr. Skelton was engaged in tabulating autographic records in the "Observatories' Room" at Victoria Street under R. H. Curtis and J. Sherman. He continued on similar work for three years after the Office moved to South Kensington. From 1913 to 1919 Mr. Skelton was at Eskdalemuir Observatory, first under L. F. Richardson and later under A. Crichton-Mitchell. For the first half of this period Mr. Skelton was in charge of the meteorological observations of the Observatory and, for the second half, the magnetic observations. In 1919 he rejoined the Instrument Branch, then under R. Corless, and continued in this part of the Office for the 36 years until his retirement. When, in the reorganization of the Office in 1948, an Instruments Division of three branches was set up, Mr. Skelton was appointed Head of the Branch concerned with the supply, testing and maintenance of equipment.

Mr. Skelton has always appeared as a tower of strength to his colleagues. When he was faced with the task of transferring the Meteorological Office Stores from South Kensington to Stonehouse, Gloucestershire, at the outbreak of the Second World War, and the much bigger task of moving to Harrow after the war, he took everything in his stride, and it was largely due to his efficient organization that these major operations were carried out so smoothly. His willingness to lend a helping hand when difficulties arise is a characteristic well known to those who worked with him. His long experience in instrument

work gave him an encyclopaedic knowledge which, together with his technical ability, has been of very great service to the Meteorological Office. In 1942 he was appointed a Member of the Order of the British Empire, a well deserved honour which all his colleagues applauded. He was promoted in 1952 to the first Chief Experimental Officer post created in the Office. With his nautical education it was natural that Mr. Skelton's recreations should be aquatic. He was a good oarsman, a swimming champion of H.M.S. *Worcester*, and he took a prominent part in the swimming galas which the Meteorological Office at Stonehouse was able to hold during the last war.

Colleagues throughout the Meteorological Office contributed to a gift to Mr. Skelton on his retirement, and this was presented to him by Dr. F. J. Scrase at a large gathering at Harrow on July 8. All his colleagues wish Mr. Skelton a long and happy retirement.

## REVIEWS

*The English climate.* By C. E. P. Brooks. 8 in.  $\times$  5½ in., pp. 214, *Illus.*, English Universities Press Ltd, 1954. Price: 12s. 6d.

This book gives a fascinating account of our climate as it affects us all in our everyday lives. Sir David Brunt in his foreword rightly says that Dr. Brooks has made climatology a subject of live human interest, and points out that too often in the past have books on climatology been crammed with indigestible facts. Perhaps the outstanding feature of the book is that even though it contains a wealth of information, particularly facts about unusual weather in the past, it is written in such a way that the dry figures come alive. It thus has the merit of being both a reference book for the professional meteorologist and a popular exposition of the subject which will hold the attention of anyone who takes an interest in the weather of these islands.

In his "Introduction" Dr. Brooks sets the scene with an account of the effects on its climate of Britain's position in the world. Chapters 2-5 deal with the effects of our physical situation in more detail. Chapter 2—Winds and warmth—shows how markedly winds from different directions control our weather and describes the characteristics of the main air masses which we experience. Chapter 3—Storms and squalls—after explaining briefly the development of depressions, discusses some outstanding storms, squalls and tornadoes, including an interesting reconstruction of the pressure distribution of the storm of November 1703 which was described by Daniel Defoe. A map showing the tracks of tornadoes which have occurred in England since 1638 is of special interest. Chapter 4—Rain, snow and hail—deals with the distribution of these elements, and also that of thunder, with special reference to some of the noteworthy floods, droughts, snowstorms, etc. of the past. There are two maps which, so far as the reviewer is aware, have not appeared elsewhere; one showing the average annual number of wet days and the other the distribution of what Dr. Brooks calls "raininess"—a combination of total amount of rain and its duration. Chapter 5—Fog and soot—describes the different types of fog and refers to notable London fogs of the past and to their effects, both on materials and mortality statistics. A map of the dirtiness of London's air based on data from various sources is of special interest; it shows, for example, how the parks form comparatively clean areas. Dr. Brooks quotes the example of Pittsburgh in the United States as showing that although the fog menace is

constantly extending it is by no means insuperable. Chapters 6—Local climate—and Chapter 7—Climate and fitness—are perhaps the most interesting in the book. The first deals with the effects of type of soil, exposure and aspect, trees, houses and nearby water on the general climate. The second emphasizes the importance of changes in weather on health and energy, and outlines the present position in the largely unexplored field of bioclimatology. The author discusses the qualities which make a climate “bracing” or “relaxing”, and is forced to the conclusion that it would be difficult to evaluate the bracing quality of a place from its meteorological statistics. Nevertheless he includes a map of bracing and relaxing climates, based on the assessments of Dr. Hawkins published over 30 years ago, which agrees fairly well with climatological expectations. The reviewer was surprised to note that Southport, where he lived for many years and always regarded as “relaxing” at least in the summer months, is included in a “bracing” area on the map. He cannot help feeling that a place which on the average has bracing characteristics may quite often be relaxing, particularly in summer when winds on the whole are lighter, and that one which is generally relaxing can often be bracing, particularly in winter. The chapter also includes a first attempt to map what Dr. Brooks calls the “energetics” of our climate. In preparing this he has taken into account, with what appear to be reasonable weighting factors, mean temperature, variability of temperature, frequency of thunder, number of wet days, sunshine and cleanness of the air. It suggests that the best places are along the south coast while the worst are industrial Lancashire, Glasgow and the extreme west of Scotland, but the author emphasizes that the range is not large considered on a world scale. Chapter 8—Where to live; where to holiday—is a practical summary of the two preceding chapters. Chapter 9—Seasons, saints and spells of weather—introduces the controversial topic of singularities and discusses their reality and possible causes. The main results of an investigation which Dr. Brooks, with the late Dr. J. E. Belasco, conducted in 1941–42 are set out, and are discussed further in the next four chapters, where these singularities form a background against which the weather of each season is discussed with special reference to outstanding occurrences in the past. It is unfortunate that the singularity graphs, as in the original article in *Weather*, are on too small a scale for the reader to extract with confidence the value for a particular day. This difficulty is emphasized when it is found that the actual values quoted on p. 140 do not always appear to fit the graphs. The tables in Chapters 10–13 which list the outstanding events in our weather history should be of special value for quick reference. It was of special interest to note that the February cold wave from Iceland, one of the singularities dealt with in some detail in Chapter 10, was strongly reproduced in 1955, when the sequence of events corresponded remarkably well with Dr. Brooks’s Fig. 21. Chapter 14—Weather cycles and other prognostics—completes the book proper with an account of various periodicities and sequences in our weather which have been found or postulated by meteorologists, but concludes that there are no known methods of forecasting for more than a few days ahead, only statistical probabilities based on past weather which may go all wrong. Summing-up, Dr. Brooks considers that in spite of its occasional ugly moods our climate is one of the best in the world, the largest item in its favour being its health-giving variety. Chapter 15—The daily weather map—appears to have been added as an afterthought and might better have been called an Appendix. It briefly

describes the surface synoptic chart, the weather charts that were televised by the B.B.C. at the time the chapter was written and the televised road weather maps.

A number of minor errors and obscurities were noted in the text and these will probably be corrected in a future edition, but a few of the more important may be mentioned here. In the table on p. 14, the source of which is not quoted, the figures for Scotland add up to 345 instead of 365; the number of days with NW. winds should perhaps be 41 instead of 21. On p. 32 we are told that line-squalls was the name formerly given to fronts; this presumably refers only to cold fronts. On p. 51 it is stated that thunder is most frequent in the southern Midlands; this is in conflict with p. 59 where it is stated, more correctly, that the greatest frequency is in Nottinghamshire. The table on p. 127 lists the main monsoon period of June 18–July 6 as an anticyclonic singularity, while the larger table on pp. 130–131 contains a column headed “Number” the meaning of which, namely “Frequency at peak date”, could only be discovered by reference to the original paper in *Weather*. On p. 146 mean temperature at night is referred to when minimum temperature is clearly intended. The source of the dates of maxima and minima of daily rainfall in London given on p. 169 is not stated; they are not in agreement with the Kew Observatory data 1871–1950. Also, it is unfortunate that the specimen road weather maps in Fig. 27 are inconsistent with the commentary on them on p. 211.

The book is well produced and the illustrations are generally adequate. The low price, in these days of high production costs, helps to make it very good value indeed and a “must” on every meteorologist’s bookshelf.

H. C. SHELLARD

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*Meteor astronomy.* By A. C. B. Lovell. *Int. Ser. Monogr. Phys.*, 9½ × 6 in., pp. xvi + 464. *Illus.*, Geoffrey Cumberlege, Clarendon Press, Oxford, 1954. Price: 60s. net.

The study of meteors has been revolutionized since 1945 by radar observations. It was suggested in 1929 that meteors might be responsible for the observed sudden increases in the ionization of the ionosphere, and correlation of the visible flight of a meteor and a burst of ionization was obtained in 1932. It was not, however, until 1945 that radio methods, using British military radar sets, were systematically applied to the study of meteors. The radar echoes from most meteors are reflections from the ionized trail behind the meteor. A few meteors also produce strong reflection from the head of the meteor. The use of radar has, in particular, revealed the existence of great day-time showers of meteors.

The author of this book, Prof. Lovell, has been a leader in the application of radar methods to the observation of meteors. The book is not however devoted to radar methods alone. It is a comprehensive treatise on the masses, speeds and directions of motion of meteors based on old and new visual observations as well as on radar.

It does not deal with the physics of meteors to which the author hopes to devote another volume. The parts of the book of particular meteorological interest are those on the mass of meteoric material entering the atmosphere, in view of the recent suggestion by E. G. Bowen that meteoric dust may produce noctilucent clouds and condensation nuclei in quantities varying sufficiently to lead to variations in rainfall, and on the zodiacal light.

There are two types of meteor, the sporadic ones which appear quite irregularly and the "shower" ones which recur annually, though with marked variations from year to year, during short fixed periods. The showers are named after the stellar constellations, e.g. Geminids from the constellation Gemini, from which they appear to emerge. Using an assumption due to the American astronomer W. F. Watson relating the luminosity and mass of a meteor it is found that the sporadic meteors with 485,000 Kg. bring annually much more meteoric material into the atmosphere than the "shower" ones which account for 130,400 Kg. Roughly 10,000 Kg. of the shower mass is attributable to four major showers of which the Arietid and Perseid showers of June contribute 41,500 Kg. Thus, though the "sporadic" mass greatly outweighs the "shower" mass over the year as a whole, during the two or three days during which major showers occur the "shower" mass markedly outweighs the average "sporadic" mass. The book concludes with a discussion of the work of van de Hulst and Öpik on the relation between meteors and the particles which, by scattering sunlight, produce the zodiacal light. Van de Hulst's theory, based on the assumption that the size distribution of the scattering particles is the same as that of meteoric matter which gives their radii as predominantly between 0.1 and 1 mm., requires a density of scattering material some 10,000 times that inferred from meteor observations unless, as that writer has suggested, the particles are moving with velocities small relative to the earth. Öpik has shown that for astronomical reasons van de Hulst's explanation cannot be correct, and has suggested that very small particles are much more numerous in the zodiacal-light particles than would be inferred from available observation of meteors. Solution of the discrepancy awaits observation of very faint meteors produced by particles less than  $10^{-3}$  cm. in diameter.

Meteorologists will look forward to the publication of Prof. Lovell's work on the physics of meteors, because of the important connexion between that subject and the structure of the upper atmosphere.

G. A. BULL

## METEOROLOGICAL OFFICE NEWS

**Academic successes.**—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

*Associate of the Royal College of Science (A.R.C.S.):* Second Class Honours in Physics, J. B. Andrews.

*City and Guilds—Telecommunications (Principles):* Grade III, J. W. O. Rowe; Grade I, M. R. G. Sea (First Class pass).

**Horticultural show.**—The Air Ministry Horticultural Society held their annual show at Whitehall Gardens on July 12. The staff of the Office were represented in all three sections—flowers, fruit and vegetables. Miss H. G. Chivers, in addition to gaining prizes for flowers and fruit, was awarded (for a dish of superb red currants) the prize for the "best exhibit in the show". Other prize winners were Miss D. J. Wordsworth (flowers) and Mr. H. A. Scotney (flowers and fruit).

## WEATHER OF JULY 1955

Pressure and temperature were decidedly below normal over most of the polar regions. The greatest anomalies were  $-8$  mb. and  $-3^{\circ}\text{C.}$ , both over Greenland, as part of an extensive cold



trough stretching far south into the western Atlantic, which seems to have been the most stationary feature of the atmospheric circulation in temperate latitudes during the month. Pressure was also 5 mb. below normal in another great trough extending to quite low latitudes over eastern Asia. East of the Atlantic cold trough the Azores anticyclone extended north-eastwards in a great quasi-permanent ridge of high pressure across the British Isles to northern Scandinavia and Finland, the greatest anomalies of +7 to +8 mb. falling over northern Ireland, Scotland and central Norway. Pressure was 2-3 mb. below normal over the Mediterranean.

Temperature was a little above normal over most of Europe and 2-4°C. above normal over much of the United States east of the Rockies.

Less than half the normal July rainfall was collected over most of Britain and Scandinavia, but there was excessive rain, up to three times the July normal, over central Germany and the Alps. Appreciable rain broke the dry season over Italy, Malta and Spain. Rain also fell in the Sahara south of 25°N. Rainfall was above normal over most of North America, especially the Rocky Mountains where over twice the usual falls occurred in many places, but a belt of dryness with only 30-50 per cent. of the normal rain extended from the Arctic coast of north-west Canada across all the north-eastern half of Canada to Newfoundland.

In the British Isles, apart from the first few days of the month when depressions moved eastward across Scotland, the weather was anticyclonic, with high pressure from the Azores region to Scandinavia, practically the entire month.

On the 1st widespread rain with local thunder accompanied a depression and its associated trough as it moved eastward across the country. The following day was generally sunny in the east, but a small and deepening depression from the Atlantic reached north-west Ireland late that evening bringing heavy rain to the west; several stations at 0900 on the 3rd measured 1½ in. of rain, which had fallen in 12 hr. Behind the depression on the 4th pressure over the country rose considerably and this began a spell of fine warm anticyclonic weather, with little rain apart from thunderstorms, which lasted till the end of the month. The weather had been cool for the first five days but a brilliantly sunny day over England and Wales on the 6th, when there were over 15 hr. of sunshine in the Channel Islands and south-west England, brought temperatures into the seventies in many places. On the islands and coasts of north and west Scotland sea fog and low cloud kept temperatures in the fifties for most of the month. The highest recorded temperatures on the 6th were in eastern Scotland where Dyce recorded 80°F. For much of the month the weather followed the same pattern day after day; easterly winds brought cloud inland at night, but this cleared from most areas during the morning to give fine warm days, except on the east coast where temperature was persistently below normal. The warmest period of the month was from the 11th to the 18th when temperature at Kew and many other places in south-east England rose above 80°F. daily and on the 17th reached 88°F. at London Airport. Thunderstorms, although scattered, occurred frequently during this period, and were often of unusual severity and accompanied by torrential rain, particularly on the 14th and 18th. On the 14th 1.02 in. of rain fell at Blandford, Dorset in 15 min., and at Croydon 0.79 in. fell from 1615 to 1630. Wind rose to 50 kt. in a squall at Croydon at 1620 during this storm although the mean hourly wind speed was only about 7 kt. A "very rare" fall occurred at Gnull Reservoir, Neath, Glamorgan, on the 18th during a severe thunderstorm when 3.37 in. was recorded in 90 min. During heavy storms in south Dorset, which caused severe flooding, Weymouth and Dorchester each registered 7½ in. during 24 hr., of which 2.5 in. fell at Weymouth from 1530 to 1700. The highest total in 24 hr. that day was recorded at Upwey, Dorset, with 9.5 in. In spite of the large rainfall amounts recorded locally, July on the whole was a remarkably dry month with a long period of drought over most of the country. Over much of the west and Midlands there was no measurable rain from the 3rd or 4th till the end of the month, and even in the east most places had at least 15 consecutive days without rain. Many places had their driest July on record and, with a total of only 0.1 in. of rain, Gorleston had the driest July since records began in 1871. Sunshine was also an outstanding feature of the month. Many places, particularly in the western part of the country, exceeded their previous best totals for July; at Southport it was the sunniest month on record since before 1896. At many places it was the warmest July since 1939.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	90	34	+1.9	37	-10	146
Scotland ...	87	29	+3.0	37	-12	172
Northern Ireland ...	82	40	+2.3	51	-14	184

# RAINFALL OF JULY 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	0·23	10	<i>Glam.</i>	Cardiff, Penylan ...	0·59	19
<i>Kent</i>	Dover ...	0·79	37	<i>Pemb.</i>	Tenby ...	0·40	13
"	Edenbridge, Falconhurst	2·37	103	<i>Radnor</i>	Tyrmynydd ...	1·22	30
<i>Sussex</i>	Compton, Compton Ho.	0·80	28	<i>Mont.</i>	Lake Vyrnwy ...	1·16	33
"	Worthing, Beach Ho. Pk.	0·08	4	<i>Mer.</i>	Blaenau Festiniog ...	3·70	43
<i>Hants.</i>	St. Catherine's L'thouse	0·36	18	"	Aberdovey ...	0·85	24
"	Southampton (East Pk.)	1·33	58	<i>Carn.</i>	Llandudno ...	0·53	22
"	South Farnborough ...	0·47	23	<i>Angl.</i>	Llanerchymedd ...	1·32	46
<i>Herts.</i>	Harpenden, Rothamsted	0·20	9	<i>I. Man</i>	Douglas, Borough Cem.	2·58	84
<i>Bucks.</i>	Slough, Upton ...	0·66	34	<i>Wigtown</i>	Newton Stewart ...	1·77	56
<i>Oxford</i>	Oxford, Radcliffe ...	0·29	12	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·96	60
<i>N'hants.</i>	Wellingboro' Swanspool	0·15	7	"	Eskdalemuir Obsy. ...	2·56	62
<i>Essex</i>	Southend, W. W. ...	0·59	30	<i>Roxb.</i>	Crailling ...	2·00	69
<i>Suffolk</i>	Felixstowe ...	0·14	7	<i>Peebles</i>	Stobo Castle ...	3·16	109
"	Lowestoft Sec. School ...	0·25	11	<i>Berwick</i>	Marchmont House ...	2·42	79
"	Bury St. Ed., Westley H.	0·00	0	<i>E. Loth.</i>	North Berwick Gas Wks.	1·87	73
<i>Norfolk</i>	Sandringham Ho. Gdns.	0·30	12	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·56	55
<i>Wilts.</i>	Aldbourne ...	0·17	7	<i>Lanark</i>	Hamilton W. W., T'nhill	1·44	50
<i>Dorset</i>	Creech Grange ...	1·06	43	<i>Ayr</i>	Prestwick ...	1·27	52
"	Beaminster, East St. ...	4·57	176	"	Glen Afton, Ayr San. ...	2·30	55
<i>Devon</i>	Teignmouth, Den Gdns.	2·79	120	<i>Renfrew</i>	Greenock, Prospect Hill	1·04	28
"	Ilfracombe ...	1·07	42	<i>Bute</i>	Rothsay, Arden Craig ...	1·11	28
"	Princetown ...	1·43	27	<i>Argyll</i>	Morven, Drimnin ...	0·74	17
<i>Cornwall</i>	Bude, School House ...	1·64	67	"	Poltalloch ...	1·40	34
"	Penzance ...	0·12	4	"	Inveraray Castle ...	1·92	39
"	St. Austell ...	0·18	5	"	Islay, Eallabus ...	0·36	11
"	Scilly, Tresco Abbey ...	0·09	4	"	Tiree ...	0·39	11
<i>Somerset</i>	Taunton ...	1·48	70	<i>Kinross</i>	Loch Leven Sluice ...	1·36	47
<i>Glos.</i>	Cirencester ...	0·14	5	<i>Fife</i>	Leuchars Airfield ...	1·22	47
<i>Salop</i>	Church Stretton ...	0·87	33	<i>Perth</i>	Loch Dhu ...	1·54	32
"	Shrewsbury, Monkmore	1·31	62	"	Crieff, Strathearn Hyd.	1·14	38
<i>Worcs.</i>	Malvern, Free Library ...	1·27	56	"	Pitlochry, Fincastle ...	0·40	15
<i>Warwick</i>	Birmingham, Edgbaston	0·43	17	<i>Angus</i>	Montrose, Sunnyside ...	0·66	25
<i>Leics.</i>	Thornton Reservoir ...	1·03	42	<i>Aberd.</i>	Braemar ...	0·74	29
<i>Lincs.</i>	Boston, Skirbeck ...	0·35	16	"	Dyce, Craibstone ...	0·83	27
"	Skegness, Marine Gdns.	0·52	24	"	New Deer School House	0·50	16
<i>Notts.</i>	Mansfield, Carr Bank ...	1·14	44	<i>Moray</i>	Gordon Castle ...	0·95	30
<i>Derby</i>	Buxton, Terrace Slopes	1·21	31	<i>Nairn</i>	Nairn, Achareidh ...	0·59	23
<i>Ches.</i>	Bidston Observatory ...	0·57	22	<i>Inverness</i>	Loch Ness, Garthbeg ...	0·54	17
"	Manchester, Ringway ...	0·92	28	"	Glenquoich ...	...	...
<i>Lancs.</i>	Stonyhurst College ...	1·06	27	"	Fort William, Teviot ...	1·50	31
"	Squires Gate ...	1·77	64	"	Skye, Broadford ...	0·97	18
<i>Yorks.</i>	Wakefield, Clarence Pk.	0·57	23	"	Skye, Duntuilum ...	1·32	35
"	Hull, Pearson Park ...	0·77	33	<i>R. &amp; C.</i>	Tain, Mayfield ...	0·40	15
"	Felixkirk, Mt. St. John ...	1·19	44	"	Inverbroom, Glackour ...	0·44	12
"	York Museum ...	1·04	41	"	Achnashellach ...	1·71	35
"	Scarborough ...	1·17	48	<i>Suth.</i>	Lochinver, Bank Ho. ...	0·82	27
"	Middlesbrough ...	1·15	45	<i>Caith.</i>	Wick Airfield ...	0·35	13
"	Baldersdale, Hury Res.	1·16	40	<i>Shetland</i>	Lerwick Observatory ...	0·83	36
<i>Nor'l'd.</i>	Newcastle, Leazes Pk. ...	1·01	39	<i>Ferm.</i>	Crom Castle ...	1·56	45
"	Bellingham, High Green	1·69	51	<i>Armagh</i>	Armagh Observatory ...	1·83	63
"	Lilburn Tower Gdns. ...	1·68	68	<i>Down</i>	Seaforde ...	3·65	114
<i>Cumb.</i>	Geltsdale ...	1·78	52	<i>Antrim</i>	Aldergrove Airfield ...	1·23	44
"	Keswick, High Hill ...	2·63	68	"	Ballymena, Harryville ...	1·16	34
"	Ravenglass, The Grove	3·35	89	<i>L'derry</i>	Garvagh, Moneydig ...	1·09	34
<i>Mon.</i>	A'gavenny, Plâs Derwen	0·13	5	"	Londonderry, Creggan	1·07	29
<i>Glam.</i>	Ystalyfera, Wern House	2·13	46	<i>Tyrone</i>	Omagh, Edenfel ...	1·51	44

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## MAXIMUM CONCENTRATION AT GROUND LEVEL OF GAS FROM A HEATED ELEVATED SOURCE

By A. C. BEST, D.Sc.

**Introduction.**—Many industrial chimney stacks emit gases which, in sufficiently high concentrations, are harmful to health, and it is a matter of considerable importance to be able to assess the maximum concentration at ground level of these gases. The effect of a specified concentration of gas varies with the individual, and on this account great accuracy in predicting the concentration is not essential.

When the chimney stack is being designed the place where the maximum ground-level concentration will occur and the meteorological conditions leading to it (provided they are not unrealistic) are almost irrelevant. The design should be such that a harmful ground-level concentration never occurs anywhere.

If the effluent has the same density as the ambient air and is discharged without significant vertical speed, there is no real difficulty. Sutton<sup>1</sup> has given a formula which can be used to compute ground-level concentrations at various distances from the stack. But if the effluent experiences significant vertical movement after leaving the stack—either because the effluent is heated or because it is discharged with significant vertical speed—the problem is more difficult. Generally in such circumstances the gas plume will be vertical at the stack exit, but at any greater height it will bend over in the direction of the wind. At great distances from the stack the centre line of the plume will be practically horizontal and at some level above the top of the stack. An approximate method of computing ground-level concentration is thus to treat the source as a cold source emitting with zero vertical speed, but to assume that the source is raised by an amount  $z$  equal to the height of the plume above the source at a distance where the plume is practically horizontal. In order to use this method it is necessary to know how to compute the “height of rise” of the plume. The purpose of the present note is to compare the effects of three formulae for this height of rise on the maximum ground-level concentration.

**Maximum ground-level concentration from an elevated source.**—Sutton<sup>1</sup> has shown that if the effluent has the same density as the atmosphere and is emitted without significant vertical motion the concentration at ground level increases with increasing distance from the source up to a critical distance and then decreases again. The maximum concentration at ground level is given by

$$\chi = \frac{2Q}{\epsilon\pi u h^2} \left( \frac{C_z}{\bar{C}_y} \right) \dots\dots\dots (1)$$

and occurs at a distance  $x$  given by

$$x = \left( \frac{h^2}{C_z^2} \right)^{1/(2-n)}, \quad \dots\dots\dots (2)$$

where  $Q$  is the strength of source,  $u$  the wind speed,  $h$  the height of source above ground,  $C_y$  and  $C_z$  the usual turbulence coefficients in Sutton's diffusion theory, and  $n$  a parameter which depends upon the stability of the atmosphere.

Sutton suggests that, with  $n = 0.25$ , equations (1) and (2) will give satisfactory results in conditions of small temperature gradient and moderate wind.

If the source is assumed to be raised to a height  $z$  above the top of the stack equation (1) should be replaced by

$$\chi = \frac{A}{u(h+z)^2}, \quad \dots\dots\dots (3)$$

where  $A [= (2Q/e\pi)(C_z/C_y)]$  is a parameter which is independent of stack design,  $u$  and  $h$ . It is intuitively obvious that  $z$  will decrease as  $u$  increases and it is convenient here to consider the effect of expressing  $z$  as a power of  $u$ . Suppose

$$z = \frac{B}{u^p}, \quad \dots\dots\dots (4)$$

then  $\chi$ , the maximum gas concentration at ground level at any distance from the stack, will be a function of  $u$ . It is easily verified that  $\chi$  has a maximum value with respect to  $u$  given by

$$\chi_{\max} = \frac{A}{B^{1/p}} \frac{1}{h^{2-1/p}} \frac{(2p-1)^{2-1/p}}{4p^2} \quad \dots\dots\dots (5)$$

$$u^p = \frac{B(2p-1)}{h} \quad \dots\dots\dots (6)$$

$$z = \frac{h}{2p-1}. \quad \dots\dots\dots (7)$$

For planning purposes it is the value of  $\chi_{\max}$  which is of interest provided the corresponding value of  $u$ , given by equation (6), is within the range of values likely to be experienced. For these same purposes the distance at which this value of  $\chi_{\max}$  occurs is unimportant in a densely populated country. The value of  $z$  is irrelevant except as an intermediate parameter introduced as a means of facilitating the computations.

**Formulae for the height of rise of a heated plume.**—There have been several formulae quoted for the value of  $z$ . Sutton<sup>1</sup> deduces a value based upon the heat output from the stack, the conservation of energy and the trajectory of a particle having a constant horizontal speed and a decaying vertical speed. Explicitly he takes  $z$  to be the height of the particle above the origin when the inclination of the trajectory to the horizontal is  $10^\circ$ . The formula thus obtained for  $z$  is of the form of equation (4) with  $p$  having the value 3 and  $B$  dependent upon various physical parameters, upon the air temperature and upon the heat output from the stack.

Bosanquet, Carey and Halton<sup>2</sup> have treated the motion of the heated plume as a problem in rate of dilution by the ambient air owing to the motion of the plume relative to the ambient air, both longitudinal and transverse, and to eddy motion. The formula finally reached for the height of rise is somewhat

complicated and will not be repeated here explicitly. It should be noted, however, that the formula involves the gradient of potential temperature in the ambient air.

Another formula, having a purely empirical basis, has been suggested from America<sup>3</sup>. This third formula again has the same form as equation (4) with the value 1 for  $p$ .

Explicit comparison of the three formulae mentioned is far from straightforward since they do not contain the same parameters. In order to compare the three formulae indirectly,  $z$  was computed by each method for four different values of heat output from the stack and for three different wind speeds. The heat outputs chosen varied from  $2.5 \times 10^6$  to  $5 \times 10^7$  cal./sec. If the stack is part of a power station it is believed that the corresponding power outputs would be, approximately, 50 and 1,000 MW. respectively. The selected wind speeds were 10, 15 and 20 ft./sec. In order to make the computations it was necessary to make assumptions concerning the characteristics of the stack, the effluent and the ambient air. The assumptions adopted were that the exit speed from the stack is 50 ft./sec., the effluent has the physical properties of air, the ambient and effluent temperatures are 288° and 423°A. respectively, and the atmospheric potential temperature increases upwards by 1°C./1,000 ft. (This last assumption is needed only for the formula of Bosanquet, Carey and Halton.) The results were discordant by a factor which varied from 2 to 30 according to the circumstances. For our present purpose, however, it was notable that the disagreement between the three formulae was least when the height of rise  $z$  was least, i.e. when the ground concentration of gas would be greatest.

Although this comparison may be said to be appropriate to a scientific assessment of the three formulae we are here concerned with the more practical problem of how to assess the maximum gas concentration (irrespective of distance from stack and ambient conditions) which may occur at ground level. If the three formulae imply that the maximum ground-level concentration will be found at three different distances and in three different sets of ambient conditions those facts are irrelevant to the planning of the chimney stack provided the ambient conditions for maximum concentration are reasonably likely to occur.

**Comparison of the formulae for maximum ground-level concentration.**—It would obviously be convenient to use equation (5) in the comparison of maximum ground-level concentrations. This equation implies that the height of rise of the heated plume is given by an equation similar to equation (4). We have seen that this condition is satisfied by Sutton's formula and by the Oak Ridge formula. The formula by Bosanquet, Carey and Halton bears no resemblance, explicitly, to equation (4). Accordingly,  $z$  was computed, as a function of  $u$ , by Bosanquet's formula for the sets of conditions in Table I.

TABLE I

Rate of heat emission (cal./sec.)	...	...	$10^5$	$10^5$	$10^8$	$10^8$
Potential-temperature gradient (°C./1,000 ft.)			1	1	1	5
Speed of efflux from stack (m./sec.)	...	...	15	5	15	15

In each case it was assumed that the ambient temperature was 288°A. and the effluent temperature 423°A.

Plotting  $z$  against  $u$  logarithmically then demonstrated that equation (4) would give a very satisfactory relationship between  $u$  and  $z$ . The value of  $p$

varied from 1.7 to 2.2 according to the conditions. The value of  $B$  was also obtained from the plotted points.

The maximum value of the ground-level concentration depends upon the height of the chimney stack. The ratio\* of the maximum ground-level concentrations according to Sutton's formula and the formula of Bosanquet, Carey and Halton was computed for each of the sets of conditions described in Table I and for three chimney heights 50, 100 and 200 m. Of the 12 answers obtained only one exceeded 1.5—that one was 1.66. It is a matter of some surprise that two such dissimilar formulae should yield such similar results though it must be remembered that the wind speed necessary to produce the maximum concentration depends upon which formula is used.

A similar ratio\* but using Sutton's formula and the Oak Ridge formula was next computed. The relevant parameters and the values adopted in this comparison were speed of efflux (5 and 15 m./sec.), stack diameter (5 and 10 m.), stack height (50, 100 and 200 m.), and heat output ( $10^5$ ,  $10^6$ ,  $10^7$  and  $10^8$  cal./sec.). There were thus 48 values obtained for the ratio. Of these 48 values 25 were less than 2.0 and 38 less than 3.0. The three greatest values 4.3, 5.6 and 6.4, occurred with the greatest chimney height of 200 m.—a value which is probably unrealistic and would in any case lead to low values of the ground-level concentration. It was also notable that, in the conditions leading to high ground concentrations, i.e. low chimney height, low speed of efflux and low heat output, the Oak Ridge formula invariably predicted a higher concentration than did Sutton's formula.

In view of the uncertainty and variability of the effects of a specified concentration of gas on a human being, the discrepancies between the three formulae mentioned above are not important. Since safety is being considered, the formula predicting the largest concentration may be preferred, but convenience in use also deserves attention. Fortunately, these two considerations lead in the same direction and suggest the Oak Ridge formula. This formula, in the form in which it is quoted in the Report of the Committee on Air Pollution<sup>4</sup>, is as follows:—

$$\chi = \frac{9 \cdot 10^6 \cdot Q}{h(14vd + H)},$$

where  $\chi$  is the maximum concentration (milligrammes per cubic meter),  $Q$  the strength of source (pounds per second),  $h$  the height of the stack (feet),  $v$  the speed of efflux (feet per second), and  $H$  the rate of heat output relative to air temperature (British thermal units per second).

It should be emphasized that this formula refers to occasions when the vertical temperature gradient is small. With a marked inversion above the top of the chimney stack the ground-level concentration may be increased markedly by an amount which will depend upon the height and intensity of the inversion.

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\*These ratios were obtained by dividing the greater by the lesser concentration and so were all greater than unity.

# NIGHT COOLING UNDER CLEAR SKIES AT HIGH-LEVEL STATIONS IN CUMBERLAND

By W. E. RICHARDSON, M.A.

Following work by W. E. Saunders<sup>1-4</sup> and others<sup>5-7</sup> an examination was made of the thermograph records covering a period of nearly two years at Alston, Cumberland. The records are for two stations, Nether Park and Riverside, especially selected to be representative of conditions on an east-facing slope and in an adjacent valley bottom. Details of the stations appear elsewhere<sup>8,9</sup>. Both stations were above grass supported by loamy soils.

Times of the evening temperature discontinuity were extracted from the thermograms of each station for clear evenings. The monthly mean times are given in Fig. 1. This shows that the same general pattern exists as at low-level stations. For much of the year the screen temperature of discontinuity  $T_r$  is much earlier at the valley station than at Nether Park, presumably owing to more rapid cooling at this lower level. The later discontinuity at Riverside in July and August may be fortuitous and due to the fact that observations began at Riverside in June 1952, and several late discontinuities which were recorded there in early July were not recorded at Nether Park, where the record began in late July.

A comparison of the values of  $T_r$  and  $T_{\min}$  (night minimum temperature) at the two stations showed that, on the average, the discontinuity occurs at Riverside at a temperature  $1.1^{\circ}\text{F.}$  lower than at Nether Park and that the difference is slightly increased during the period of subsequent cooling,  $T_{\min}$  at Riverside being  $1.8^{\circ}\text{F.}$  lower than at Nether Park.

The curve for Riverside (given in Fig. 1) shows spring and autumn discontinuities of the type commented on in some recent papers<sup>1,4,5,7</sup>. In spring it is

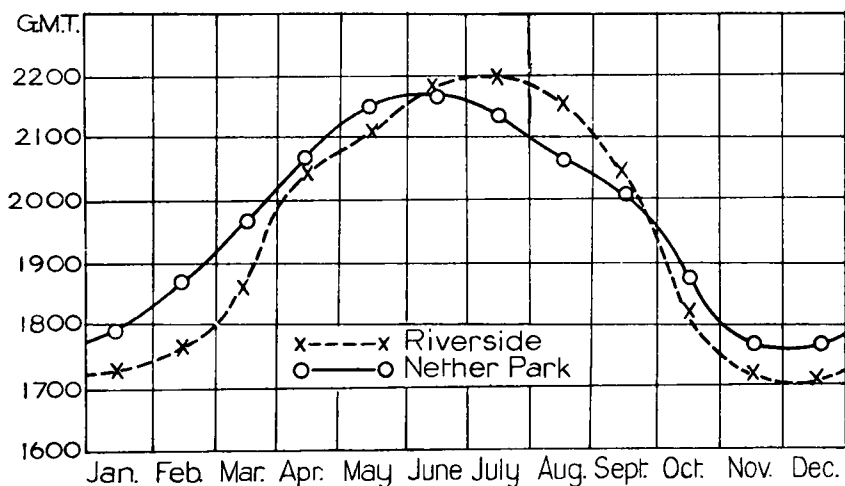


FIG. 1—ANNUAL VARIATION OF TIME OF EVENING TEMPERATURE DISCONTINUITY

Alston, June 1952–April 1954

Number of observations used

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Riverside	4	10	24	18	8	12	14	9	4	9	2	5	119
Nether Park	3	9	30	18	11	9	11	9	8	8	0	4	120

suggested that the really significant change is that in March, when the time of discontinuity is later than would be expected from straightforward variation with time. W. J. Bruce<sup>7</sup> on the other hand lays stress on the subsequent further change towards a relatively earlier time in April. This feature may have been over-emphasized by Bruce, owing to his having drawn his smooth curve for June 1953 rather too late. Only three observations are plotted for May and June, and these all lie about one hour earlier than the times shown by the curve. If these suggestions are correct, the spring changes are due to drying-out as originally postulated by Saunders<sup>1</sup>. However this could be drying of the air as well as of the underlying surface in view of the low dew points which are markedly a feature of the spring months. These were especially prevalent in 1953<sup>10</sup>, as is shown by the figures for relative humidity at Alston given in Table I.

TABLE I—AVERAGE MONTHLY RELATIVE HUMIDITY AT 0900 G.M.T.  
AT ALSTON CLIMATOLOGICAL STATION (1,070 FT.)

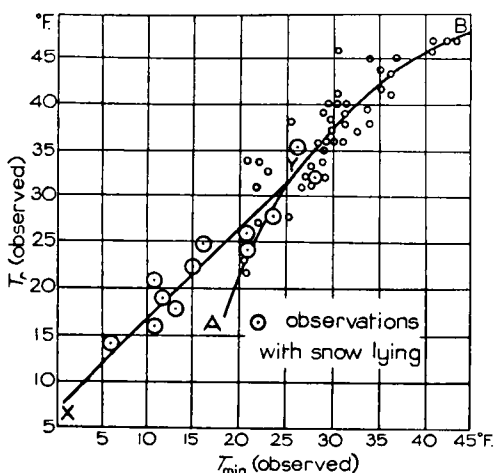
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	<i>per cent.</i>											
1952	87	86	87	73	73	80	81	83	80	86	90	90
1953	91	91	74	76	75	80	83	78	85	85	88	91
1954	87	93	86	74	76	82	85	84	83	89	89	90
1955	88	92	80	75	...	...	...	...	...	...	...	...

The observed values of  $T_r$  and  $T_{\min}$  taken from the thermographs at Nether Park and Riverside were plotted on graphs, separately for each station and for the summer and winter half years. The results are given in Fig. 2, occasions of snow-lying at 0900 G.M.T. being shown separately (XY). The mean deviation of individual cases from the curves drawn is of the order 2°F. Owing to lack of upper air information it was impossible to carry the analysis further, e.g. by classifying the cases according to gradient wind or according to whether or not there was an air-mass inversion as distinct from the surface-radiation inversion. Furthermore, some doubt must remain as to whether all the nights whose records were used were in fact completely clear nights within the definition "mean cloud amount not greater than one okta", since Alston is not a 24-hr. station. In view of all these circumstances the relationships between  $T_r$  and  $T_{\min}$  seem to be remarkably close, and provide further confirmation of the idea upon which Saunders' work<sup>1</sup> on subsequent cooling is based, i.e. that the final temperature should be expressed as a function of the initial temperature.

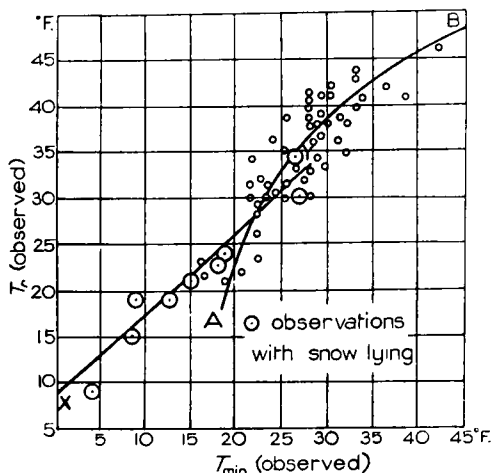
The curves of Fig. 2 are similar for Nether Park and Riverside, and show the relation to be of the same type as at a low-level station, though the amount of subsequent cooling is less. However the inherent faults of curve-fitting, used in all work hitherto undertaken on this subject, are clearly demonstrated here, for the curves for Riverside and Nether Park being almost identical suggest that subsequent cooling at both stations is the same. It has been stated above that further cooling to the extent of 0.6°F. on the average takes place at Riverside in addition to that at Nether Park. The differences between  $T_r$  and  $T_{\min}$  at Riverside and Nether Park are plotted on Fig. 3. It is interesting to note that a further analysis of the observations in relation to air-mass type at 0000 gives a very satisfactory curve for the non-anticyclonic groups. Assuming this curve to be linear, the following equation is found:

$$\Delta T_{\min} \simeq 1.2 \Delta T_r - 0.9,$$





Nether Park

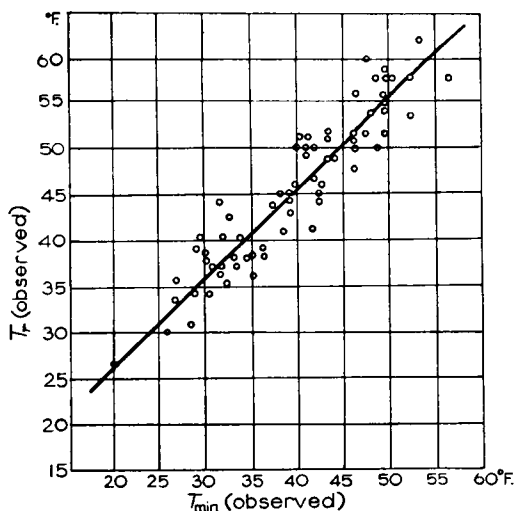


Riverside

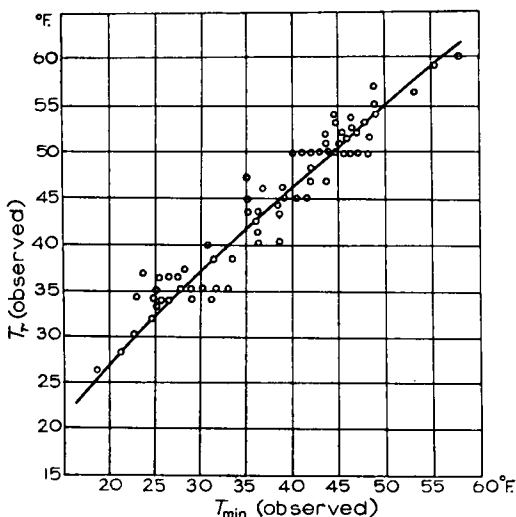
OCTOBER-MARCH

XY=curve for days with snow lying.

AB=curve for days with no snow lying.



Nether Park



Riverside

APRIL-SEPTEMBER

FIG. 2—RELATION BETWEEN NIGHT MINIMUM TEMPERATURE ( $T_{\min}$ ) AND TEMPERATURE AT THE TIME OF EVENING DISCONTINUITY ( $T_r$ )

where  $\Delta T_{\min}$  is the difference between the minimum temperatures at Riverside and Nether Park and  $\Delta T_r$  is the difference between the temperatures at their discontinuities. For this work Belasco's classification<sup>11</sup> was used.

The main feature of Fig. 2 is the marked decrease in the amount of subsequent cooling with low values of  $T_r$  in winter in the absence of snow-cover. This suggests that under these conditions even the valley bottom is unlikely to produce a minimum below 15°F. With snow-cover, however, low values of  $T_r$  are followed by appreciably lower values of  $T_{\min}$  than would be experienced in the absence of snow, a result which is of course to be expected having regard to the low thermal conductivity of snow.

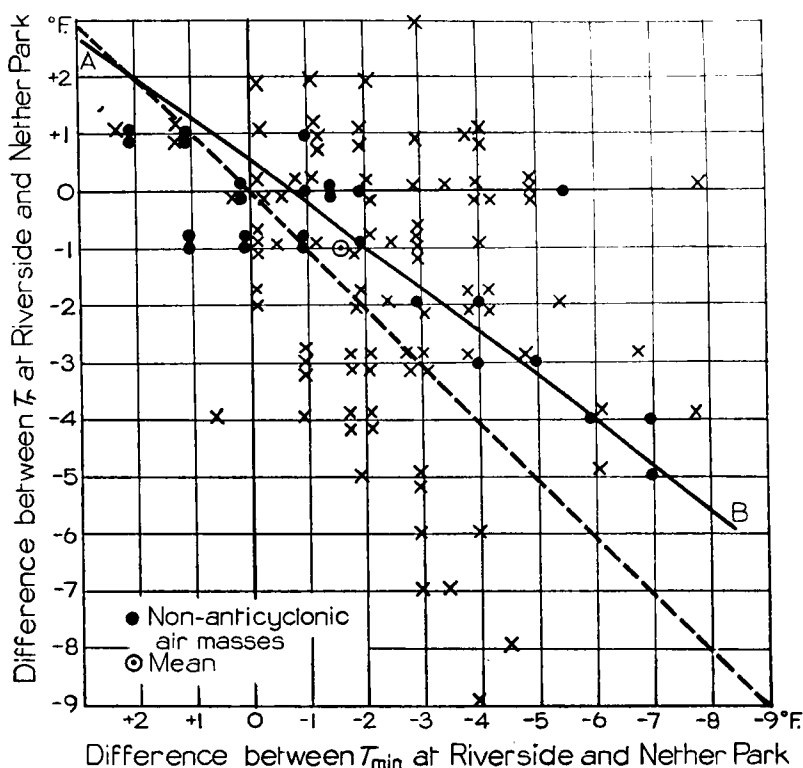


FIG. 3—DIFFERENCE IN TEMPERATURE BETWEEN RIVERSIDE AND NETHER PARK

AB = line fitted to observations with non-anticyclonic air masses  
Broken line = line with equal subsequent cooling at Riverside and Nether Park

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### WIND EROSION IN THE FENS

By M. T. SPENCE, B.Sc.

A "blow" is the local name in the Fens for a storm which lifts the top soil, fills the air with grit and dust, and reduces visibility sometimes to a few yards. A "blow" causing widespread loss of soil occurs about once in five years. Such a "blow" was experienced on May 4-5, 1955. The essentials for a "blow" are:—



*Reproduced by courtesy of N. J. Sneeby*

DYKE FILLED BY BLOWN SOIL IN THE FENS  
(see opposite)



*Reproduced by courtesy of the Farmers Weekly*

**BLOWN SOIL COLLECTED IN THE LEE OF AN OBSTACLE**

The blown soil collects in the lee of the gate and leaves the characteristic ripple of blown sand. The increased wind under the bars of the gate scoops out the soil leaving a hollow trough.

(i) soil particles small enough to be lifted and either kept aloft in the air (duststorm), or, having the size distribution of sand, simulate a sandstorm which is maintained by the grains never rising to great heights, but the bulk of them travelling in trajectories fairly near the ground, each grain gaining sufficient forward momentum from the wind to bounce again or to eject one or more other grains on hitting the ground and so keeping the sandstorm in motion.

(ii) a wind strong enough to raise the top soil of cultivated fields.

(iii) soil particles dry enough not to be cohesive.

A sample of "blown" soil taken from a typical deposit left by the storm of May 4-5 was composed almost entirely of grains corresponding in size to fine sand, i.e. some 0.02-0.2 mm. in diameter. This piece of evidence suggests that a "blow" in the Fens has more the characteristics of a sandstorm than a duststorm, basing the distinction on particle size. Further support for this view is obtained from the shape and location of the deposits. Dust particles move as part of the air stream in which they are being carried and therefore pass over or around ditches and obstacles. On the other hand sand grains fall through air and have an appreciable terminal velocity of fall. Therefore, at any place in a sandstorm where the wind is systematically reduced a deposit of sand accumulates because the gravitational pull is given relatively more time to bring down the grains, and if on descent the falling grains do eject others the wind is too light to carry them away. Now on May 4-5, 1955 the "dykes" on the edge of eroded fields were filled with soil deposit (see photograph facing p. 304) and deposits were also formed near obstacles in the path of the wind, these deposits were in drifts, like snow drifts, a few of them showing the characteristic ripples of blown sand (see photograph facing this page). This photograph is of interest in another connexion too, because it shows both the sheltering effect of a barred gate extending to leeward a distance several times the height of the gate and the erosive effect of the increased wind caused by funnelling immediately underneath the gate.

Yet another piece of evidence that grains were "blowing" is that people who experienced the storm out of doors complained of the "stinging" felt on their hands and faces. Some dust was mixed with the grains, however, because a dust deposit was found on indoor furniture after the "blow" even when windows had been closed.

In a field in which potatoes had been ridged, the furrows were filled with soil deposit showing ripple structure. The ripples were particularly noticeable because the crest of each ripple was lighter in colour than the rest of the field; these crests were found to be composed of quartz grains. It is characteristic of sand ripples formed by wind that the coarsest material collects at the crests and the finest in the troughs<sup>1</sup>.

With regard to wind, Bagnold<sup>1</sup> shows that when the wind increases beyond the threshold speed at which sand begins to move, the quantity of sand blown increases as the cube of the excess wind. On the morning of May 4 "blowing" began in a small way with a wind averaging about 20 kt. at Mildenhall, measured by an anemometer with its vane at an "effective height" of 60 ft. On the 4th and the night of the 4th-5th "blowing" was intermittent, but the wind increased on the 5th and reached a mean speed of 39 kt. at 1400 continuing over 30 kt. all afternoon when the "blow" reached its height. On the 4th a gust

reached 41 kt., and on the afternoon of the 5th, 56 kt.; and many gusts over 45 kt. were recorded on the latter day. The strength of the wind undoubtedly goes a long way to explain the magnitude of the "blow" on this occasion.

It is difficult to know which drying factors are the most important in preparing the soil for a "blow". Sand on a beach has been known to dry sufficiently between two high tides to be set in motion by the wind. This suggests that only recent rains may have significance where "blows" in the Fens are concerned provided there has been good drying since the last rain. Nevertheless, in the particular case under review, April and the first three days of May were all comparatively dry (0.64 in. in April, 0.25 in. in the period May 1-3). In the week before the "blow" drying was very good on at least two days with relative humidity of the order of 40 per cent. in the afternoon and wind moderate in force. On the afternoons of May 4 and 5 relative humidity was 40-50 per cent. which, combined with strong wind, meant that the air had exceptionally good drying properties at the time of the "blow".

The state of cultivation of the soil is another important factor. In spring most of the land has been prepared as seed beds and therefore brought to a fine tilth; it is no mere coincidence that the worst cases of "blowing" occur between mid March and early May. The soil eroded in May 1955 was in fact the top inch or two to which the farmers had devoted so much attention in preparation for seed sowing—soil, which a correspondent to *The Times*, writing about the events of May 4-5, described as "the black sand formed by the breaking down of the peat".

The fields which suffered most erosion were those prepared for seed but still bare and those recently sown with sugar beet, carrots and other root crops in which the plants had only just emerged. Fields of barley an inch or two above ground were generally intact, except for abrasive damage to the leaves from blowing soil, though one case was reported of a patch of soil in a field of barley having been lost. Fields of winter wheat with upper surface some five inches or more above ground were quite immune from "blowing" but much abrasive damage was done to the leaves.

A farmer who anticipated the "blow" hurriedly ridged up a bare field with ridges at right angles to a SW. wind; he not only prevented loss of soil but acquired soil in his furrows from other fields. In another field, in which potatoes had been ridged several days before the storm, erosion occurred—the soil from the top of each ridge was lost; presumably the material difference between this and the previous case is the interval of time between ridging and the storm which allowed the surface of the potato field to dry out.

An instructive lesson in protection from erosion is to be learnt from one farmer's experience. He had a field, which was cropped with rye in 1954, and strips, aligned at right angles to a SW. wind, had been left to a width of about 13 yd., alternating with 34 yd. of bare land, scheduled to be drilled with sugar beet. Little or no erosion occurred in this field though fields round about, but without the strips of rye, were badly eroded.

Hedges and belts formed by trees on the windward side of fields gave complete protection to leeward for a distance of 6-10 times the height of the hedge or belt. This is disappointingly poor protection when it is considered that, in the lee of a shelter-belt, at a distance of some 20 times the height of the belt, wind may be reduced to a speed 60 per cent. of the free wind. However, the favourable

conditions to be satisfied for this result are (i) a wind at right angles to the sheltering belt and (ii) a belt with about 50 per cent. permeability, the openings distributed evenly over the obstruction. The comparatively poor results in May 1955 were no doubt due to the strength of the wind which was probably much in excess of the "threshold" speed for sand blowing, and therefore recovered to the "threshold" speed in the lee of the shelter-belt before the speed of the "free" wind was reached. Other factors are that the few belts of trees which exist in the Fens are of varying and irregular permeability, and no belt was at right angles to the wind all the time of the "blow" because wind direction varied between SSE. and SW. It is worthy of note, however, that some of the worst erosion occurred round Manea, an area of the Fens in which virtually no hedges or trees are to be seen except on a far horizon.

The general estimate of the height of the top of the cloud formed by blowing soil was 50–60 ft., but staff at the meteorological office, Mildenhall, estimated the top to be 150 ft. at the worst period of the "blow". Visibility at Mildenhall was reduced to 300 yd. for 4 hr. at the height of the "blow" on the afternoon of the 5th.

I am indebted to Mr. N. J. Sneesby of the Agricultural Land Service, Eastern Province, for information concerning the extent of erosion in "sheltered" fields.

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### UNUSUAL BEHAVIOUR OF A DEPRESSION, APRIL 17–23, 1954

By H. D. HOYLE, B.Sc.

**Development and movement of the surface depression.**—The depression referred to as low A in the *Daily Weather Report* first appeared on the charts at 1800 G.M.T. on April 17, 1954, at the southern tip of Greenland; 12 hr. previously there was a shallow non-frontal low Y 250 nautical miles to the west-south-west and an old occluded depression N 800 nautical miles to the south (see Fig. 1). From 1800 on the 17th to 1800 on the 18th, the depression A moved east-north-east at an average speed of 17 kt. The depression then began to turn to the right and from 0000 on the 19th to 0000 on the 20th moved steadily south-south-east at an average speed of 22 kt. The depression then turned further to the right and for the 24 hr., 0000 on the 20th to 0000 on the 21st, moved fairly steadily south-west at an average speed of 20 kt. After this the depression was slow moving, describing roughly a small half-circle, in a cyclonic sense, during the next 48 hr., and it finally filled completely by 1800 on the 23rd.

There were thus five main stages: Stage I formation, Stage II east-north-east movement, Stage III south-south-east movement, Stage IV south-west movement, Stage V slow movement.

**Upper air charts.**—*Stage I: Formation* (up to 1800 on the 17th).—Although a shallow depression at mean sea level, low Y had an associated closed cyclonic circulation at all levels up to and including 300 mb., whilst low N had an associated closed cyclonic circulation up to the 200-mb. level. These two features gave, together, a large-amplitude upper trough at about 49° W. At 500 mb. the distances to the next up-stream and down-stream troughs were appreciably shorter than the equilibrium stationary wave-length, which is

consistent with the eastward progression which actually took place<sup>1</sup>. In particular the motion of the upper low from its position in association with low Y to a position near that given for low A at 1800 on the 17th was to be expected.

The 1000–500-mb. thickness showed a well marked trough to the west of low Y terminating in the south in a closed cold pool south-west of low N (see Fig. 2). The pattern is favourable<sup>2,3</sup> for the formation, to the north of low N, of a new centre, which could be expected to move north-north-east to the position given for low A at 1800 on the 17th. Thus low A may have been historically the same depression as low Y or it may have been a development associated with low N.

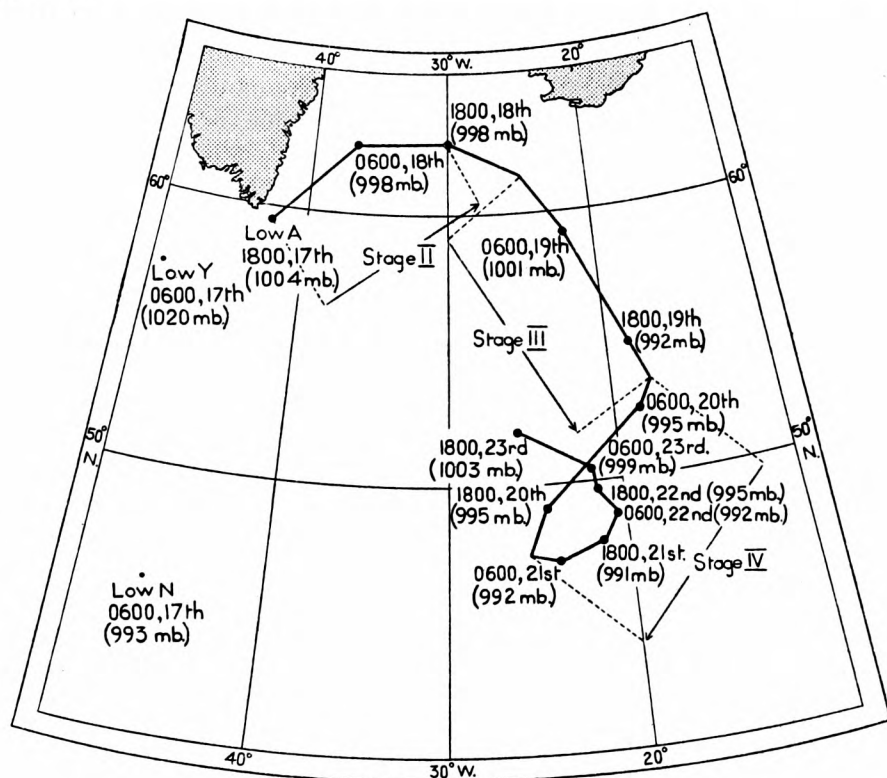


FIG. 1—TRACK OF THE DEPRESSION A, APRIL 17–23, 1954

*Stage II: East-north-east movement* (1800 on the 17th to 1800 on the 18th).—Associated with low A was an intense closed cyclonic circulation up to 300 mb., which extended later to 200 mb. also. The 1000–500-mb. thickness pattern over low A was a fairly conventional sinusoidal type, but became very distorted later. Towards the end of this period a closed cold pool was beginning to be apparent. The 500–300-mb. layer, however, showed the coldest air to the east of the surface centre with warmer air from the west encroaching. The 300–200-mb. layer showed a warm centre just west of the position of low A.

*Stage III: South-south-east movement* (0000 on the 19th to 0000 on the 20th).—The closed circulation at all contour levels up to and including 200 mb. remained intense and at all levels, was almost concentric with low A. The 1000–500-mb. thickness also showed a cold pool almost concentric with low A. In the 500–300-mb. layer the coldest air was still east of low A with encroachment of the warm ridge from the west (see Fig. 3). In the 300–200-mb. layer the warm centre associated with low A persisted and was nearly concentric with low A.



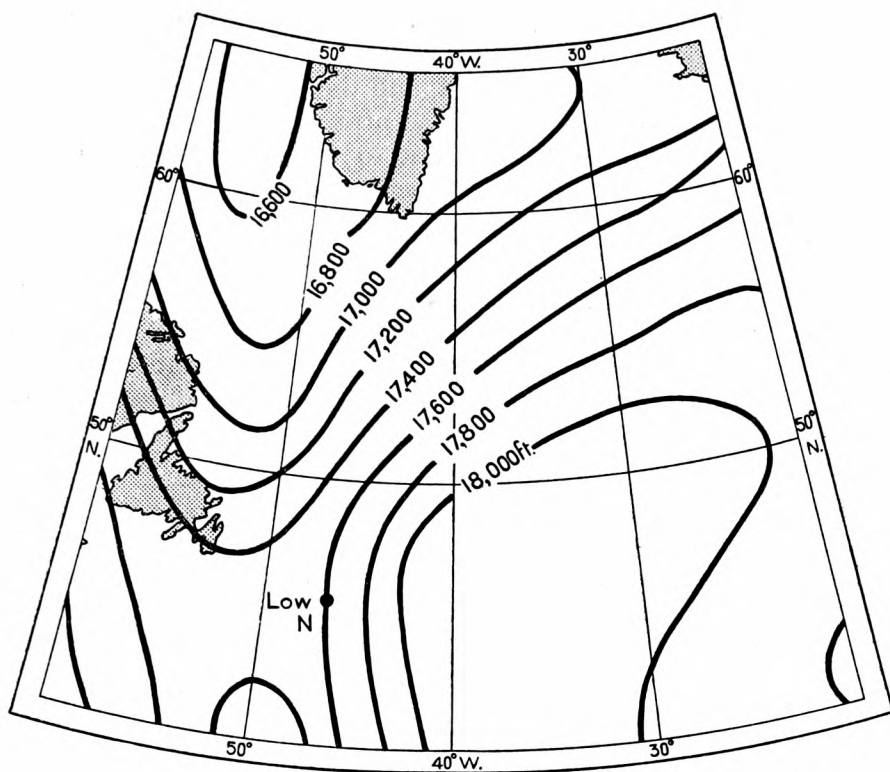


FIG. 2—1000-500-MB. THICKNESS, 0300 G.M.T., APRIL 17, 1954

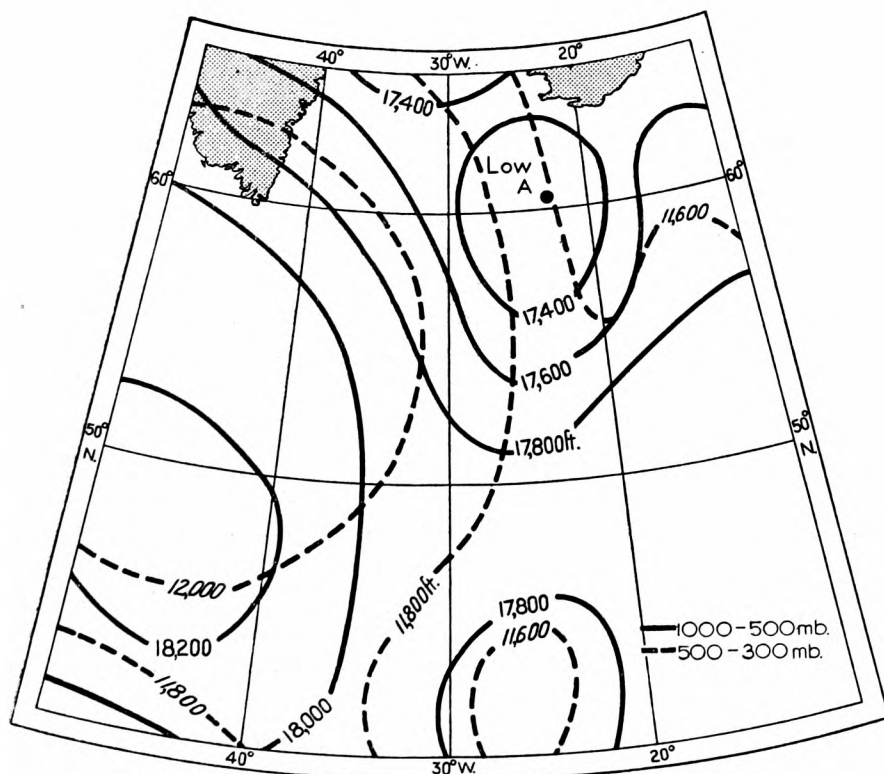


FIG. 3—1000-500-MB. AND 500-300-MB. THICKNESS, 0300 G.M.T., APRIL 19, 1954

*Stage IV: South-west movement* (0000 on the 20th to 0000 on the 21st).—The closed circulation at all contour levels up to 200 mb. persisted. The cold pool in the 1000–500-mb. thickness remained, and the 500–300-mb. layer now also showed a closed cold pool, again almost concentric with low A. The 300–200-mb. layer showed the warm centre somewhat to the north-west of the surface centre, and this layer was thus the one with the best defined thermal-wind direction over low A.

*Stage V: Slow movement* (after 0000 on the 21st).—A large closed circulation was still apparent in the contours at all levels up to 200 mb. The thermal winds were weak for all layers, but a more conventional thickness pattern was established in the lower layers with slight ridge formation ahead and with the coldest air moving round the western and then the southern side of low A. Conventional ideas of steering by the 1000–500-mb. thermal wind would thus suggest the slow circular track of low A during this final period.

**Direction of motion.**—Stages II, III and IV are the more interesting ones with regard to the direction of motion. Measurements were made, for the standard thickness layers, of the mean thermal wind over an area centred on the depression, by a method similar to that used by the author elsewhere<sup>4</sup>. The measurements were made over an area of radius about 300 miles and over one twice as great. The mean of the two values so obtained is shown in Table I. It will be seen that the direction of motion of the depression was in agreement with the thermal-wind direction for successively higher layers during stages II–IV. The directions in agreement are shown in *italics* in the table.

TABLE I—MEAN THERMAL-WIND DIRECTIONS

	Stage II	Stage III	Stage IV
	<i>degrees true</i>		
Track of low ... ..	<i>245</i>	<i>335</i>	<i>40</i>
300–200-mb. thermal-wind direction ...	25	43	33
500–300-mb. thermal-wind direction ...	301	337	339
1000–500-mb. thermal-wind direction ...	<i>244</i>	<i>265</i>	<i>260</i>

**Comparison with an earlier case.**—A depression of October 4, 1952 described by Lowndes<sup>5</sup> had several points of close similarity. In both cases there was a closed cyclonic circulation extending up to 300 mb. Both cases were noteworthy for the manner in which the coldest air in the 500–300-mb. layer was ahead of the surface depression. Both depressions moved south-east at variance with 1000–500-mb. thermal steering, but in good agreement with the 500–300-mb. thermal wind.

**Relative divergence during stage III.**—A “development chart” was drawn for the 1000–500-mb. layer, using the Sawyer-Matthewman scale<sup>6</sup>. The values found (see Fig. 4(a)) were not very large, indicating no great relative divergence through this layer, and they failed to explain the south-south-east movement in that they indicated cyclonic development towards the east-north-east of the centre. The same principle was applied to the 500–300-mb. layer (see Fig. 4 (b) ). This layer gave much larger values of relative divergence and shows cyclonic development towards the south-south-east, in agreement with actual developments.

**Speed of motion.**—It is possible to obtain a theoretical estimate of the speed of motion by assuming the form of the curve of divergence against pressure and using equations obtained by Sutcliffe<sup>3</sup>.

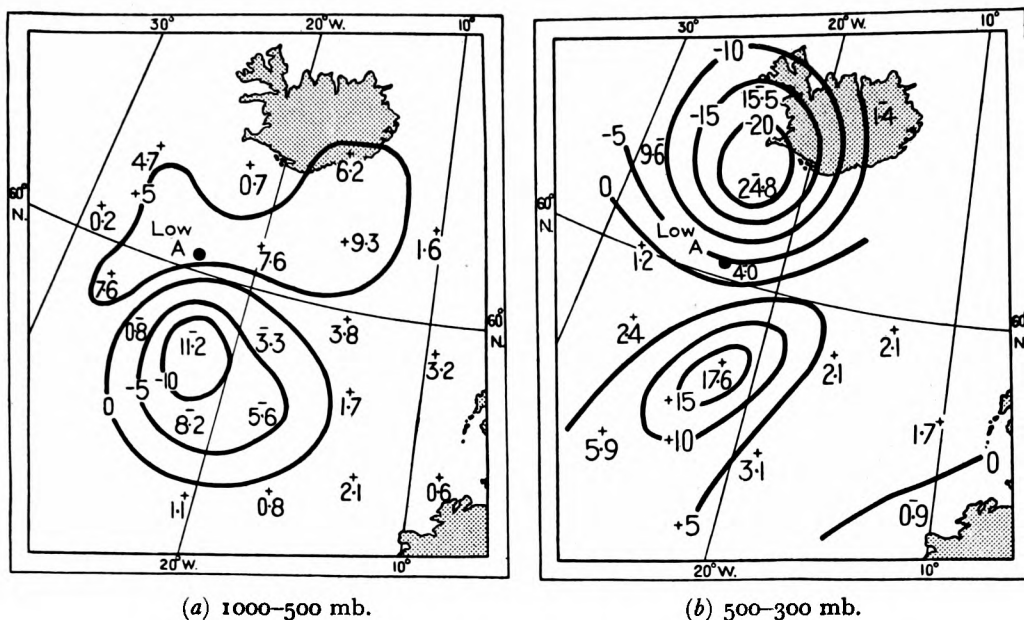


FIG. 4—DEVELOPMENT CHARTS, 0300 G.M.T., APRIL 19, 1954

Values are given in units of  $10^{-2} \text{ hr.}^{-2}$ , positive for cyclonic development and negative for anticyclonic development.

The essential features of the case considered, during stage III, are a negligible 1000-500-mb. thermal wind, and hence an almost identical flow pattern at all levels up to 500 mb., but appreciable relative divergence through some layers above 500 mb. We thus consider the steering of the 500-mb. low by the thermal wind in the layer above, and infer the motion of the surface low by virtue of the identical pattern through the lower layers.

An approximation to the type of flow found is made by simply assuming no relative divergence from 1000 to 500 mb., divergence increasing linearly with pressure from 500 to 200 mb. and no divergence above 200 mb. (see Fig. 5).

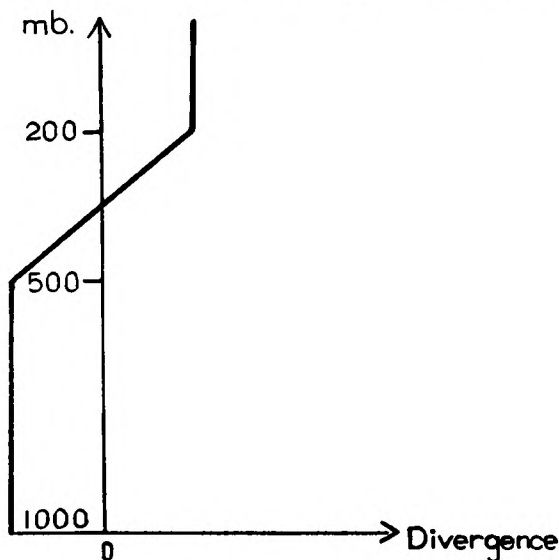


FIG. 5—ASSUMED FORM OF DIVERGENCE PROFILE

As a rough approximation we may assume that convergence and divergence balance, in a vertical column. That is, if  $p_0$  is the surface pressure,

$$\frac{dp_0}{dt} = - \int_0^{p_0} \text{div}_p \mathbf{V} dp = 0 \quad \text{approximately.}$$

The assumed form of the divergence curve (Fig. 5) then gives

$$13 \text{ div } \mathbf{V}_5 + 7 \text{ div } \mathbf{V}_2 = 0, \tag{1}$$

where  $\mathbf{V}_5$  and  $\mathbf{V}_2$  are the winds at 500 mb. and 200 mb. But if we consider “steering” effects only and apply Sutcliffe’s equation for the relative divergence to the 500–200-mb. layer then

$$l(\text{div } \mathbf{V}_2 - \text{div } \mathbf{V}_5) = - 2V' \frac{\partial \zeta_5}{\partial s}, \tag{2}$$

where  $\zeta_5$  is the vorticity of the 500-mb. flow, and  $\mathbf{V}'$  is the 500–200-mb. thermal wind. Eliminating  $\mathbf{V}_2$  from equations (1) and (2) we obtain

$$l \text{ div } \mathbf{V}_5 = \frac{7}{10} V' \frac{\partial \zeta_5}{\partial s}. \tag{3}$$

Now we may use the equation

$$\frac{d\zeta}{dt} = - l \text{ div } \mathbf{V}$$

and obtain

$$\frac{d\zeta_5}{dt} = - \frac{7}{10} \mathbf{V}' \cdot \nabla \zeta_5. \tag{4}$$

But  $d\zeta_5/dt = \partial \zeta_5/\partial t + \mathbf{V}_5 \cdot \nabla \zeta_5$ , and since we are dealing with a closed circulation (approximately circular) at 500 mb. the second term on the right will make little contribution. Equation (4) thus gives an approximation for the local change of vorticity ( $\partial \zeta_5/\partial t$ ) and shows this to be equivalent to advection of the 500-mb. vorticity at a speed roughly 70 per cent. of the 500–200-mb. thermal wind. Considering the very simple form assumed for the divergence-pressure curve, the values shown in Table II are in reasonable agreement.

TABLE II—RELATION OF SPEED OF DEPRESSION TO 500–200-MB. THERMAL WIND SPEED

	Stage III	Stage IV
	<i>knots</i>	
Average speed of depression ... ..	22	20
500–200-mb. thermal-wind speed ...	19	19

**Conclusions.**—Steering by the thermal wind at levels above 500 mb. would seem to be operative during stages III and IV in the movement of this depression. It is suggested that whenever the thermal wind becomes weak, or of ill defined direction through the lower layer so that there is almost identical flow at all levels through that layer, then thermal steering by the layer above may become operative

This is similar to the view put forward by Scherhag<sup>7</sup> but refers to “thermal” steering rather than “contour” steering. For example, during stage III of the motion of the depression considered in this note the 500–300-mb. thermal wind had a well defined direction but the contours showed closed circulations to 200 mb.

The formation of a closed cold pool in the 1000–500-mb. thickness is a fairly frequent feature of the later stages of the life-cycle of a depression. Although we cannot draw conclusions of general application from this isolated example, it is possible that thermal steering at levels above 500 mb. is sometimes operative in other cases. The abnormal feature of the present case was probably the strength and direction of the thermal wind at the higher levels.

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[A search was made through the *Daily Aerological Record* and the working charts for 1949–54 to see whether any cases similar to that described by H. D. Hoyle have occurred in the post-war years. The field of investigation was limited to the area covered as a routine by the *Daily Aerological Record*; this extends roughly from Iceland to Gibraltar and from 25°W. to 25°E. All cases were noted where the surface depression was concentric, or nearly so, with a cold pool in the 1000–500-mb. thickness pattern and where the thermal wind in the 500–300-mb. layer across the centre was 15 kt. or more.

In six out of the ten examples satisfying these criteria it was not possible to observe the effect of the upper thermal wind upon the lower vortex; either the surface depression filled quickly and disappeared or further development took place in the baroclinic zones ahead of the 1000–500-mb. trough. There was some evidence of steering in the remaining four which occurred during the following periods:—

0300 G.M.T. January 14, 1950 to 0300 G.M.T. January 15, 1950  
 2100 G.M.T. January 22, 1951 to 0900 G.M.T. January 23, 1951  
 1500 G.M.T. October 30, 1951 to 1500 G.M.T. October 31, 1951  
 1500 G.M.T. February 10, 1954 to 1500 G.M.T. February 11, 1954.

The depressions in none of these sequences approached the depth of that of April 17–23, 1954 nor did they retain their identity for so long a period.—  
 F. E. DINSDALE]

### PRELIMINARY ANALYSIS OF STANDING-WAVE REPORTS RECEIVED AT NORTHOLT DURING THE WINTER OF 1953–54

By R. K. PILSBURY

**Introduction.**—The forecasters at Northolt Airport and the pilots of British European Airways and Aer Lingus have for some years shown a great interest in standing waves. During the winter of 1953–54, pilots operating from Northolt were told by the forecaster at briefing, on the basis of previous experience, when waves were considered to be likely and the pilots were invited to make observations of any wave effects encountered. An attempt was then

made to deduce the upper air conditions prevailing in the area concerned at the time of each report and to analyse these conditions to ascertain whether any features were common to all reports. This note gives the result of the analysis.

**Data and their limitations.**—During the period October 1953 to April 1954, 95 reports were received from pilots: 66 were concerned with lee waves found over the British Isles, 8 with waves over the nearby Continent and the remaining 21 reported no waves found. The investigation was most intense during November and December 1953 and January 1954; thereafter interest in the scheme was spasmodic.

Civil aircraft, based at Northolt, operated along well defined flight paths within a layer usually extending from 4,500 to 10,500 ft. above sea level. Flights were made irregularly from 8 a.m. to 10 p.m. Thus it was not possible to investigate closely the changes in wave structure with time, distance or height. Furthermore, the determination of the upper air conditions, representative of the undisturbed air stream up wind of the hilly terrain, involved interpolation from upper air data and was sometimes unreliable. This was particularly true of the waves which occurred over the nearby Continent, and such reports were therefore excluded from the analysis. Although forecasters suggested to pilots the occasions on which they might, with advantage, be on the watch for wave effects, it is not considered that the analysis was prejudiced by this, especially as similar meteorological conditions were also common to many spontaneous reports which were received.

**Method of analysis.**—For each reported case of waves over the British Isles, an attempt was made to deduce the upper air temperature and wind structure representative of the undisturbed air stream, up wind of the incident. As most reports were received from areas not far removed from the sea, i.e. north Wales, the Lake District and south-west Scotland, and as upper winds were generally from a westerly direction, diurnal modification of the air stream during its passage from sea to land was not considered. Synoptic surface and upper contour charts were studied to aid in the selection of upper air data, and to indicate their likely modification due to time and space changes in the weather situation.

Each representative ascent was then examined and the layers having markedly different stability were noted; in addition the vertical profile of the parameter  $l^2$ , discussed by Scorer<sup>1</sup>, was calculated, using the scale devised by Wallington<sup>2</sup>. Attempts were then made to see whether any particular conditions of stability or wind structure were common to all cases of waves. Data were also examined to ascertain if there were any connexions between the strength of vertical currents reported and the wave-length, the wind at 2,000 ft., the increase of wind with height, the aircraft height in relation to the stable layers, or variations in Scorer's parameter  $l^2$ .

Further analyses were made into cases of no waves and of waves associated with strong vertical currents.

**Analysis of 66 reports of waves over the United Kingdom.**—*General upper air conditions.*—Certain upper air conditions were found to be common to these reports of lee waves, namely:—

- (i) A layer of steep lapse rate from surface to at least 2,000 ft.; there were several cases where this layer was 7,000 ft. deep.

(ii) A second layer above (i) with marked stability. This layer was often isothermal and sometimes contained steep temperature inversions. The thickness of this stable layer varied from 800 ft. to over 10,000 ft.

(iii) In 62 cases, there was a layer above (ii) but below 18,000 ft., where the lapse rate once again became steeper.

(iv) The wind at 950 mb. (approx. 2,000 ft.) was at least 15 kt. and in all but five cases it was over 20 kt.

(v) Wind direction was almost constant with height throughout the first and second layers.

(vi) In every case but one, the wind increased with height to at least the top of the stable layer (thus there was a reinforcing thermal wind).

*Synoptic situations.*—The analysis indicated that waves were found in a wide variety of synoptic situations, all satisfying the upper air conditions given above. Waves were reported in advance of warm fronts, in warm sectors, to the rear of cold fronts, along stationary fronts and in cold air. An examination of the nine days when widespread waves were reported revealed that on six of these warm-sector conditions prevailed, whilst on two days reports referred to positions just to the rear of a cold front. On the ninth day a stationary front lay across the area from which the reports were received.

*Height, location and frequency of occurrence.*—Civil aircraft operating from Northolt flew at certain fixed height levels between 4,500 and 10,500 ft. with an occasional flight over Wales between 14,000 and 18,000 ft. Waves were reported at all levels within these ranges. On one occasion, when over the English Channel in a northerly air stream, a pilot stated that he experienced waves having vertical currents of 100 to 200 ft./min. when flying at 6,000 ft. He then ascended to just above the haze top at 8,000 ft. and the waves ceased. From the Crawley radio-sonde ascent it appears that, when at 6,000 ft., the pilot was flying in a stable layer between two inversions; on ascending to 8,000 ft. he was just above the second inversion. This is consistent with the variation of lee-wave amplitude through inversions, as deduced theoretically by Scorer<sup>3</sup>; he found that the amplitude decreased very rapidly above an inversion. Approximately 90 per cent. of reports were received from pilots operating from Northolt and flying along the following three British air corridors:—

(i) Northolt–Daventry–Lichfield–Ringway–Dean Cross–Renfrew–Edinburgh.

(ii) Northolt–Daventry–Lichfield–Wallasey–Belfast.

(iii) Northolt–Daventry–Nevin–Dublin.

Thus an examination of the geographical distribution of the occurrence of waves would reveal little of material significance. The strongest vertical currents were reported near the highest mountains of north Wales, the Lake District and southern Scotland, i.e. where the mountains rise to 2,000 ft. or more in the vicinity of the above corridors. On some occasions, however, waves were widespread, and were experienced from soon after take-off from Northolt to destinations in Scotland and Ireland. One pilot found them practically all the way across the Irish Sea from Wallasey to Belfast. It is noted however that in many cases, wave trains of sufficient intensity to affect powered aircraft did not persist over long distances to the lee of the high ground causing them. On many occasions pilots flying the Dublin route reported waves over Wales, but other pilots flying along the other two routes at about the same time and height

but some 30–60 miles further to the leeward of the Welsh mountains did not find them, although later they were experienced when the Lake District was crossed.

Reports of waves were most frequent from November 1953 to January 1954. During this period they were found on an average of one day in three in November and January and one day in seven in December, over some parts of the British Isles. On six days in these three months they were widespread. A further period of widespread waves worthy of special note was on April 13, 14 and 15, 1954. Occasionally some pilots reported waves but other pilots, flying at about the same time at or near the same height on the same route, failed to detect them. A further note on these cases will be found later.

*Wave-length of lee waves.*—As the orientation of the aircraft course to the wave train was not known, it was not possible to calculate accurately the wave-lengths of the lee waves in these reports. It is significant, however, that the shortest reported distance from crest to crest was 2 miles, whilst many lay in the range 3–8 miles. Of the six occasions when vertical currents were 1,000 ft./min. or more, five gave an apparent wave-length of 5–6 miles. A British European Airways pilot, when flying over south-west Scotland at 6,000–8,000 ft. reported that he was experiencing waves of length 3–4 miles whilst above him he observed bands of lenticular cloud at about 12,000–15,000 ft. spaced at intervals of about 20 miles.

*Strength of vertical currents with special mention of cases reported in excess of 800 ft./min.*—An analysis was made of the vertical currents reported and their relationship to the three layers mentioned on p. 314. Pilots who happened to be flying in the upper part of the stable layer reported stronger currents than those in other positions within the layer. Aircraft flying near the bottom of the stable layer or below it found vertical currents were slight. In the six cases where pilots were flying above this stable layer but still experiencing currents of 500 ft./min. or more there was always a second stable layer above the flight level.

In four cases, the strength of both upward and downward currents was given. In three of these the upward current was much the stronger.

The speeds of the majority of vertical currents lay within the range of 300–500 ft./min., but some were as low as 100–200 ft./min. The most violent case in this series was over the sea to the north of Great Orme's Head, when an Aer Lingus pilot, flying at 4,500 ft. at 2030 G.M.T. on March 22, 1954, experienced an uplift of 2,200 ft./min. He did not find any corresponding downward current, but with upper winds from the south it is probable that his east–west course lay parallel to the wave crests. The second strongest vertical current was found by a British European Airways pilot on April 15, 1954, at 0800 G.M.T. near Dollar Law, south of Edinburgh where he measured an uplift at the rate of 1,900 ft./min.; the corresponding downward flow was only of the order of 500 ft./min.

When vertical currents of 800 ft./min. or greater were reported, an examination of the position of the aircraft, relative to the surface analysis of synoptic conditions prevailing, revealed that in 8 cases out of 10, the pilot was flying just to the rear of the surface cold front. The remaining 2 cases occurred within a warm sector. In every case there was an inversion present whilst in 6 cases there was a double inversion. It is worthy of note that, in relation to the wind



structure, in 8 cases the wind increased rapidly with height above the base of the inversion and at 18,000 ft. it was double and sometimes treble the speed at 2,000 ft. The wind speed at 2,000 ft. in the undisturbed air stream, before reaching the high ground which caused the waves, was in 8 cases 25 kt. or more and in 4 cases over 30 kt.

These strong vertical currents were found both in daylight and at night, at various heights from 4,500 to 8,500 ft., and in several mountainous regions.

*Turbulence and variations in the wave train.*—Of the 66 cases examined 20 found some turbulence, although all but 2 stated that it was only slight. Several pilots found this slight turbulence to be of the “cobblestone” variety, and one commented that vibrations were of the order of 60 times a minute.

The two cases where turbulence was classified as moderate were examined further:—

November 11, 1953, 0930 G.M.T.—An Aer Lingus pilot flying over Wales at 7,500 ft. found several ill defined waves giving up and down currents of only 100–200 ft./min. with moderate turbulence. A second pilot, on the same route at 6,500 ft., one hour later experienced several waves with currents of 300 ft./min. and only slight turbulence. That evening two other pilots again found waves but no turbulence. No reports of waves were received the day before this series but there were several cases on the following day.

December 28, 1953, 2200 G.M.T.—A British European Airways pilot, flying over south-west Scotland at 5,000 ft. experienced two distinct waves with moderate turbulence. At midday another pilot found isolated waves over south-west Scotland and numerous well defined wave trains over north-west England giving much greater vertical currents; the first pilot had also found numerous waves over the Irish Sea at 1300–1400 G.M.T. that day. No reports of waves were received on the following day.

An examination of the position of all cases of turbulence in relation to the wave train showed that three occurred near the troughs of the wave, two near the crests and two each in the ascending and descending currents.

**Analysis of 21 cases of no waves.**—The reports do not comprise a random statistical sample and conclusions about the relative frequency of waves and no waves cannot, therefore, be drawn.

Of the 21 cases, 6 referred to occasions when some of the upper air conditions enumerated on p. 314 were not present and thus waves were not expected. In each of the remaining cases, waves were not found by one pilot but were found on nearby routes by other pilots some time during that day. In 3 cases the aircraft probably did not pass near enough to the lee of high ground likely to cause waves, whilst on 8 occasions changing conditions of upper air temperature or wind profile could account for no waves being found. Thus two cases were left without explanation and both are interesting as they occurred over north Wales when reports of waves from other pilots were numerous at about the same time on each occasion.

**Some tentative conclusions on lee-wave formation.**—The upper air conditions which appear to be present, when waves strong enough to affect powered aircraft occur, are as follows:—

- (i) A layer of steep lapse rate from the surface to at least 2,000 ft.

- (ii) A stable layer or, even better, an inversion above (i)
- (iii) Wind speed of 20 kt. or more at 2,000 ft.
- (iv) An increase of wind speed with height, but with wind direction approximately constant, to above the top of the stable layer (ii).

As one would expect, these conditions imply the variations of  $l^2$  with height found theoretically by Scorer to be necessary for lee waves to be possible. The conclusions are thus consistent with theory<sup>4</sup>.

There is little evidence to indicate what happens at heights greater than 10,000 ft., but the few reports received show that if the upper air temperatures indicate several inversions or stable layers with shallow unstable layers between, wave formations are propagated to great heights, provided the wind direction still remains reasonably constant and the wind speed does not decrease with height.

It is significant that nearly all the strongest vertical currents were reported from positions to the rear of slow-moving cold fronts, in regions where there was a good inversion and a strong reinforcing thermal wind. Furthermore the currents were strongest near the top of the inversion.

Lee-wave reports were much more numerous in winter than in summer, both in this series and in the earlier reports mentioned by Turner<sup>5</sup>. It seems that the requisite upper air conditions obtain more often in winter than in summer, as would be expected.

#### REFERENCES

1. SCORER, R. S.; Forecasting the occurrence of lee waves. *Weather, London*, **6**, 1951, p. 99.
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3. SCORER, R. S.; Theory of airflow over mountains: III—Airstream characteristics. *Quart. J. R. met. Soc., London*, **80**, 1954, p. 417.
4. CORBY, G. A.; The airflow over mountains: a review of the state of current knowledge. *Quart. J. R. met. Soc., London*, **80**, 1954, p. 491.
5. TURNER, H. S.; Air flow to the lee of hills—a study of pilots' reports. Typescript, Meteorological Office, London, 1954.

#### METEOROLOGICAL RESEARCH COMMITTEE

The 35th meeting of the Synoptic and Dynamical Sub-Committee was held on June 16, 1955, under the Chairmanship of Professor P. A. Sheppard who has succeeded Sir Charles Normand. Discussion of the paper by Dr. D. G. James<sup>1</sup> on the nocturnal dissipation of stratocumulus cloud led to the conclusion that the problem of growth and dispersal of this form of cloud merited further synoptic-dynamical study in addition to any detailed physical study which might be practicable within and near the cloud. The two related papers by Mr. J. M. Craddock<sup>2,3</sup> on the representation of the annual variation of temperature in the northern hemisphere were received with much interest, and represent an item in the preparatory stage of the investigation of variations of weather over the British Isles during intervals of about a month. After discussion of the significance of certain temperature anomalies in Europe, it was agreed that the general procedure which had been adopted for temperature should be applied to other weather elements as far as practicable. Mr. H. Heastie presented an interim report<sup>4</sup> on the method of preparation of circum-polar charts of standard isobaric surfaces (700–100 mb.) for the revised edition of *Geophysical Memoirs* No. 85 "Upper winds over the world". The various devices and adjustments necessitated by scarcity of direct observations in some regions were described.

The 33rd meeting of the Physical Sub-Committee was held on June 23, 1955. There was considerable discussion on Dr. K. H. Stewart's highly instructive report<sup>5</sup> on the experimental investigation of radiation fog at Cardington. The complexities of the processes in operation were noted. Suggestions for further work, including the study of radiation effects, were generally approved, and recommendations made for the study of the variation in humidity between day and night at different heights, the fall-out of droplets from fog, the frequency of visibilities at short-range intervals between 200 and 1,000 yd., and the possibility of obtaining temperature, wind and humidity observations on masts up to about 1,000 ft., or by use of low-level radio-sonde apparatus. The Sub-Committee then discussed the paper by Dr. James<sup>1</sup> already considered by the Synoptic and Dynamical Sub-Committee, and recommended that the Meteorological Research Flight should make suitable observations in and near stratocumulus cloud according to a programme to be agreed with the Forecasting Research Division. The other main item before the meeting was atmospheric turbulence in relation to aviation. After discussion of Mr. G. A. Corby's paper<sup>6</sup> and certain recommendations of the Gust Research Committee of the Aeronautical Research Council, it was agreed that the Meteorological Research Flight with suitable instrumentation of the Canberra should be able to assist in providing data for investigation of the structure of atmospheric turbulence, and that, in seeking a method independent of the use of aircraft, the use of the latest techniques in the radar tracking of a free balloon should be further explored.

#### ABSTRACTS

1. JAMES, D. G.; The nocturnal dissipation of stratocumulus cloud. *Met. Res. Pap., London*, No. 913, S.C. II/187 and S.C. III/184, 1955.

Typical cases of dissipating and non-dissipating stratocumulus were examined statistically for advection and vertical motion, radiation from cloud top, turbulent mixing with air above or below, and cloud thickness. A parameter  $\xi = x - 9.15y - 0.77z$  is devised, where  $x$  = maximum depression in degrees Fahrenheit of dew point below temperature up to 50 mb. above cloud top,  $y$  = average hydrolapse in  $10^{-2}$  gm./Kg./mb. over 50 mb. below cloud base, and  $z$  = cloud thickness in millibars. The majority (74 per cent.) of "no breaks" had  $\xi < -20$ , 76 per cent. of "breaks" had  $\xi > -20$ . Exceptions are discussed.

2. CRADDOCK, J. M.; The representation of the annual temperature variation over central and northern Europe by a two-term harmonic form: *Met. Res. Pap., London*, No. 915, S.C. II/188, 1955.

In this paper the long-period annual variation of temperature at 42 stations in central and northern Europe is analysed from 5-day means for the first four harmonics. The first two represented nearly all the annual variation, except for about 10 5-day periods which had the same anomaly at all or nearly all stations. These singularities persist when independent periods are examined; the most obvious is a positive anomaly in late May and early June. Charts show amplitudes and phases of first two harmonics.

3. CRADDOCK, J. M.; The variation of the normal air temperature over the northern hemisphere during the year. *Met. Res. Pap., London*, No. 917, S.C. II/189, 1955.

This paper gives and charts the amplitude, phase and date of maximum of the first two harmonics of 12 monthly values (1921-40) for 305 stations in the northern hemisphere. The best method of allowing for the different lengths of the months is discussed.

4. HEASTIE, H.; Average height of the standard isobaric surfaces over the area from the North Pole to 55°N. in January. *Met. Res. Pap., London*, No. 918, S.C. II/190, 1955.

A revision of "Upper winds over the world" was begun by constructing circumpolar charts for standard pressure levels for January 1949-53. The sources of data are given and method of construction described. Charts give contour heights (in geopotential decametres) for 700, 500, 300, 200, 150 and 100 mb. and intervening thicknesses.

5. STEWART, K. H.; Radiation fog. Investigations at Cardington, 1951-54. *Met. Res. Pap., London*, No. 912, S.C. III/183, 1955.

Numerous meteorological elements were observed at Cardington, at 4, 20 and 55 ft. on a tower, up to 4,000 ft. by captive balloon, and in the ground to 40 cm., whenever fog was forecast. The site and instruments are described by R. H. Pedlow. Six typical cases are discussed: two

(most frequent types) with steep inversion below 50 ft. in early evening, sharpening and deepening; two with cooling spread through lowest few hundred feet; and two when fog did not form. Mean wind profiles show a decrease in speed with increasing height above 750 ft. on foggy nights, probably a thermal-wind effect. In section 3 the heat balance, heat exchange with cooling layer, and flow of water vapour are discussed quantitatively. At the earth's surface the heat losses by radiation, conduction and convection are roughly equal. Section 4 takes up empirical fog forecasting and produces a diagram based on screen temperature and dew point at time of dew formation, and the forecast grass minimum. Future lines of research are suggested. Appendices discuss various physical problems.

6. CORBY, G. A.; Atmospheric turbulence in aviation. *Met. Res. Pap., London*, No. 919, S.C. III/186, 1955.

The problem of forecasting turbulence at high levels is discussed. Turbulence is important in planning operations, flight forecasting and design of aircraft, but little research is being done. Proposals include full reports by civil pilots and research with accelerometers and hot-wire anemometers.

## OFFICIAL PUBLICATION

The following publication has recently been issued:—

### PROFESSIONAL NOTES

No. 115—*Cloud in relation to active warm fronts, Bircham Newton, 1942–46*. By J. S. Sawyer, M.A., and F. E. Dinsdale, B.Sc.

The cloud structures of 76 active warm fronts are examined in relation to a number of parameters available to the operational forecaster. The only significant correlation (about 0.4) is between the extent of frontal cloud and the component of wind relative to the surface front taken normal to the front at its upper boundary. An examination of the vertical distribution of cloud in relation to the frontal zone reveals a tendency for the slope of the edge of the cloud to be steeper than the slope of the front.

## NOTES AND NEWS

### West London tornado, December 8, 1954

A tornado swept across west and north-west London soon after 1700 G.M.T. on December 8, 1954 in a north-east to north direction leaving a trail of destruction some 100–400 yd. wide. The boroughs of Brentford and Chiswick, Acton and Willesden seem to have suffered most severely.

The tornado struck Gunnersbury station, Chiswick at 1708 G.M.T. unroofing station buildings, blocking and short-circuiting the track. Six people on the platform were injured. Rush-hour traffic was dislocated. In the borough of Acton alone five houses had their end walls blown out or were unroofed and many other houses suffered less serious damage. Over twelve people were injured. Railway buildings at Willesden were damaged. A lorry was overturned near Golders Green at 1720 showing that the tornado travelled at about 40 m.p.h. Buildings were also damaged at Golders Green and at Hampstead Garden Suburb. A factory was damaged at Southgate.

The damage is comparable with that caused by the Linslade and Leighton Buzzard tornado of May 21, 1950, and probably with most tornadoes in the United States.

Mr. H. H. Lamb of the Meteorological Office reports that the main trunks of several full-grown trees in the Acton area were twisted off at 5–10 ft. above the ground by the great shear of wind across their width. This is one of the most characteristic sights left by a tornado. The tree tops are finally left lying on the north-east side of the trunk in those instances where the track is from south-west to north-east.

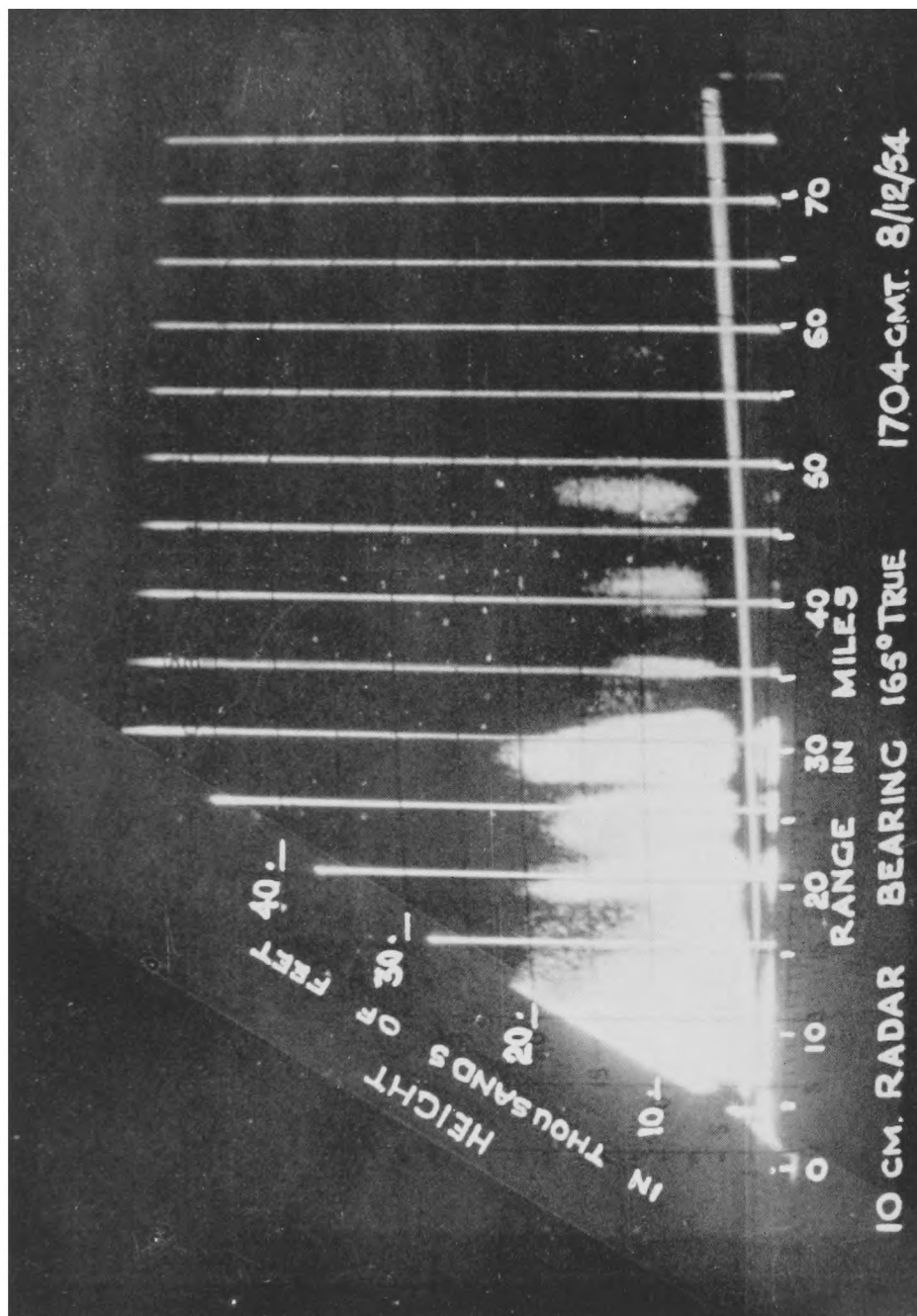


FIG. 1—HEIGHT-RANGE RADAR PHOTOGRAPH ON A BEARING OF  $165^{\circ}$  FROM EAST HILL, BEDFORDSHIRE AT 1704 G.M.T., DECEMBER 8, 1954

The large intense echo centred on 29½ miles was given by the cumulonimbus which produced a tornado, which a few minutes later caused much damage at Gunnersbury Station (see p. 321).

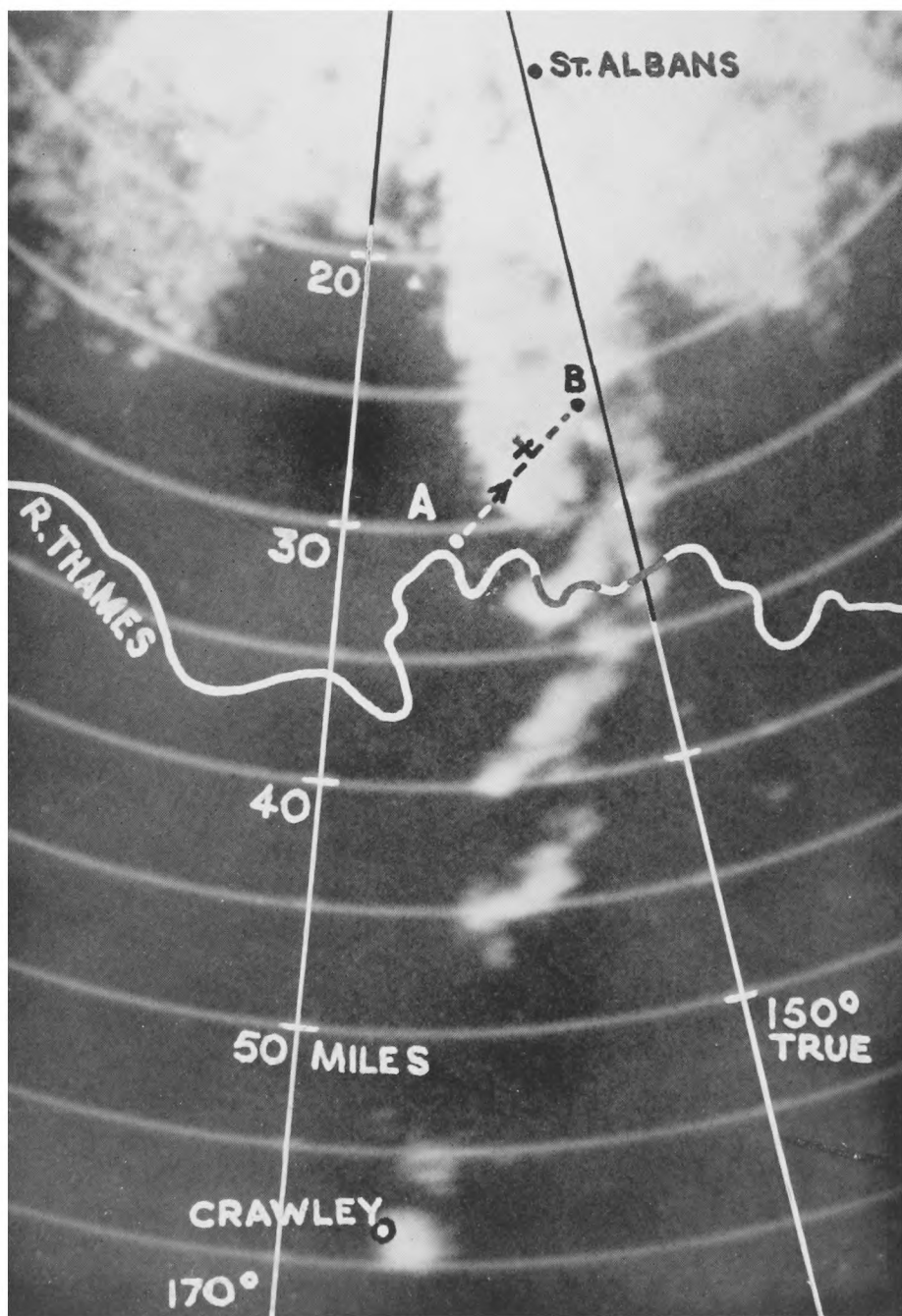


FIG. 2—PLAN-POSITION RADAR PHOTOGRAPH AT  
1708 $\frac{1}{2}$  G.M.T., DECEMBER 8, 1954

The intense echo marked with a cross was given by the cumulonimbus which produced a tornado. The track of the tornado is indicated by the line AB (see opposite).

The instruments at Kew Observatory showed no record of the tornado. At 1800 G.M.T. the surface winds at Kew and London Airport were respectively 22 and 23 kt. from 190°.

The tornado occurred during a thunderstorm accompanied by very heavy rain and hail of unusual violence for southern England in the winter. A very deep depression, central pressure below 956 mb., was centred over the mouth of the Bristol Channel at 1800 G.M.T. on December 8. The depression developed over the Atlantic about 55°N., 30°W. on the 6th and moved south-eastwards and deepened rapidly. The occlusion of the depression passed north-eastwards over the London area soon after midday on the 8th.

G. A. BULL

Radar equipment at the Meteorological Office at East Hill, 32 miles north-north-west of London, was in use on December 8, 1954, and it is of some interest that two of the radar photographs (facing pp. 320 and 321) clearly define the storm which struck west London in the late afternoon.

Fig. 1 is a height-range radar photograph taken at 1704 G.M.T., 3-4 min. before the tornado reached Gunnersbury Station. It was taken at a reduced gain setting in order to show the intense cores of cumulonimbus imbedded in the prevailing cloud mass, adjusted for maximum intensity on the very intense cumulonimbus echo at 29½ miles, bearing 165°. This cumulonimbus was larger and taller than any neighbouring cumulonimbus. The echo is 5 miles in diameter, which is large for a winter thunderstorm, and is very sharp-edged, indicating an active stage of development. The echo top shows as 22,000 ft., but a full-gain photograph taken a few seconds earlier recorded its echo top as 24,000 ft.

Fig. 2 is a plan-position radar photograph taken at 1708½ G.M.T., coinciding with the passage of the tornado across the Uxbridge Road at Acton Vale. This was also taken at a reduced gain setting. The 5-mile diameter cumulonimbus is marked with a cross (range circles are at 5-mile intervals) and the whirlwind track AB from Gunnersbury to Golders Green is shown by a broken line. The agreement in time and position makes it certain that the tornado was associated with this storm. It can be seen to be part of a north-south line of cumulonimbus clouds extending from Crawley to St. Albans, where the line merges into a much more extensive area of precipitation.

The whirlwind track has an azimuth of 205° while the echo movement measured from other radar photographs taken about this time was 210° 46 kt. The 2,000-ft. wind found at Crawley at 2000 G.M.T. was 208° 49 kt. If the echo over Acton is traced back it is found to coincide exactly with an isolated cumulonimbus echo 3 miles north-west of Midhurst, Sussex, on a radar photograph taken at 1622 G.M.T. The echo was then about 3 miles in diameter. A further extrapolation takes us to within 1 mile of the Langstone Toll Bridge to Hayling Island at 1605 G.M.T. It was at Langstone that a waterspout did damage that same afternoon, wrecking a boat-builder's shed close to the bridge. A police officer at Leigh Park near Havant reported, "a conical-shaped cloud travelling in the direction of Leigh Park, and when it was near Emsworth the point of the cloud curled upwards and disappeared into the cloud above". This is typical of the later stages in the life of a waterspout. The Hampshire Constabulary report that the clock in the toll collector's office at the Langstone Toll Bridge stopped at 1610 G.M.T. when the whirlwind passed. This agreement between

calculated and reported times is sufficiently close to make it certain that the waterspout at Langstone and the tornado over London were associated with the same cumulonimbus.

Stout and Huff\* state that unusually large and strong radar precipitation echoes are almost always present when tornadoes occur in America, masking any tornado structure which might otherwise be visible on radar. This is seen to be the case with the west London tornado.

W. G. HARPER

## REVIEWS

*Selected meteorological papers of Sir Napier Shaw, F.R.S.* Selected and arranged by R. G. Lempfert and E. E. Austin. 11¼ in. × 8½ in., pp. 276, *Illus.*, Macdonald & Co. Ltd., London, 1955. Price 50s.

This handsome and well bound volume is a credit to the editors, the printers, and publishers. It is printed on beautiful paper in clear type and the numerous diagrams are well executed. The price is surely modest as prices go today, and any serious student of meteorology will be glad to possess a copy.

Sir Napier Shaw, of whom an excellent portrait, dated 1922, appears as frontispiece to the volume, was born on March 4, 1854 and died on March 23, 1945, more than ten years ago. Before his death he expressed a wish that the trustees of his estate, who are the editors of the volume, should publish a collective edition of a selection from his meteorological lectures, addresses, essays and contributions to scientific journals. The editors compiled and printed at the end a bibliography of Shaw's works. They number no less than 381 and are dated from 1878 (an article on electrolysis for the 9th edition of the "Encyclopaedia Britannica") to four short papers in 1937. They include considerable works like the "Manual of meteorology" in four volumes, "Forecasting weather", "The air and its ways", "The drama of weather", as well as original papers on various aspects of meteorology, smoke abatement, reform of the calendar, daylight saving, units of measurement, meteorology in schools and colleges, fog and its dispersion, thermodynamics, and earlier, hygrometry, ventilation, "Practical physics" (with R. T. Glazebrook), and a number of other subjects, as well as numerous reviews and obituary notices.

The task before the editors was therefore bewildering—there was a mass of material, and the difficulty was to decide what to include in the volume and what to omit. Nor was the task mitigated by the fact that so long an interval had to elapse, owing to printing and publishing difficulties consequent on the Second World War, before a final selection could be made. The editors are to be heartily congratulated on their actual selection and also on the fact that the volume is published in 1955, the centenary year of the Meteorological Office. Shaw was Secretary of the Meteorological Council from 1899 to 1905 and Director of the Office from 1905 to 1920, and I feel that he would have been immensely pleased by the coincidence.

One of the main reasons which led Sir Napier to lay the charge of publishing a volume of his collected works upon his trustees was no doubt the fact that he himself was greatly disappointed that his first major excursion into dynamical meteorology, "The life history of surface air currents", which appeared in an

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\*STOUT, G. E., and HUFF, F. A.; Radar records Illinois tornado-genesis. *Bull. Amer. met. Soc., Lancaster Pa.*, **34**, 1953, p. 281.



edition of only 350 copies as an official publication in 1906, passed practically unnoticed by the meteorological world. Efforts to produce a reprint remained unsuccessful, and the reviewer knows that it was Shaw's wish that this work, at any rate, should be reproduced. Mr. Lempfert and Miss Austin have placed it first in the volume. Such is the modesty of some meteorologists that there is hardly an inkling in the book under review that the paper was the joint work of Shaw and Lempfert. It is believed that Lempfert drew all the charts, traced the "trajectories" of air and wrote the discussion of individual cases which forms Parts II and III of the Work, while Shaw no doubt supervised the work and wrote Part I.

At this point we might with advantage pause to consider the state of dynamical meteorology in this country in 1906. It is no exaggeration to say that it was then in process of being born, for apart from Scott's "Elementary meteorology", Abercromby's early edition of "Weather", a little but excellent pamphlet by Clement Ley entitled "Aids to the study and forecast of weather" (which incidentally was out of print) and a few papers in the journals of the Royal Meteorological Society and Scottish Meteorological Society, there was practically nothing available to the student except the regular issues of the *Daily Weather Report*. But in none of these works was there any suggestion that the track of a particle of surface air in a moving depression was otherwise than spirally towards the centre of the depression, and perhaps the greatest contribution made by the "Life history" was to demonstrate beyond question that this idea was incorrect, and that in fact surface air in a depression could travel thousands of miles almost along a great circle across the Atlantic. Incidentally present-day forecasters would be aghast if they could picture the material available to their predecessor of half-a-century ago—no information from Iceland, none from the Azores, nothing from the Atlantic, no upper air data, only a very few simple observations from western Europe and the western Mediterranean shores. Wireless telegraphy had not been developed and brought into use, while broadcasting and teleprinters were of course unknown. Shaw was indeed a pioneer in the field of dynamical meteorology, and he personally superintended the work of the Forecast Division until 1910.

The reprint of the "Life history" occupies 131 of the 275 pages of the book. The next paper is "The law of sequence in the yield of wheat for eastern England, 1885-1905" in which Shaw traced a connexion (remarkably exact for the years considered) between the yield of wheat in the eastern counties of England and the rainfall of the previous autumn, a dry autumn being followed by a good wheat yield. Like so many such relationships this one proved to be unreliable.

The next paper is the preface to an official publication entitled "Barometric gradient and wind force" by E. Gold. This initiated the Office practice, still current, of using "gradient" winds (now more properly called "geostrophic" winds) to obtain estimates from an isobaric chart of wind speed and direction at 1,500 ft. above sea level.

There are 10 other papers, memoranda, letters or notes in the Volume, of which probably the two most important are "The convective energy of saturated air in a natural environment", and "Note on the graphic representation of pressure and temperature obtained from observations of balloons, aeroplanes or kites". In these two papers the advantages of the well known  $T-\phi$  diagram

or tephigram as it is now called, for plotting upper air observations of temperature and pressure, and the properties of this method of representation were demonstrated for the first time. The method is still in official use in this country, and it has proved to be of very great value in considering questions of vertical stability and in the forecasting of thunderstorms.

From 1918 to 1920 Shaw became very interested in the part which "revolving fluid" might play in the atmosphere, following on a paper by the late Lord Rayleigh, which suggested that the conception of travelling columns of revolving air was very important in meteorology.

In two papers "The travel of circular depressions and tornadoes and the relation of pressure to wind for circular isobars" and "The birth and death of cyclones" which together occupy 35 pages of the Volume, Shaw endeavoured to prove that revolving fluid exists in the atmosphere not only in the obvious cases of tropical revolving storms, but in certain instances in parts of depressions in temperate latitudes where the wind is usually very strong.

Shaw's interest in agricultural meteorology was considerable, and this is represented in a short paper, "The book of the grower's year", in which the calendar comes under review.

The subject of units for meteorological measurements was always to the fore in Shaw's mind. He changed the unit of barometric pressure from the inch of mercury, which as he pointed out was not a scientific unit of pressure at all, to the millibar, which is 1000 dynes/cm.<sup>2</sup> The reviewer well remembers a Monday morning in about 1913 when Shaw arrived at the Office with a bulky mass of manuscript. It transpired that he had spent the week-end compiling a logical scheme of meteorological units based on the C.G.S. system which subsequently formed part of "The computer's handbook". A paper entitled "Units for meteorological measurements" contains this material and much more, while a paper with the rather grandiloquent title of "Principia atmospherica: a study of the circulation of the atmosphere", sets out a scheme for the orderly study of atmospheric laws, lemmas and postulates.

The last reprint in the Volume, "The march of meteorology: Random recollections", was published in a special number of the *Quarterly Journal of the Royal Meteorological Society* for April 1934, issued to celebrate Shaw's 80th birthday. It is a very interesting review of Shaw's own career, and fittingly brings this remarkable volume to a close, except for the bibliography and a complete index.

R. CORLESS

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*Radio astronomy.* By J. L. Pawsey and R. N. Bracewell. *Int. Monogr. Radio.* 9½ in. × 6¼ in., pp. vi + 374, *Illus.*, Oxford University Press, London: Geoffrey Cumberlege, 1955, Price: 55s.

This book, one of the series *International monographs on radio*, is written by two workers in the Radiophysics Laboratory, Sydney, Australia, where notable contributions to the science of radio astronomy have been made. This science can be said to date effectively from the end of the last war, and its subsequent world-wide development along various lines of research has been most striking. The book performs the very useful functions of describing the basic principles involved, and of summarizing and discussing the results obtained by many

different research workers; in general, work published up to about mid 1952 has been considered though there are a few references to results published in 1953.

The aim of the authors has been to cater for radio physicists with little knowledge of astronomy and also for astronomers with little knowledge of radio, the result being a book which may be understood without specialized knowledge of either science. Two of the early chapters are concerned entirely with the radio aspect and describe the principles of the various methods of measurement of extraterrestrial radio emissions and the theory of the passage of radio waves through ionized gases. Of particular interest to a meteorologist are the two following chapters which are concerned exclusively with the sun. In the first of these a straightforward account is given of various aspects of solar physics, including a discussion of sun-spots and other visible features of changes in the sun's state; this chapter also includes useful diagrams illustrating the geometry of sun-earth relationships. In the second chapter dealing with the sun, attention is confined to the sun's radio emissions which have been continuously recorded since about 1947 at a number of stations by various developing techniques. Five types of solar radio waves are tentatively classified: a basic thermal component, a slowly varying part, and three types of shorter-period variation termed respectively noise storms, outbursts, and isolated bursts; the complex relationships between these various types of emission on the one hand and known features of the sun and of solar-produced earth phenomena on the other are discussed at length. Symptomatic of the power of the radio tool and of the speed with which it is being put to use is the recent attainment of important results by this means in two old problems of geomagnetism; these results, which are foreshadowed in this book, are connected with the detection of the expulsion of solar particles and with the mysteries of the sun-spot-geomagnetic disturbance relationship.

The various lines along which radio astronomy has developed are dealt with in turn. A chapter is devoted to cosmic radio waves (historically the first of the basic discoveries of the science) with a preceding chapter in which relevant aspects of astrophysics are discussed. Separate sections describe the reception of thermal radio waves from the moon and the use of the echo method for obtaining information about extraterrestrial bodies. The echo method has been most fruitfully employed in observations of meteors and a separate section describes this development. As has been shown in recent years these meteor observations are capable of yielding apparently reliable information about winds in high levels of the atmosphere, but meteorologists will be disappointed to find that this aspect of the meteor observations is not considered by the authors. There is further disappointment for meteorologists in the penultimate chapter of the book in which the effects of the lower atmosphere and ionosphere on the reception of extraterrestrial radio waves—a potentially useful method of revealing the nature of atmospheric irregularities—are considered only very briefly. The opening chapter of the book contains an account of the basic discoveries which led to the birth of the science and gives an outline of its scope. In a short concluding chapter the authors speculate on the probable future mode of development of the science.

It is hardly a valid criticism of this book that the authors have not pursued matters of meteorological interest as far as they might. Writing in the capacity

of radio astronomers they have produced a book which must be invaluable to the specialist but which also contains much of interest to workers in all branches of physics.

D. H. MCINTOSH

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*Man and the winds.* By E. Aubert de la Rue. Translated by Madge E. Thompson. 8¼ in. × 5½ in., pp. 206, *Illus.*, Hutchinson & Co. Ltd., London, 1955, Price: 18s.

The pattern of life on this planet—perhaps even its very presence—much depends upon adequate air movement, and this book—a study of “human geography”—is a semi-popular development of this basic theme.

The first five chapters describe the main general and regional wind systems. Attention is then turned to the physiological effect of wind, its influence on architecture, and, in the next four chapters, its activity as a transporter of sand and soil. The final 80 pages deal mainly with the wind as a source of energy in relation to agriculture, industry, and aviation.

A number of inaccuracies and half-truths occur, particularly in the early part of the book where the author is dealing with the physical mechanism of the wind, but this over, the reader is treated to a vigorous, readable, but not necessarily complete or up-to-date account of wind in its more violent moods. The text is illustrated by a number of appropriate and attractive photographs. There will be few interested in the weather, who will not find something novel in these pages, but the last sentence, “The wind appears sometimes as a friend of man, sometimes as an enemy, but more often in the latter role.” may be questioned.

There is a useful bibliography, mainly from French sources; the book is well produced and the translation smooth and efficient.

R. W. GLOYNE

### METEOROLOGICAL OFFICE NEWS

**Academic successes.**—Information has reached us that the following members of the staff have been successful in recent examinations; we offer them our congratulations.

*B.Sc.(General)*: pure and applied mathematics and physics, L. Dent.

*B.Sc.(Special)*: second class honours in physics, J. B. Andrews.

*Intermediate B.Sc.*: pure and applied mathematics and physics, B. Entwistle, P. J. Rollins, P. J. Wiggett; pure and applied mathematics, physics and chemistry, R. J. Thorne.

*General Certificate of Education (Advanced Level)*: pure and applied mathematics and physics, J. M. C. Burton, G. A. Dent, D. Oseman, D. S. Reed; pure and applied mathematics, J. M. Bayliss, A. Stemmler; pure mathematics, V. A. Winslow; applied mathematics, A. R. Belton, Miss C. Bulgin, B. G. Ellis; physics, D. H. A. Gamble, P. B. Gildersleeves, B. Stapleton; physics and applied mathematics, F. Burns, J. P. T. Randles.

*City and Guilds Intermediate and Final Certificate in Telecommunications Engineering*: A. F. Hope.

**Sports activities.**—*Netball.*—The Meteorological Office Ladies' Netball team won the Air Ministry championship on August 20 for the seventh consecutive year. A cup has now been awarded for this competition by the Ariel Club.

## WEATHER OF AUGUST 1955

In the Atlantic and European sector the weather during August continued to show the same broad features as those which characterized July. Pressure and temperature were again below normal in the Greenland area. The north-eastward extension of the Azores anticyclone across Scotland to Scandinavia was a very frequent feature of the daily maps resulting in a very large anomaly of +10 mb. in the mean monthly pressure in this region and a corresponding temperature anomaly of 2–3°C. above the normal for the month.

Elsewhere the main features of note in the mean pressure and temperature distribution were below normal pressures in the Florida region of the United States in association with hurricanes experienced there, and pressures also below normal over Russia and over north-west Canada. Temperatures were above normal over most of southern Canada and the northern United States but below normal over much of the Mediterranean and south-east Europe.

Less than half the normal August rainfall fell over most of Britain and much of Scandinavia and north France, but rainfall was above normal in Czechoslovakia and most of the Mediterranean region including the southern half of France. Slightly over the normal rainfall for August was experienced in the extreme north of Norway, Iceland and Faeroes. Rainfall was below normal over much of the central United States but was a little above normal in north Canada; rainfall was also much above normal in the eastern United States as a result of the hurricanes.

In the British Isles weather was anticyclonic for the major part of the month but conditions were rather unsettled from the 14th to the 19th.

During the first week depressions moved across the Atlantic in high latitudes and frontal systems crossing the country were mostly weak except for the one moving southwards on the 2nd and 3rd which gave  $\frac{1}{2}$  in. of rain at Aldergrove and Mildenhall and similar amounts in north-east England. Weather was sunny and warm generally. Reports of 11 and 12 hr. sunshine were common during this period and on the 4th some stations in the north-west had more than 14 hr. Temperature rose to 80°F. at London Airport on the 1st and 2nd and to 83°F. at Leuchars on the 1st. A depression from Iceland became established over Scandinavia on the 6th, and although the British Isles remained chiefly under the influence of anticyclones to the west and south-west, the more northerly air stream produced somewhat lower temperature than of late. There was some ground frost in Scotland; grass temperature at Dyce fell to 29°F. early on the 9th and 10th. The 9th was dull with occasional rain as a weak trough moved into western districts, but the following day a general rise of pressure took place and from the 10th to the 13th an anticyclonic belt extended from the Azores across the British Isles to Scandinavia. Temperature rose slowly in most places to the middle seventies. Thunderstorms developed in many areas from the 10th with outbreaks of heavy rain locally; storms were particularly widespread on the night of the 12th–13th when more than  $\frac{1}{2}$  in. of rain fell in parts of London and south-east England and 3·44 in. fell in 1 hr. 20 min. during a heavy storm at Annaghanoon, Co. Down. A general increase in cyclonic activity occurred over the Atlantic from the 14th to the 19th. A south-westerly air stream covered the British Isles, and with this moister air widespread fog formed early but cleared quickly during the morning. There were outbreaks of thundery rain and scattered thunderstorms in most areas on the 17th and 18th as troughs moved across the country. For the remainder of the month, apart from the last day or two anticyclonic conditions were re-established over the British Isles. Temperature rose steadily and exceeded 85°F. at many places on the 22nd, 23rd and 24th and reached 90°F. at Chivenor on the 23rd; in some places during these three days temperature did not fall below 65°F. at night. Fog was again widespread during the early morning and persisted throughout the day in some coastal areas, but weather was generally dry and sunny apart from the last two days of the month when troughs from the Atlantic brought fairly general rain to the north-west. Rainfall was below the average everywhere, and monthly amounts only exceeded 50 per cent. of the average in south-east England and locally in Wales, north-west England and southern Scotland. There was less than 25 per cent. of the average over the Midlands and south-west England.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	90	32	+3·5	34	—8	116
Scotland ...	89	32	+3·5	30	—10	123
Northern Ireland ...	83	39	+4·1	24	—12	111

# RAINFALL OF AUGUST 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	0·95	43	<i>Glam.</i>	Cardiff, Penylan ...	1·54	36
<i>Kent</i>	Dover ... ..	1·79	77	<i>Pemb.</i>	Tenby ... ..	0·46	12
<i>"</i>	Edenbridge, Falconhurst	0·79	30	<i>Radnor</i>	Tyrmynydd ... ..	1·51	28
<i>Sussex</i>	Compton, Compton Ho.	1·50	49	<i>Mont.</i>	Lake Vyrnwy ... ..	2·12	40
<i>"</i>	Worthing, Beach Ho. Pk.	1·48	65	<i>Mer.</i>	Blaenau Festiniog ...	3·14	28
<i>Hants.</i>	St. Catherine's L'thouse	1·58	82	<i>"</i>	Aberdovey ... ..	1·69	38
<i>"</i>	Southampton (East Pk.)	0·96	37	<i>Carn.</i>	Llandudno ... ..	1·13	40
<i>"</i>	South Farnborough ...	0·97	44	<i>Angl. *</i>	Llanerchymedd ... ..	0·88	24
<i>Herts.</i>	Harpenden, Rothamsted	0·75	30	<i>I. Man</i>	Douglas, Borough Cem.	2·44	64
<i>Bucks.</i>	Slough, Upton ... ..	0·97	45	<i>Wigtown</i>	Newton Stewart ...	1·66	40
<i>Oxford</i>	Oxford, Radcliffe ...	0·45	20	<i>Dumf.</i>	Dumfries, Crichton R.I.	1·71	42
<i>N'hants.</i>	Wellingboro' Swanspool	0·58	24	<i>"</i>	Eskdalemuir Obsy. ...	1·54	30
<i>Essex</i>	Southend, W. W. ...	1·70	92	<i>Roxb.</i>	Crailing... ..	0·71	24
<i>Suffolk</i>	Felixstowe ... ..	1·75	100	<i>Peebles</i>	Stobo Castle ... ..	1·88	53
<i>"</i>	Lowestoft Sec. School ...	1·51	69	<i>Berwick</i>	Marchmont House ...	0·57	17
<i>"</i>	Bury St. Ed., Westley H.	1·71	66	<i>E. Loth.</i>	North Berwick Gas Wks.	0·57	18
<i>Norfolk</i>	Sandringham Ho. Gdns.	0·75	28	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·05	33
<i>Wilts.</i>	Aldbourne ... ..	0·48	17	<i>Lanark</i>	Hamilton W. W., T'nhill	1·46	43
<i>Dorset</i>	Creech Grange... ..	0·97	34	<i>Ayr</i>	Prestwick ... ..	1·62	51
<i>"</i>	Beaminster, East St. ...	0·67	21	<i>"</i>	Glen Afton, Ayr San. ...	1·55	29
<i>Devon</i>	Teignmouth, Den Gdns.	0·46	20	<i>Renfrew</i>	Greenock, Prospect Hill	1·24	24
<i>"</i>	Ilfracombe ... ..	0·37	10	<i>Bute</i>	Rothesay, Arden Craig ...	1·48	30
<i>"</i>	Princetown ... ..	1·06	16	<i>Argyll</i>	Morven, Drimnin ...	1·73	33
<i>Cornwall</i>	Bude, School House ...	0·34	12	<i>"</i>	Poltalloch ... ..	1·87	38
<i>"</i>	Penzance ... ..	0·48	15	<i>"</i>	Inveraray Castle ...	3·73	57
<i>"</i>	St. Austell ... ..	0·22	6	<i>"</i>	Islay, Eallabus ... ..	1·15	26
<i>"</i>	Scilly, Tresco Abbey ...	0·36	13	<i>"</i>	Tiree ... ..	1·31	31
<i>Somerset</i>	Taunton ... ..	0·72	30	<i>Kinross</i>	Loch Leven Sluice ...	0·99	26
<i>Glos.</i>	Cirencester ... ..	0·98	32	<i>Fife</i>	Leuchars Airfield ...	0·27	9
<i>Salop</i>	Church Stretton ... ..	1·09	33	<i>Perth</i>	Loch Dhu ... ..	1·37	20
<i>"</i>	Shrewsbury, Monkmore	1·46	53	<i>"</i>	Crieff, Strathearn Hyd.	1·22	29
<i>Worcs.</i>	Malvern, Free Library...	0·67	23	<i>"</i>	Pitlochry, Fincastle ...	1·17	33
<i>Warwick</i>	Birmingham, Edgbaston	0·58	19	<i>Angus</i>	Montrose, Sunnyside ...	0·53	19
<i>Leics.</i>	Thornton Reservoir ...	0·61	22	<i>Aberd.</i>	Braemar ... ..	0·88	26
<i>Lincs.</i>	Boston, Skirbeck ... ..	0·68	28	<i>"</i>	Dyce, Craibstone ... ..	0·35	12
<i>"</i>	Skegness, Marine Gdns.	0·98	40	<i>"</i>	New Deer School House	0·50	17
<i>Notts.</i>	Mansfield, Carr Bank ...	0·82	29	<i>Moray</i>	Gordon Castle ... ..	2·28	72
<i>Derby</i>	Buxton, Terrace Slopes	0·89	20	<i>Nairn</i>	Nairn, Achareidh ...	0·40	16
<i>Ches.</i>	Bidston Observatory ...	1·53	50	<i>Inverness</i>	Loch Ness, Garthbeg ...	0·57	18
<i>"</i>	Manchester, Ringway...	1·00	30	<i>"</i>	Glenquoich ... ..	..	..
<i>Lancs.</i>	Stonyhurst College ...	1·03	20	<i>"</i>	Fort William, Teviot ...	1·17	27
<i>"</i>	Squires Gate ... ..	1·11	32	<i>"</i>	Skye, Broadford ... ..	1·70	26
<i>Torks.</i>	Wakefield, Clarence Pk.	0·29	11	<i>"</i>	Skye, Duntuilm ... ..	1·31	29
<i>"</i>	Hull, Pearson Park ...	0·77	26	<i>R. &amp; C.</i>	Tain, Mayfield... ..	0·56	21
<i>"</i>	Felixkirk, Mt. St. John...	0·77	27	<i>"</i>	Inverbroom, Glackour...	0·93	22
<i>"</i>	York Museum ... ..	0·59	23	<i>"</i>	Achnashellach ... ..	2·89	46
<i>"</i>	Scarborough ... ..	0·72	26	<i>Suth.</i>	Lochinver, Bank Ho. ...	1·26	38
<i>"</i>	Middlesbrough... ..	0·81	30	<i>Caith.</i>	Wick Airfield ... ..	0·57	21
<i>"</i>	Baldersdale, Hury Res.	1·45	44	<i>Shetland</i>	Lerwick Observatory ...	0·89	30
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	1·14	40	<i>Ferm.</i>	Crom Castle ... ..	0·73	18
<i>"</i>	Bellingham, High Green	1·19	34	<i>Armagh</i>	Armagh Observatory ...	1·10	30
<i>"</i>	Lilburn Tower Gdns. ...	0·61	22	<i>Down</i>	Seaforde ... ..	1·21	32
<i>Cumb.</i>	Geltsdale ... ..	1·94	47	<i>Antrim</i>	Aldergrove Airfield ...	1·60	44
<i>"</i>	Keswick, High Hill ...	4·36	84	<i>"</i>	Ballymena, Harryville...	0·97	23
<i>"</i>	Ravenglass, The Grove	3·10	68	<i>L'derry</i>	Garvagh, Moneydig ...	0·63	16
<i>Mon.</i>	A'gavenny, Plás Derwen	0·74	22	<i>"</i>	Londonderry, Creggan	1·31	28
<i>Glam.</i>	Ystalyfera, Wern House	3·48	56	<i>Tyrone</i>	Omagh, Edenfel ... ..	0·91	21

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METEOROLOGICAL OFFICE

# THE METEOROLOGICAL MAGAZINE

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## AN INSTRUMENT FOR THE CONTINUOUS RECORDING OF SOIL TEMPERATURES AT A NUMBER OF DEPTHS

By N. E. RIDER, B.Sc.

**Introduction.**—A knowledge of soil temperature is often required for agricultural and engineering purposes as well as in purely meteorological investigations such as the study of the heat balance at the earth's surface. Continuous records of such temperatures have been obtained in the past from mercury-in-steel thermographs<sup>1</sup>, from platinum resistance thermometers<sup>2</sup>, and from single thermojunctions working in conjunction with photographic recording galvanometers<sup>3</sup>. All these methods have disadvantages. In siting the "thermometers" it is necessary to remove considerable quantities of soil, and it is virtually impossible to insure that the soil, when replaced, has the same degree of packing as in the undisturbed state. Moreover any vegetation cover is at least severely damaged. Mercury-in-steel thermographs are relatively cumbersome to handle and photographic recording is never convenient on a field site which may be far removed from darkroom facilities. The instrument to be described depends on the thermo-electric principle, and is a development of that used by Pasquill<sup>4</sup> and others in heat-balance observations for which the indications of a sensitive eye-reading galvanometer were sufficient. It is simple to construct, does not disturb the soil or vegetation to any great extent on siting, and provides an immediately visible record at a convenient distance from the point of exposure. No power supply—other than that provided by a 6V. accumulator—is required.

**General construction.**—The thermometer, as at present constructed, enables temperatures at five depths, 1, 5, 10, 20, and 40 cm., to be recorded to  $0.2^{\circ}\text{F.}$  over a range of  $60^{\circ}\text{F.}$  when working with the recording galvanometer to be described. The depths may be chosen to suit any particular need when the instrument is constructed. A view of the thermometer, together with some constructional details, is shown in Fig. 1. It consists of a tufnol tube,  $1\frac{1}{2}$  in. outside diameter and  $\frac{3}{4}$  in. inside diameter, which is closed at one end by a brass spike and at the other end by a brass cap. Copper plugs, which form the thermometer bulbs, are inserted through the wall of the tube at appropriate intervals along its length and at each depth three bulbs are spaced  $120^{\circ}$  apart around the tube. Three complete sets of bulbs are thus provided, the S<sub>1</sub>, S<sub>2</sub>, and S<sub>3</sub> of Fig. 2 which shows a schematic wiring diagram for the apparatus. Each set has a reference junction (R<sub>1</sub>, R<sub>2</sub>, and R<sub>3</sub> of Fig. 2) which is normally kept in melting ice contained in a vacuum flask. The thermojunctions are made from enamelled 28 s.w.g. constantan and 32 s.w.g. copper wire, and each bulb has a small hole drilled through its centre into which a pair of these

wires is soldered, each thermojunction pair being made of the same lengths of wire and covered with polyvinyl-chloride sleeving. The copper bulbs are tight push fits in the wall of the tufnol tube and, to give added strength, they are stuck in position with araldite D. After insertion the bulbs are filed to be flush with the tufnol and the instrument is covered with a coating of araldite to insulate the bulbs and render the whole watertight. The thermocouple leads are brought up the centre of the tube and leave near its upper end by way of three short brass side tubes which are screwed into the tufnol wall, the wires from one set of bulbs leaving by each tube. The wires are terminated in junction boxes where they are joined by those from the reference junctions. Between the thermometer and the junction boxes the leads are protected by polyvinyl-chloride tubing which fits tightly over the brass side tubes at one end and over the junction boxes at the other end. The constantan leads of each of

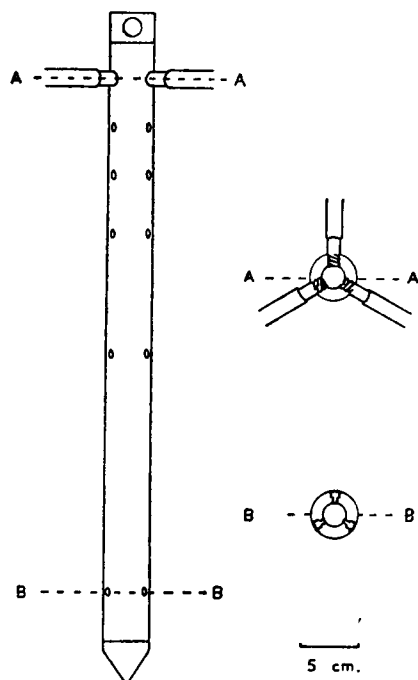


FIG. 1—GENERAL CONSTRUCTION OF THE THERMOMETER

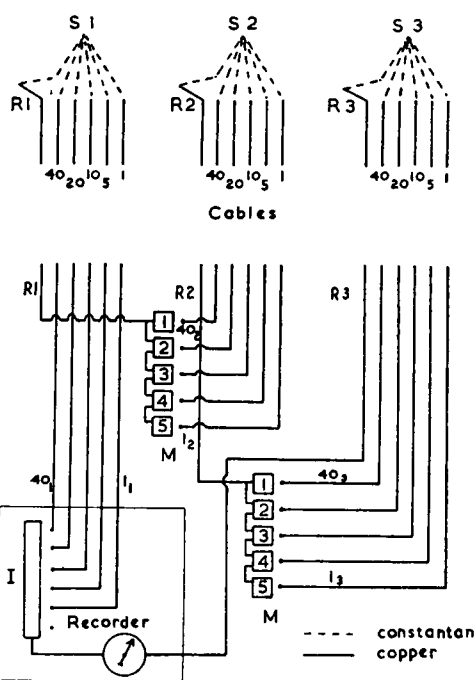


FIG. 2—SCHEMATIC WIRING DIAGRAM FOR THE THERMOMETER AND ITS RECORDING CIRCUITS

the three sets, together with that from the appropriate reference junction, are soldered together in the junction boxes which also contain any excess lengths of lead. A six-core cable with 22 s.w.g. copper conductors leaves each of the boxes and leads to the recorder. As at present constructed the cables are 100 yd. long, but they could be made considerably longer with slight loss of sensitivity if desired.

An Elliott six-circuit, six-colour recording galvanometer having a coil resistance of 35 ohms and a full-scale deflexion for  $40 \mu\text{amp.}$ , is used. This recorder, as supplied by the manufacturers, has a double-pole six-position rotary switch for circuit selection which is operated by an electromagnet which also actuates the colour-changing mechanism. The switching interval is 2 min. and is regulated by a clock attached to the instrument. A 6V. d.c. supply is required.



The eighteen copper leads from the thermometer are brought to a board near the recorder on which are mounted six Post Office type 3,000 relays (100 ohms, 6V. operating), the M's of Fig. 2. Each has two platinum contact pairs which are made on energizing the relay. In Fig. 2, only five relays are shown, the sixth being used to provide a zero position on the galvanometer chart. The relays are energized in the required sequence by applying current through one side of the rotary switch in the recorder, the wiring of the latter being modified for this purpose. The other side of the rotary switch, I of Fig. 2, is used as indicated in the figure. The back electromotive force produced on switching the relays is suppressed by the use of a condenser and resistance circuit across each relay coil and arcing at the rotary switch is avoided. It will be seen that at each depth at which a temperature record is required there is in effect a thermopile having three "hot" and three "cold" junctions. The output from a single thermojunction pair is insufficient to provide the necessary current to give a reasonably open scale of temperature on the recorder chart, unless the galvanometer employed has a much higher current sensitivity or d.c. amplifiers are employed. The use of a more sensitive galvanometer would entail photographic recording and the use of d.c. amplifiers leads to well known complications.

The apparatus provides a record of the temperature at each of the five depths once in every 12 min., and there is no possibility of the recording mechanism becoming out of step with the relays. Soil temperatures below freezing point can be recorded by moving the zero position of the galvanometer, which represents 32°F., and when such conditions are expected the galvanometer zero is set some way up the chart.

**Calibration.**—The thermometer and its associated recorder are calibrated as a single unit. The calibration is conducted in the normal way by the use of stirred water baths. After reasonable care in construction the calibration factors are found to be the same for the circuits at all depths. However, calibration shows an increase in deflexion per degree with increase in temperature, the increase amounting to 4 per cent. over the range from 30° to 90°F. The overall resistance of a circuit for one depth, including the galvanometer and 100 yd. of cable is approximately 95 ohms, and one scale division of the recorder chart represents approximately 1.4°F. No change in calibration could be detected as a result of heating by the relay coils, the relays being mounted so that any heat generated would have a minimum effect on the contacts.

**Field use.**—The thermometer is driven vertically into the soil and the cables are led away to a small hut which houses the recorder and the accumulator. The only attention required is a replacement of the ice flask every second day in average summer conditions (latitude 52°N.). One 6V. 65 amp.hr. capacity accumulator will operate the apparatus for one week on a single charge. A typical record is reproduced in Fig. 3. In the original each trace is in a distinctive colour and is much easier to identify than the black-on-white figure indicates.

**Conclusion.**—Three sets of the apparatus have been exposed at Cambridge for more than a year and no faults have developed in the thermometers; such loss of record as has occurred has been the result of minor mechanical faults in the recorders. In future construction it would be desirable to replace the

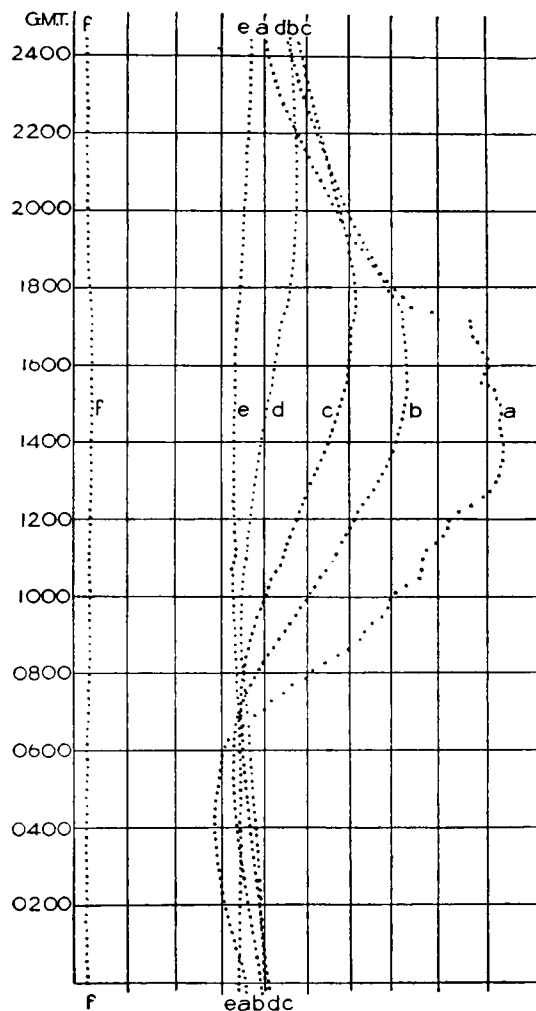


FIG. 3—TRACING OF TEMPERATURE RECORD

Thermometer exposed in bare soil on May 10, 1954, near Cambridge

a = 1 cm. depth                      d = 20 cm. depth  
 b = 5 cm. depth                    e = 40 cm. depth  
 c = 10 cm. depth                  f = zero line 32°F.

The vertical lines are drawn at intervals of 4 scale divisions and represent temperature differences of approximately 5·5° F. The chart is 12 cm. wide.

three junction boxes and cables by single units as this would facilitate handling on the site. The time taken to install the apparatus and move it from site to site can be measured in minutes rather than in hours as has been the experience with apparatus used previously.

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## THE STORMS AND ASSOCIATED STORM SURGES OF DECEMBER 21-23, 1954

By R. MURRAY, M.A., and Lt-Com. C. P. W. MARSHALL, R.N., F.R.I.C.S.

**Introduction.**—The weather during the period December 21-23, 1954, was very stormy over the British Isles-North Sea region; widespread north-westerly gales occurred and there were some extremely severe squalls. Furthermore, the storm surges experienced on the coast of East Anglia on December 22 and 23 were the largest since the disastrous surge of January 31-February 1, 1953. However, owing to the fortuitous circumstance that the surges did not coincide with a spring tide only slight flooding of the coastal defences resulted. Although neither the storms nor the surges were unprecedented in severity, there were a number of interesting aspects which probably merit recording. Moreover, the general synoptic picture appears worthy of discussion, not merely because in it naturally lies the root cause of the storms and surges, but also since it illustrates rather well the behaviour of certain mobile depressions in relation to the thermal field and to the large-scale upper air pattern.

**Broad-scale upper air pattern.**—On the largest scale the tropospheric flow pattern during December 20-24, 1954, changed but little over a wide sector from America to Europe. The main features of the quasi-stationary broad-scale pattern in the middle and upper troposphere consisted of a cold trough over eastern America, a warm ridge over the Atlantic, a rather broad cold trough down stream over Europe, and an exceptionally strong upper flow. The powerful upper current swept north-eastwards on the forward side of the American trough, turned eastwards in the south Greenland-Iceland region then south-eastwards over the British Isles. The characteristic features of the broad-scale pattern are well illustrated by the mean 500-mb. contours for the 4-day period from 0300, December 20 to 0300, December 24, shown in Fig. 1.

The strength and persistency of the upper flow over the British Isles are shown by the fact that the wind at about 30,000 ft. at Stornoway in the Isle of Lewis averaged about  $310^{\circ}$  150 kt. during the three days December 21-23; the wind, measured at 30,000 ft. at 0800 and 2000 G.M.T. and at 300 mb. at 0200 and 1400 G.M.T., varied in speed between 116 and 180 kt. and in direction between  $289^{\circ}$  and  $330^{\circ}$ . The maximum speed in the core of the jet stream was even higher than indicated by the winds at 30,000 ft. or at 300 mb.; indeed the remarkable speeds of 196 kt. at 27,000 ft. at Stornoway at 2000 G.M.T. on December 21 and 198 kt. at 33,000 ft. at Leuchars at 2000 G.M.T. on December 22 are amongst the highest that have been observed over the British Isles.

It is interesting to compare the observed wave-length of the long waves on the mean chart shown in Fig. 1 with the computed stationary wave-length given by Rossby's well-known formula,  $L_r = 2\pi\sqrt{(U/\beta)}$ , where the symbols have their usual meanings for the barotropic model atmosphere in which the flow has zero divergence. The practical computations should be made at the latitude most representative of the flow connecting the two troughs. The best latitude for the American trough is about  $50^{\circ}$ N., whereas it is somewhat higher, say  $55^{\circ}$ N., for the European trough. Computations were made for the trough pair at both  $50^{\circ}$  and  $55^{\circ}$ N. ( $84^{\circ}$  and  $110^{\circ}$  of longitude respectively) and the mean, which was taken as applicable to the trough pair, came out at  $97^{\circ}$  of

longitude in fair agreement with the observed wave-length of  $90^\circ$  of longitude. The level of non-divergence is generally considered to be nearer 600 mb. than 500 mb. on the average, so the computations of the zonal flow  $U$  were adjusted to apply to the 600-mb. level, and the computed stationary wave-length was found to be  $87^\circ$  of longitude which agrees very well with the distance between the American and European troughs in Fig. 1.

The broad-scale tropospheric air flow may be regarded as the steering current for the motion of the two depressions which early in their life history were quite small-scale features near south-east Greenland, but which later became major storms over the North Sea. Both depressions moved from Greenland then south-eastwards in the peripheral circulation of the large-scale upper ridge located over the Atlantic (see Fig. 1), deepening meanwhile in the strongly baroclinic zone.

The individual synoptic features in the life history of the two major storms will be discussed below with the aid of Figs. 2-5.

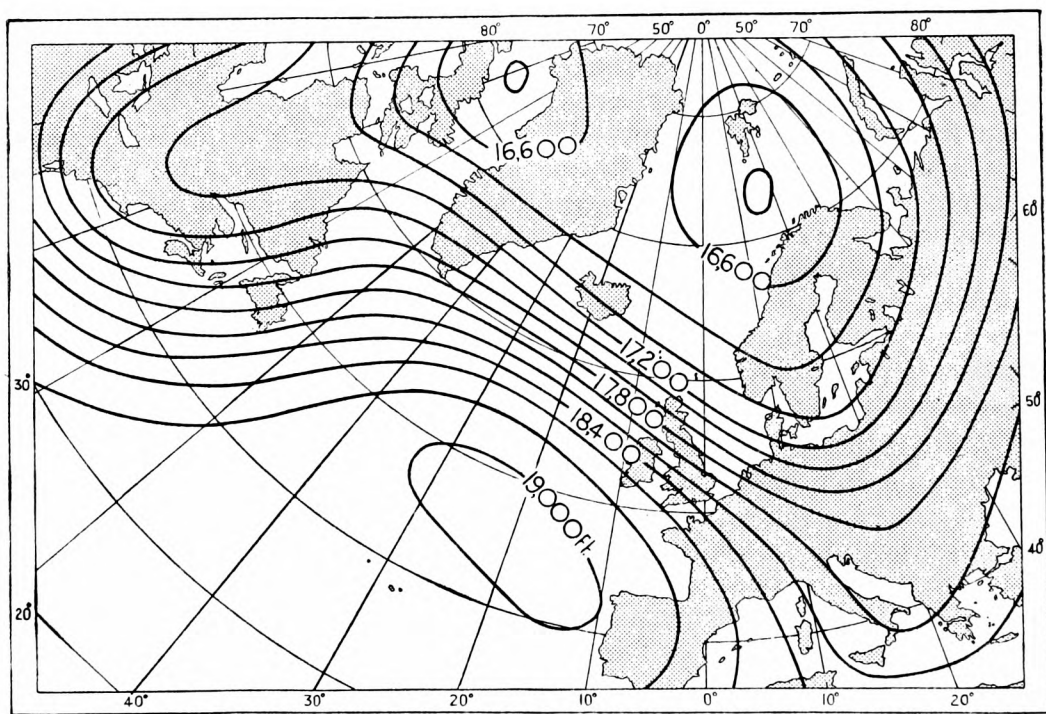
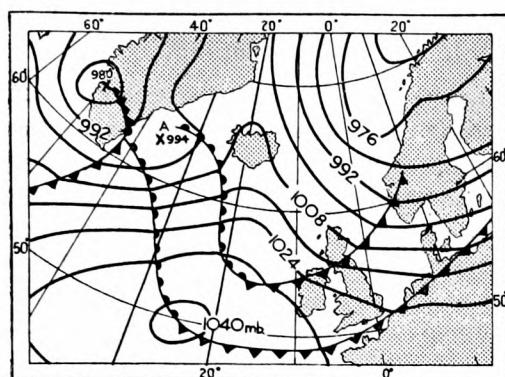
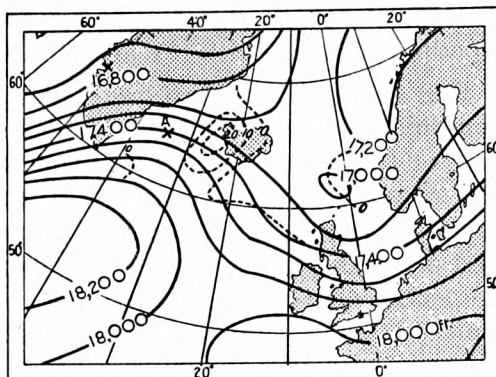


FIG. 1—MEAN 500-MB. CONTOURS, 0300 G.M.T., DECEMBER 20  
TO 0300 G.M.T., DECEMBER 24, 1954

**Synoptic aspects of the first storm.**—The first of the two major storms can be said to have originated as an incipient low of around 1000 mb. at about 0900 G.M.T. on December 20, off south-east Greenland, when a fairly deep depression, which had moved north-eastwards from eastern Canada, struck the west coast of Greenland. In Fig. 2(a) the old low from Canada is seen to be just inland over west Greenland, and the new low A off south-east Greenland is shown with a central pressure of 994 mb. Cyclogenesis in this geographical region is a common occurrence when the upper flow has a pronounced zonal component across and to the south of southern Greenland and when the primary depression moves to the western side of Greenland. In the present



(a) Surface chart, 1200 G.M.T.



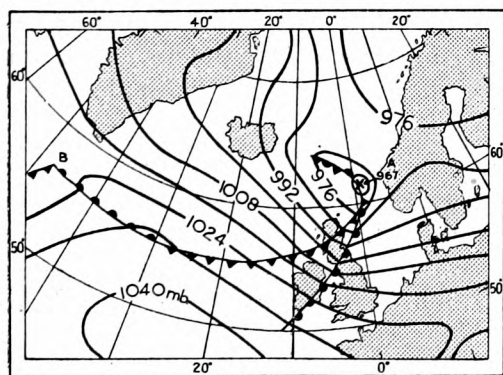
(b) 1000-500-mb. thickness chart, 1500 G.M.T.

FIG. 2—SYNOPTIC CHARTS, DECEMBER 20, 1954

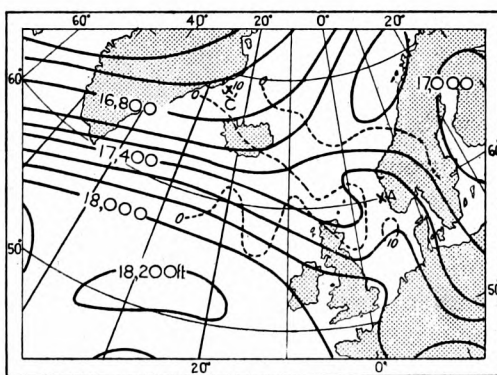
Isopleths of Sutcliffe's development parameter in units of  $10^{-2}\text{hr.}^{-2}$  are shown by broken lines in the thickness chart which also indicates the positions of the surface lows by crosses.

case, as quite typically happens, the primary low rapidly filled up over Greenland and was replaced by, or transformed into, the new rapidly deepening low between Greenland and Iceland. This type of transformation is essentially a process of cyclonic development set in operation in this particular manner by suitable upper flow and thermal patterns in relation to the topography of southern Greenland. Whatever the precise mechanism may have been, the process culminated in the maximum of cyclonic vorticity being located to the east of Greenland as if it had been transferred there by thermal steering from the west of Greenland. Subsequently the deepening depression A moved rapidly in the strong thermal current (see Fig. 2(b)) across Iceland to near Shetland by noon on December 21 (Fig. 3(a)), then the low decelerated during the following 24 hr. and became almost stagnant in the southern Baltic (Fig. 4(a)). The track of the depression and values of the central pressure at 6-hourly intervals are shown in Fig. 4(a).

During the phase of great mobility and deepening the baroclinic aspects were evidently dominant in view of the strong thermal and the pre-existing thermal diffuence between Iceland and Scotland (see Fig. 2(b)). Indeed an estimate of the Sutcliffe development parameter<sup>1</sup>, computed with the scale prepared by Sawyer and Matthewman<sup>2</sup> shows a pronounced maximum of



(a) Surface chart, 1200 G.M.T.



(b) 1000-500-mb. thickness chart, 1500 G.M.T.

FIG. 3—SYNOPTIC CHARTS, DECEMBER 21, 1954

Isopleths of Sutcliffe's development parameter in units of  $10^{-2}\text{hr.}^{-2}$  are shown by broken lines in the thickness chart which also indicates the positions of the surface lows by crosses.

cyclonic development near west Iceland in advance of the surface depression A, broadly consistent with the low's eastward motion and deepening.

The thermal modifications which occurred during this phase were not abnormal, and were qualitatively understandable. The warm ridge to the west of Iceland moved eastwards then south-eastwards over the British Isles in a considerably weaker form in association with the motion and deepening of the depression. Meanwhile a new cold thermal trough developed to the west of the thermal ridge as the cold-air advection intensified in the rear of the deepening depression A, and this new thermal trough quickly and effectively replaced the pre-existing one which travelled east-south-eastwards into Europe. Thus on reaching Shetland the depression A was already intense and fairly well occluded with a rather weak thermal structure over its central area (Fig. 3 (b)).

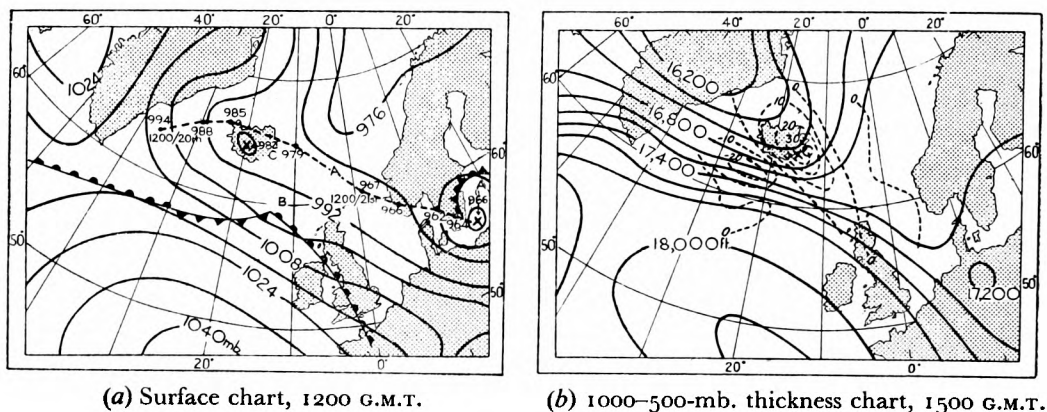


FIG. 4—SYNOPTIC CHARTS, DECEMBER 22, 1954

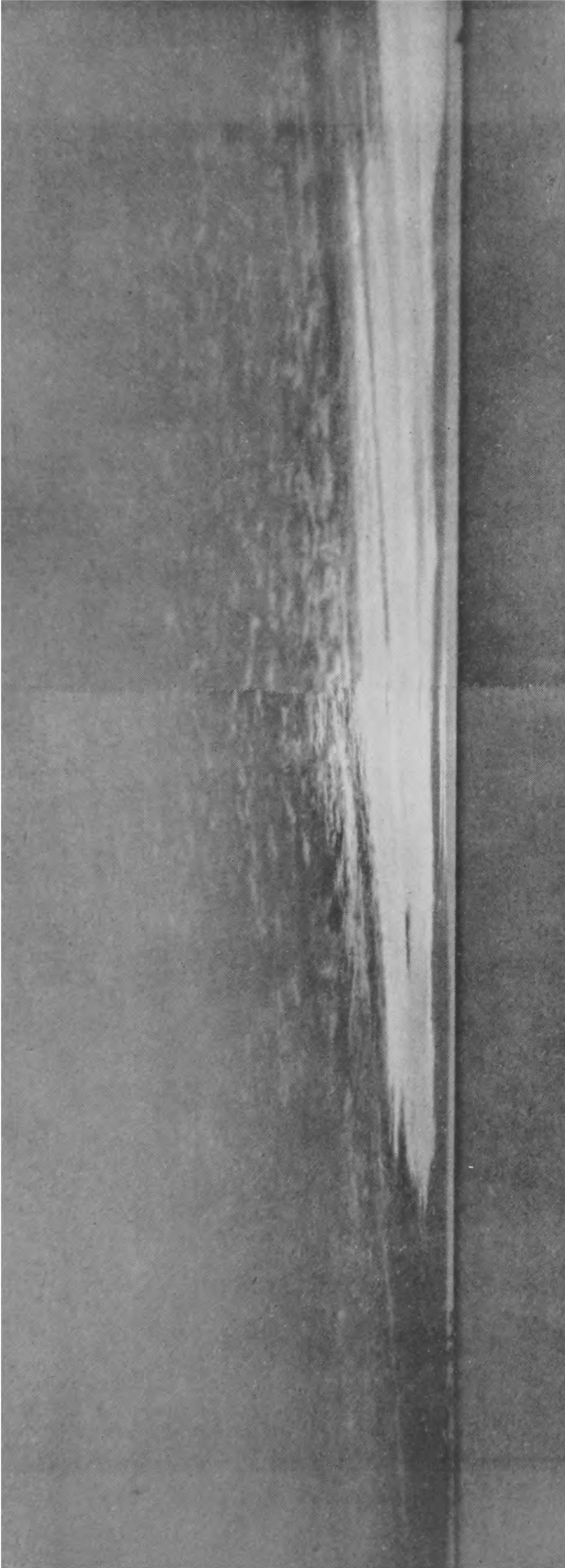
Track of low A is shown by a broken line in the surface chart, with central pressure indicated at 6-hr. intervals. Isopleths of Sutcliffe's development parameter in units of  $10^{-2}\text{hr.}^{-2}$  are shown by broken lines in the thickness chart which also indicates the position of low C by a cross.

The next phase of deceleration and only slight deepening was consistent with the weakening thermal structure and the change-over to nearly barotropic conditions (Fig. 4 (b)). The Sutcliffe development parameter at about the beginning of this stage shows a relatively uniform field distribution, with only slight cyclonic development over and near south-west Norway (Fig. 3 (b)), consistent with little further deepening of the surface depression A and movement more or less under its own inertia until almost complete stagnation within the near-barotropic axis region of the stationary broad-scale upper trough.

Throughout the life history of this depression a major anticyclone, the surface counterpart of the broad-scale upper ridge, was slow moving in the Atlantic (Figs. 2 (a), 3 (a) and 4 (a)); and the intensity and persistence of this anticyclone contributed largely to the creation of the very strong pressure gradient between the centres of low and high pressure, and consequently to the occurrence of the widespread gales.

**Synoptic aspects of the second storm.**—The second storm appears to have had its birth in the Denmark Strait, although a fast-moving wave travelled across the extreme north of the Atlantic and formed part of the deep depressional system over the North Sea. As early as midday on December 21





*Reproduced by courtesy of H. H. Lamb*

ANTARCTIC SUNSET: AN INTERESTING ALTOCUMULUS SKY NEAR  $65^{\circ}\text{S}$ .  $108^{\circ}\text{E}$ .

The photograph, looking south at a point near the ice margin 130 miles north of the coast of Antarctica on February 10, 1947, gives an unusually long, though inevitably foreshortened, view of a curved (sickle-shaped) belt of altocumulus seen in the absence of low cloud and in the very clear atmosphere of high latitudes. The south-western edge of the cloud system was beautifully illuminated by the setting sun in shades of magenta pink against a golden sheen of cirrus above. The narrow cloud belt, showing the characteristic curvature, convex towards the east towards the west, of a frontal system in either hemisphere, was believed to mark the upper front of an occlusion.



*Reproduced by courtesy of H. H. Lamb*

#### WILD CUMULONIMBUS SKY OFF FINISTERRE

The photograph is looking west into wind and towards the setting sun near  $43^{\circ}\text{N}$ ,  $9^{\circ}\text{W}$ . on May 9, 1947. The cloud tops were estimated as reaching 15,000 ft. Apart from some dense cirrus, proceeding from the anvils, and traces of altocumulus cumulonimbus only cumulonimbi were present, separated by clear sky of pale hue and great transparency of the atmosphere. This condition of the sky is characteristic in air masses of arctic origin over the warm waters of the eastern Atlantic from the latitude of Spain to Norway. Although the surface winds were rather light where this picture was taken, well south of a quasi-stationary depression in  $55^{\circ}\text{N}$ ,  $20^{\circ}\text{W}$ ., the form of the anvils suggests considerable wind shear and upper winds of some strength. A further note of some interest is that the ship's doctor had to deal with a crop of sunburn patients very soon after this clear polar air was first encountered in  $32^{\circ}\text{N}$ . and in spite of the fact that the patients had long been exposed to the sun in the hazier atmosphere of the tropics on a voyage from Cape Town.



a rather weak trough was apparently left behind near the east Greenland coast after the first depression had moved away south-eastwards, and a shallow wave B, which had broken away in the strong upper flow and thermal wind from the primary depression near Nova Scotia, was located to the south of Cape Farewell (Fig. 3 (b)). The wave B was embedded, so to speak, in a strong thermal current and flow at this time and indeed throughout its history (see Figs. 2 (b) and 3 (b)), so great mobility was to be expected; moreover, the tendency for thermal diffuence near northern Scotland favoured some development. The probable track of the wave B is shown in Fig. 5 (a), although there is some doubt about the precise positions and central pressures over the Atlantic owing to the scarcity of observations. The fine structure of the thermal pattern must also be in doubt in the region. It is of interest to note that a weak but probably significant centre of cyclonic development in terms of Sutcliffe's parameter was indicated in the Denmark Strait at this time (Fig. 3 (b)). Some slow fall of pressure gradually took place in this cyclogenetic region, and by midnight of the 21st, a low C of central pressure 990 mb. had

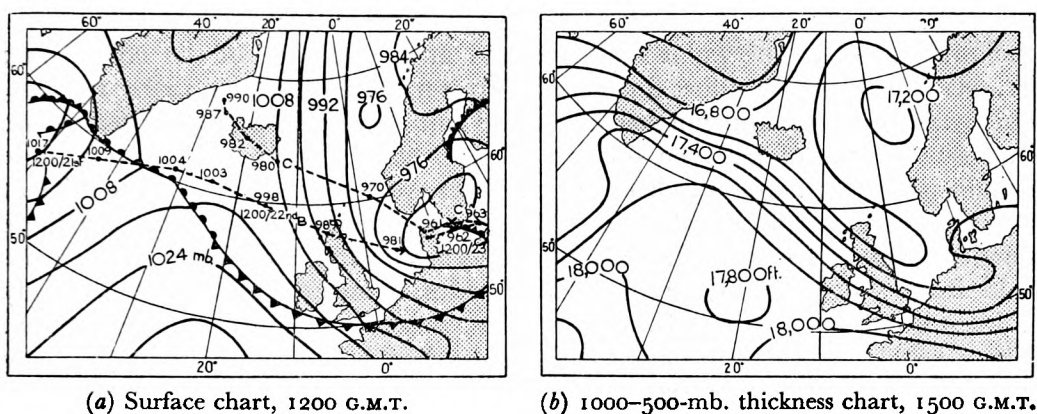


FIG. 5—SYNOPTIC CHARTS, DECEMBER 23, 1954

Tracks of lows B and C are shown by a broken line in the surface chart with central pressure indicated at 6-hr. intervals. Isopleths of Sutcliffe's development parameter in units of  $10^{-2}\text{hr.}^{-2}$  are shown by broken lines in the thickness chart.

formed in the Denmark Strait. By noon on the 22nd the depression C had moved rather slowly south-east over Iceland and had deepened somewhat. The afternoon thermal pattern (Fig. 4 (b)) was clearly diffluent to the south-east of Iceland and a maximum of cyclonic development was located near south-east Iceland. The field of Sutcliffe's parameter, as roughly computed, was reasonably in accord with the deepening of low C, but suggested rather slow movement of the centre. However, the subsequent motion of low C away from Iceland was consistent with the strong west-north-west flow in the middle and upper troposphere.

The synoptic changes were rather complex in detail for a time during the afternoon and evening of December 22. It appears that the low C moved away south-east from Iceland with further deepening and absorbed into its circulation the wave B which had travelled quickly across the Atlantic to the North Sea. Meanwhile another complicating feature was the quite pronounced fall of pressure of about 10 mb. over the southern part of the Norwegian Sea, where a centre of low pressure formed in the trough associated with an old depression near Bear Island in the Arctic. The deepening of the Norwegian Sea low is not

easily accounted for in terms of thermal development in view of the very weak thermal gradients existing over the Norwegian Sea, although the great instability of the air mass may have contributed to the rapid cyclonic development. Equally quickly the Norwegian Sea low lost its temporary dominance and became a mere secondary to the storm off south Norway. In the meantime the still vigorous remnants of the first storm in the south Baltic became caught up in the circulation of the new storm. Taking a very broad view, the enormous area of low pressure over and near north-west Europe constituted, in association with the broad-scale upper trough, a single, almost stationary, system. However, the components or individual centres of the system formed, not untypically, a complex and rapidly changing pattern.

As in the case of the first storm, the intensity and persistence of the Atlantic anticyclone, although it drifted south and weakened a little, played an essential part in the re-establishment of the very strong pressure gradient and gales over a wide region to the south-west of the storm centre.

**Some details concerning the storms.**—Gales and severe squalls occurred on December 21 over the British Isles to the right of the path of the centre of the first storm in the polar air mass and at the passage of the cold front; W.-NW. winds of Beaufort force 9 and 10 were reported from many stations, chiefly in Scotland and northern England but also as far south as Felixstowe in Essex. Gusts of between 60 and 70 kt. occurred widely. Some notable squalls were 90 kt. (104 m.p.h.) at Kinloss at 1210, 82 kt. (94 m.p.h.) at Wick at 1120, and 78 kt. (90 m.p.h.) at Middleton St. George at 1447 G.M.T.; these particular gusts appear to have been closely associated with the passage of the cold front shown in Fig. 3 (*a*). Severe gales, mostly from a north-westerly point, also affected much of the North Sea, the Low Countries and Germany. The coastal areas of the Low Countries and of Germany were particularly affected and Beaufort force 10 was reported from several stations on December 22, whilst a gust of 84 kt. (97 m.p.h.) from WNW.-NW. was recorded at Norderney on the German coast.

The second storm was also responsible for widespread gales or severe gales on December 23 over more or less the same region as that affected by the first storm. In this case, as with the first storm, the severe gales developed in areas to the right of the path of the storm centre in the polar air mass. Noteworthy British gusts on December 23 were 78 kt. (90 m.p.h.) from 290° at Exeter at 0355, 76 kt. (88 m.p.h.) from 280–300° at Middleton St. George at 0456 and 75 kt. (86 m.p.h.) from 310° at Stornoway at 0315 G.M.T. Gusts greater than 60 kt. occurred widely. The Low Countries and north-west Germany were badly affected by the storm. A squall of nearly 86 kt. (99 m.p.h.) was recorded at Bremerhaven on the afternoon of December 23. Several of the Continental stations adjacent to the southern part of the North Sea reported Beaufort force 10, 11 or 12 during the afternoon and evening of December 23.

The magnitude of the geostrophic wind over the North Sea nowhere approached the phenomenal values (150 kt. over a limited zone and 120 kt. over the western and central parts) associated with the great storm of January 31, 1953, which was discussed by Douglas<sup>3</sup>. Nevertheless the two storms of December 1954, produced north-westerly geostrophic winds of 70–90 kt. over quite substantial parts of the North Sea; these figures are very nearly comparable with the highest observed this century, excluding the

January 1953 storm, judging from the article by Douglas<sup>3</sup>. As was pointed out by Doodson and Dines<sup>4</sup>, very strong NW.-N. geostrophic winds are closely correlated with the development of large tidal surges; clearly then, during the period under examination the meteorological conditions were very favourable for setting up storm surges. Unusually large surges did in fact occur, and these will be discussed below.

Newspaper reports indicate that the two storms were responsible for very considerable disorganization of shipping and air traffic and for extensive damage to property, trees and telegraph poles throughout western Europe. Ships of many nations were in distress in the North Sea, and several, including the *Henri de Weert* (about 1,300 tons), the *Katingo* (about 7,000 tons) and the *Gerda Toft* (about 2,900 tons) were lost or driven ashore. Nearly a score of seamen died when the *Gerda Toft* lifeboat capsized. It is estimated that at least 40 people were killed in western Europe on December 22 and 23, mostly in Germany and Austria, by collapsing houses, falling tiles and chimney pots, etc. Many thousands of guards and troops manned the sea defences of Germany, Holland and eastern England. The German and Dutch dykes were breached at several points but no really serious damage was done, whilst only very slight flooding occurred in East Anglia.

**Storm surges.**—The storm surges\* of December 22 and 23, 1954, were very close in magnitude to the surge of January 31–February 1, 1953, but occurred during the period between neap and spring tides, so that along most of the coast of eastern England the effects were of little importance. In the Lowestoft area, however, lying as it does close to a nodal point, there is a difference of only  $1\frac{1}{2}$  ft. between the average heights of spring and neap high waters, so that neap periods can be almost as dangerous as spring-tide periods. Thus, at Lowestoft, the “danger level”† specified by the East Suffolk and Norfolk River Board is 6·3 ft. above the Ordnance Datum (Newlyn), and the level of mean high water spring tides is 2·8 ft. above the Ordnance Datum, giving a margin of 3·5 ft. on days of average spring tides; but the level of mean high water neap tides is 1·4 ft. above the Ordnance Datum, giving a margin of 4·9 ft. on days of average neap tides. Other places on the east coast have a similar margin for spring tides but a more generous margin at neap tides owing to high water neap tides being appreciably lower than spring tides. Clearly then, a large surge at neap tides, which may be harmless at most places on the coast, can be a serious threat in the Lowestoft area.

The passage of the two surges down the North Sea can best be studied by means of Fig. 6, which presents in graphical form the tidal and surge data for five British stations (Aberdeen, Immingham, Lowestoft, Harwich and Tilbury) and for one Dutch station (Delfzijl). The cold front over north Scotland at 1200 G.M.T. on December 21 (Fig. 3 (a)) swept southwards from Aberdeen to Tilbury in some 6 hr., and very strong north-westerly geostrophic winds became established over almost the entire North Sea in the rear of the front. It will be seen from Fig. 6 that the peak of the first surge occurred at Aberdeen about 1830 G.M.T. on December 21 (nearly 6 hr. after the passage of the cold front) and arrived at Tilbury about 0700 G.M.T. on December 22, almost  $12\frac{1}{2}$  hr.

\* The term storm surge, as now generally used, may be defined as the excess of the observed sea level, at any moment or series of moments, over the predicted sea level at the same moments.

† The danger level referred to throughout is the level decided by the various river boards, for which, if the water level is expected to reach it, they require warning. It does not necessarily indicate the level at which flooding will occur.

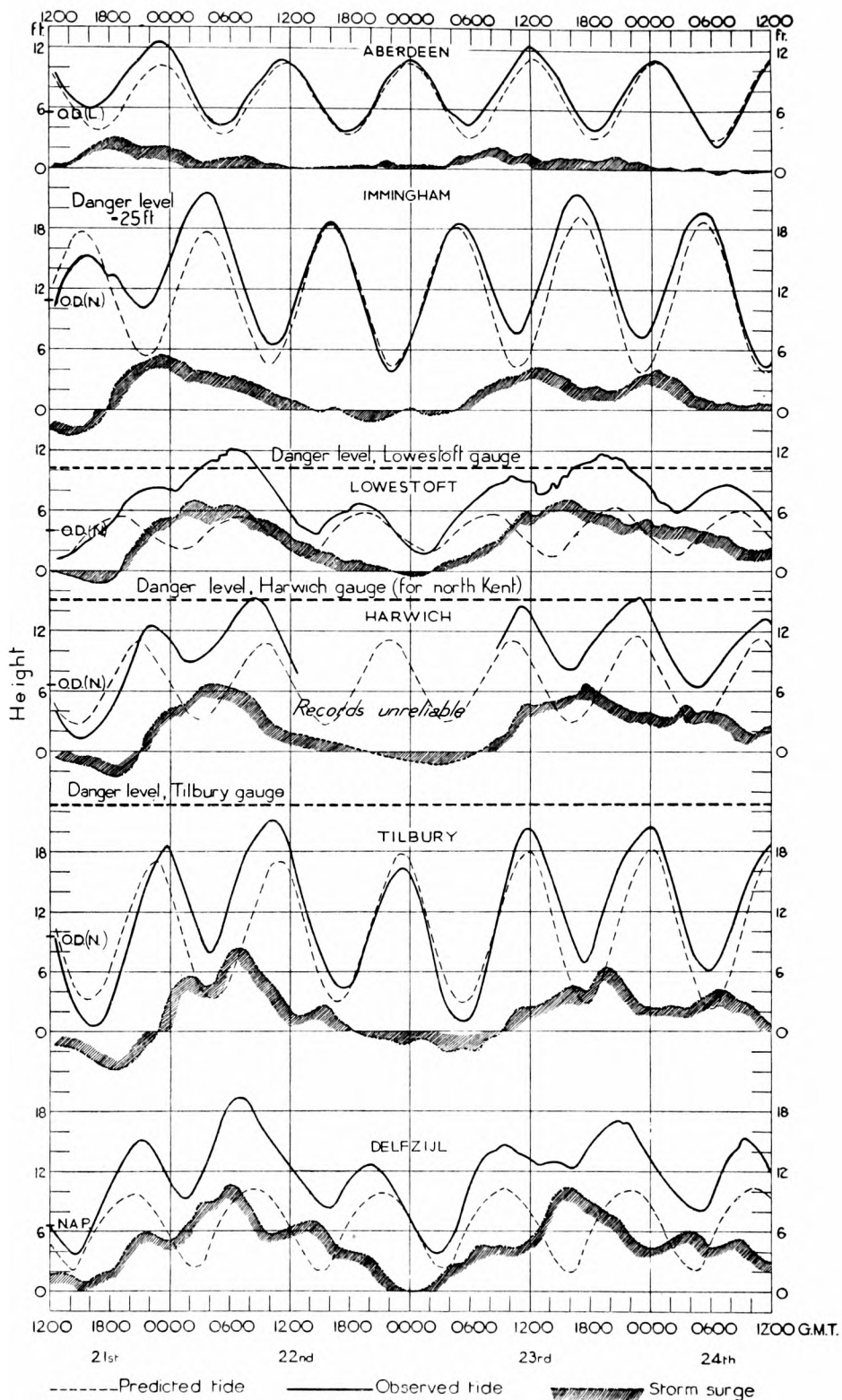


FIG. 6—TIDAL AND SURGE DATA FOR ABERDEEN, IMMINGHAM, LOWESTOFT, HARWICH, TILBURY AND DELFZIJL

The zero of each height scale represents the chart datum for tidal levels (predicted and measured), and the normal sea level (i.e. predicted) for the amount of surge.

O.D.(L.) = Ordnance Datum (Liverpool)

O.D.(N.) = Ordnance Datum (Newlyn)

N.A.P. = Normaal Amsterdams Peil\*

} about mean sea level

\* The land-levelling datum in Holland

later. The peak of the second surge occurred at Aberdeen about 0830 G.M.T. on December 23 and reached Tilbury just over 11 hr. later, by which time very strong geostrophic winds had been established over the North Sea for some 12 hr. in the rear of the cold front shown in Fig. 5 (a) over Europe.

The behaviour of the surges was normal in that their speed of travel was about the same as the speed of the purely tidal wave, and they increased in magnitude as they reached the more confined and shallower parts of the southern North Sea, the wind remaining comparatively steady in direction and speed during the period of building up. A surge will tend to decay unless the wind behind it maintains its strength and direction, but in this case the tendency was more than counteracted as far as Lowestoft and about balanced from Lowestoft into the Thames Estuary. Another complication, the source of considerable doubt from the practical point of view of surge forecasting, is the modification in shape and speed which the surge wave undergoes as it reaches very shallow water. Thus the surge at Tilbury is seen to have been considerably distorted from its shape on the open coast, its sharply defined peak arriving well before the time of high water. Additional reporting stations are Leith and Tynemouth, but these curves have been omitted to save space, being very similar to Aberdeen but proportionately displaced in time. A point of some interest at Lowestoft is that sea level rose almost continuously for a period of 17 hr. from 1300 on December 21 until 0600 G.M.T. on December 22. This is in notable contrast to the normal average tidal period, in British waters, of  $6\frac{1}{4}$  hr. rise followed by  $6\frac{1}{4}$  hr. fall. It will be seen from Fig. 6 that this arose from the small range of the normal predicted tide for the day (about 3 ft.) compared with the range of the surge (about 7 ft.); in other words the surge movement "swamped" the tidal movement. Also to be noted is the fact that the water level remained above Lowestoft danger level for 6 hr. on the 22nd and 5 hr. on the 23rd.

Warnings were issued from Dunstable by the Duty Hydrographic Officer, for the Lowestoft and Thames Estuary areas, which are seen to have been amply justified in the former case but only just for the latter. Danger level was exceeded by about 2 ft. and 1 ft. respectively at Lowestoft on the two days, and some flooding was reported from this area, but the north Kent danger level was only exceeded by an inch or two on each occasion.

Tidal readings from the recording gauges on the east coast are now repeated to the Netherlands authorities, for whom they provide valuable advance warning. The curves for Delfzijl have been added to Fig. 6; it will be seen that the two surges were higher there than on the English coast, and that on the morning of December 22 the peak of the surge arrived so close to predicted high water time that the observed high water was 9 ft. above the predicted height.

**Acknowledgement.**—Tidal observations for Delfzijl were kindly supplied by the Rijkswaterstaat of Holland.

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## DAY-TIME DARKNESS OVER LONDON ON JANUARY 16, 1955

By N. C. HELLIWELL, B.Sc. and M. J. BLACKWELL, M.A.

**Introduction.**—On Sunday, January 16, 1955, a belt of extreme darkness crossed London shortly after midday, causing widespread public interest and attention in the National Press at the time. The track of this belt is described, and an attempt has been made to find reasons for its formation in terms of the synoptic developments preceding it and of the local distribution of smoke pollution accompanying it.

**General synoptic situation.**—Pressure was low over the Norwegian Sea with a deep northerly air current over Scotland and northern England. A depression, which at noon on Friday, January 14, was at  $45^{\circ}\text{N}$ .  $30^{\circ}\text{W}$ . moving steadily east-north-east, was just north of the Scilly Isles by 0600 G.M.T. on the 16th. The warm front associated with this depression had reached a line from Liverpool to the Wash, and the warm air brought a thaw with widespread advection fog south of this line.

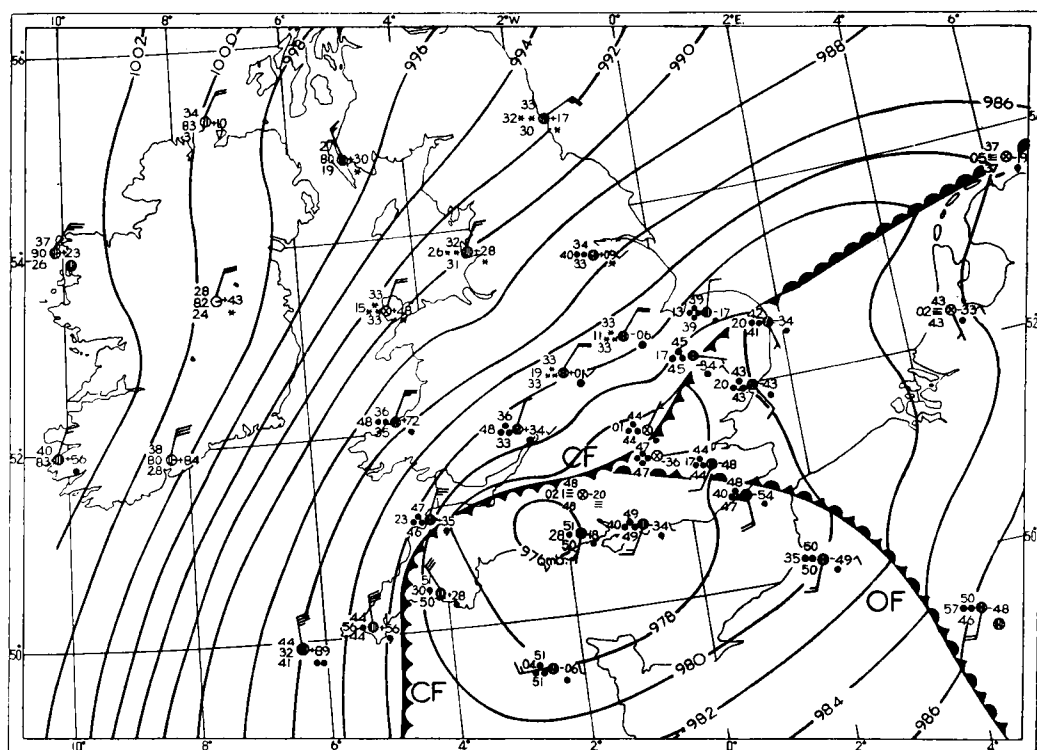


FIG. 1—SYNOPTIC WEATHER MAP, 1200 G.M.T., JANUARY 16, 1955

Fig. 1 shows the synoptic situation at 1200 G.M.T. January 16 and the position of the centre of the depression as it moved eastwards across southern England during the day. At 0600 the warm front had already become retrograde and was moving slowly south as a cold front CF with a marked rise of pressure to the north of the front. The warm air aloft, however, continued to move north for a short time longer, giving rise to outbreaks of precipitation well to the north of CF. Screen temperatures to the north of the front were about  $33^{\circ}\text{F}$ .; to the south, the temperature ranged from  $44^{\circ}$  to  $46^{\circ}\text{F}$ . with dew point from  $41^{\circ}$  to  $45^{\circ}\text{F}$ . As the cold air returned, frontal activity intensified and moderate to heavy falls of rain occurred, later turning to snow some distance to the north of the front.

The air over central and southern England, although maritime in origin, had been so modified in crossing France that, when air from the Atlantic began to flow into England, an air-mass discontinuity was established, and an occlusion OF was introduced into the analysis of hourly charts at the Central Forecasting Office, Dunstable. This unmodified maritime air had a temperature of 50°F. and was very moist.

As the low moved east at 30–35 kt. close to the south coast and OF moved east-north-east across southern England, a wide area of moderate to heavy rain developed. Shortly before midday, the warm occlusion OF joined up with CF, which was now moving south-east across the Chilterns. Pressure fell rapidly near the newly formed triple point causing a second low-pressure centre to form on OF near Kew, the original centre now lying over the Dorset-Hampshire border. Whilst the new centre moved east-north-east into the North Sea, the main depression continued along the south coast and through the Strait of Dover to reach Schleswig-Holstein by midnight. The main front CF now accelerated south-eastwards and the cold air reached the extreme south-east of the country by 1800.

**Situation in the London area.**—Towards midday the discontinuity CF became more pronounced; this was shown by outbreaks of heavy rain at, among other stations, Little Rissington and West Raynham. At Kew the temperature had risen gradually during the morning until about 1322 when the combined front passed over south-eastwards. The anemograph trace at Kew indicates a change from flat calm to north-westerly 15 kt. between 1318 and 1322, and a sudden marked rise of pressure is shown on the microbarograph trace at 1318. The temperature on the photothermograph trace at Kew fell from 49.1°F. at 1322 to 40.6°F. at 1353 and continued to fall afterwards, though less rapidly.

**Upper air ascents.**—The ascents for Liverpool show the warm air aloft, with the returning polar air just showing in the surface layers at 0300 and much deeper cold air penetrating southwards at 1500. The 0245 ascent for Hemsby (Fig. 2) shows the modified warm air, saturated in the lower layers with an inversion up to 940 mb. caused by advection of the warm air over the cold snow-covered ground. The afternoon ascent indicates the southward movement of the polar air extending across to the east coast up to 900 mb., but with warmer air still moving northwards above about 750 mb. with the movement of OF.

The 0300 ascent at Crawley was made in the modified maritime air mass and shows subsidence of the air above 780 mb. (which partly accounts for the discontinuity between the drier air and the very moist unmodified maritime air to the south-west of OF) and an isothermal layer up to 950 mb. Above this level, temperatures are almost coincident with the saturated adiabatic line for 50°F.

The 1400 ascent at Crawley (Fig. 2) shows the structure within the very moist direct maritime air south of CF and OF with temperatures close to the saturated adiabatic line for 53°F. There is no inversion and, although the air mass is stable up to 700 mb., there is a possibility of potential instability above this level. The humidities reported suggest dense cloud to over 10,000 ft. There may also have been convective cells above 700 mb. An aircraft flying from Preston to London reported unbroken cloud from 1,300 to 13,500 ft., and this supports the general picture obtained from all the ascents.

**Smoke pollution.**—During the morning, light winds moved smoke-polluted air from south-east London towards the north-west. Trapped beneath the low-level inversion, the smoke moved with the surface wind field. Geostrophic balance was not realized, as shown by the movement of CF against the gradient wind.

To investigate the origins of the smoke, hourly surface-wind-field charts were constructed from the reported winds. Flow lines were drawn to give the general direction of the air motion at any point, wind speeds being taken as the local mean of observations in the area. Secondly, a track chart of the actual belt of darkness was built up from all available reports, official or otherwise, and Fig. 3 gives isochrones of the onset of darkness between the Chilterns and the south coast. Stations to the north-west of London, such as Benson and Bovingdon, did not experience the main effect of the belt which emerged as a clearly defined zone shortly before midday. The smoke moving north-westwards reached the foot of the Chilterns just as the cold front CF crossed them.

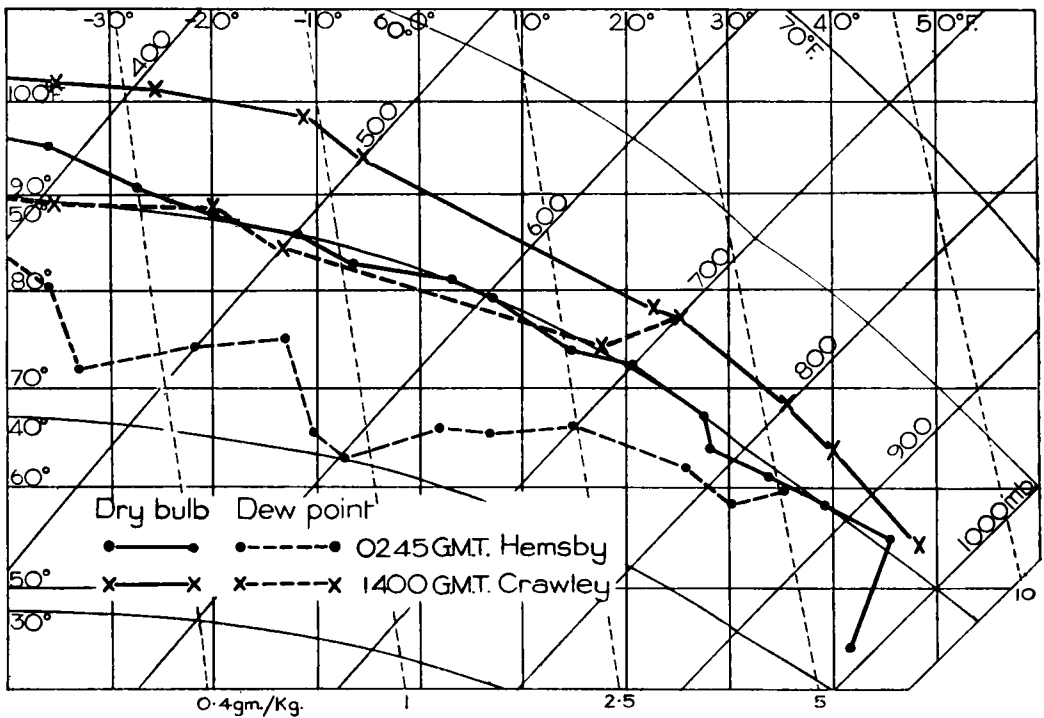


FIG. 2—TEPHIGRAM OF UPPER ASCENTS AT HEMSBY AND CRAWLEY, JANUARY 16, 1955

Taking a line running from south-west to north-east along the edge of these hills, which rise here to over 300 ft. and identifying this with the position of the dark belt at 1130, parcels of air were traced back hour by hour according to the charts of surface wind. The result, shown in Fig. 4, illustrates the drift of smoke across London from an area to the south-east of Croydon at 0600. Having sufficiently defined the area over which the pollution occurred, parcels of air were traced forwards from this area by various methods using the local hourly winds and interpolated half-hourly winds. The resulting tracks are very similar whatever the method adopted, and represent the movement of polluted air in a wide arc to the Chiltern Hills, and then a return south-eastwards across London and on to the coast with increasing speed.



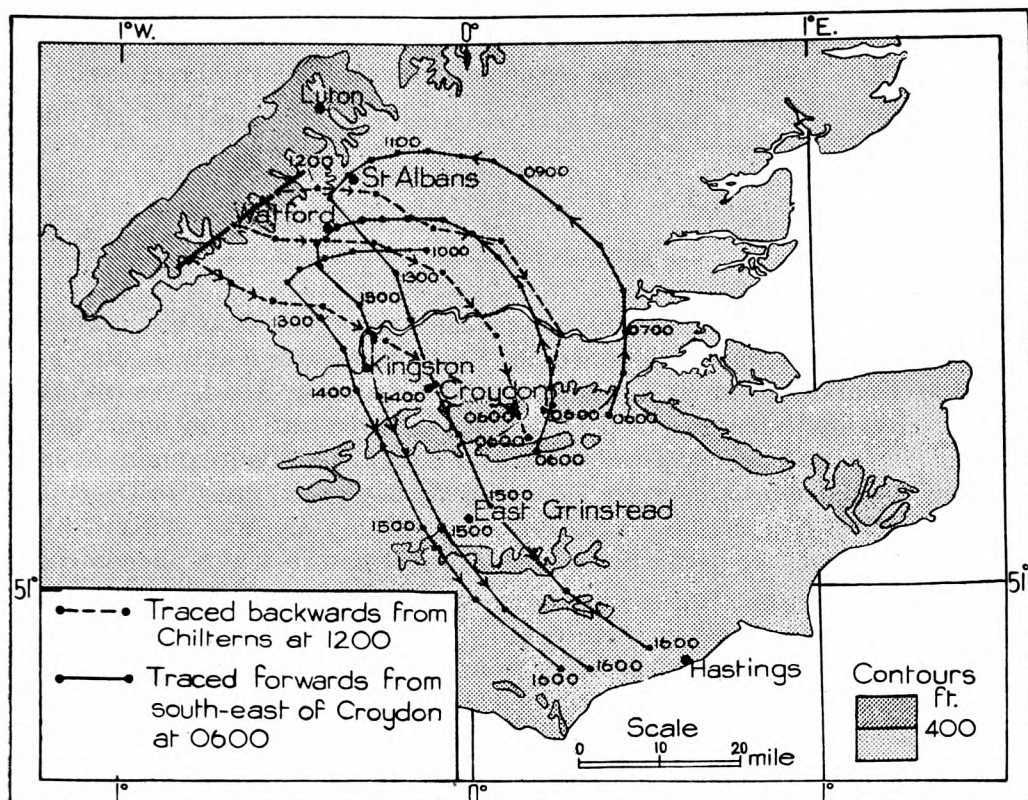


FIG. 3—ISOCHRONES OF THE ONSET OF DARKNESS, JANUARY 16, 1955

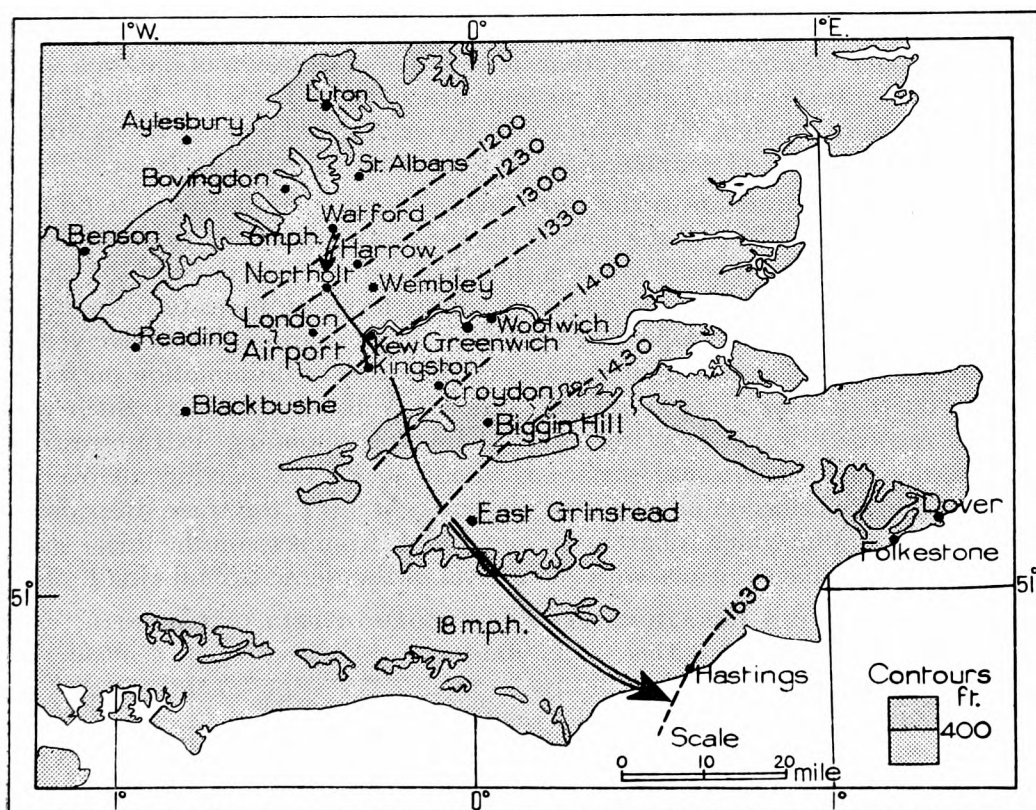


FIG. 4—TRACKS OF SURFACE AIR CURRENTS, JANUARY 16, 1955

TABLE I—SMOKE POLLUTION IN THE LONDON AREA

									1315	1345	1415
	0000 to 0700	0700 to 0800	0800 to 0900	0900 to 1000	1000 to 1100	1100 to 1200	1200 to 1300	1300 to 1400	to 1345	to 1415	to 1445
	<i>milligrammes per cubic metre</i>										
Grosvenor Road ...	0.2	0.3	0.3	0.8	1.3	1.1	0.3*	0.3	...	...	...
Kew Observatory ...	...	...	...	...	0.3	0.45	0.45	0.3*	...	...	...
Greenwich ...	...	...	...	...	...	...	...	...	0.36	0.7*	0.1

\* Period when darkness was observed.

Attention was next given to the more quantitative data from records of the solid-pollution detectors maintained at Kew Observatory and at the Fuel Research Establishments at Greenwich and Grosvenor Road, Westminster. Table I gives the intensities of pollution at the three stations in terms of the sampled concentrations which are made over a period of about 20 min. in each hour. By comparison, values recorded during the notorious "smog" of December 5, 1952 reached 4.2 mg./m.<sup>3</sup> at Greenwich and 2.5 mg./m.<sup>3</sup> at Kew. The difference here may be partly due to the transient nature of this phenomenon.

For present purposes, it is of interest to examine the record for the establishment at Grosvenor Road in more detail. This shows relatively high values around 1100, and air traced forwards from this site was found to arrive in the Kew area at approximately the same time as the dark belt, as shown in Fig. 4. Air from the Watford area was also traced across the western fringe of London.

From the line of the Chilterns at about 1130 the belt of darkness subsequently moved south-east to reach Kew at the same time as the previously discussed triple point at 1318. On the front itself the cloud base fell to 100 ft., visibility to about 100 yd., and daylight illumination almost to zero. Fig. 3 shows that, starting with a speed of 6 m.p.h. near Watford, the belt reached a speed of 18 m.p.h. over Hastings. Observations of the time of duration of darkness and the derived values for the width of the zone are given in Table II. From this a coherent picture emerges of a narrow belt between 1 and 2 miles wide, which retained its identity and characteristics at least as far as the south coast.

**Daylight illumination in the dark belt.**—Some quantitative data on the optical nature and effects of the zone of darkness can be derived from the Kew daylight illumination record, which is shown in Fig. 5. The dots on the chart are at minute intervals and the 5 and 10 kilolux levels of intensity (on a horizontal surface) have been superposed for clarity. An examination of five years' records at Kew has shown<sup>1</sup> that the average intensity of illumination on fairly heavily overcast days at 1300–1400 in January is about 7 kilolux. Such was indeed recorded from 1300 to 1314. The corresponding extraterrestrial illumination on a horizontal surface is about 36 kilolux—giving an overall atmospheric transmission of about 20 per cent. At 1314, the trace drops from 7 kilolux to a value which is barely distinguishable from zero on the linear scale of chart used. This coincides with the arrival of the dense frontal cloud. The

TABLE II—TIME, DURATION, SPEED AND WIDTH OF BELT OF DARKNESS

	Time	Duration	Speed*	Width
	G.M.T.	min.	m.p.h.	miles
Watford and Ruislip ...	1200	10–15	6	1.0–1.5
Kew Observatory ...	1320	6–8	10	1.0–1.3
Kingston† ...	1338	5	16	1.3
Croydon ...	1400	6	18	1.8

\* estimated from Fig. 3

† supplied by Mr. Finch of the Meteorological Office, London Airport.

remarkable change occurred in only 6 min., becoming complete by 1320 when the cloud mass on CF was overhead. After a further 6 min. of almost total darkness there was a more gradual recovery to normal levels of light intensity. Though a precise measurement of the minimum intensity is not possible, it can be reliably estimated that it did not exceed 0.03 kilolux, and the following discussion is based on such a value.

The atmospheric transmission with typical nimbostratus cloud is about 15 per cent. and the actual figure of 20 per cent., found before 1314, is consistent with layered cloud immediately ahead of the front. The transmission 6 min. later had fallen to something of the order of 0.1 per cent., and most of this effect must be attributed to the local concentration of smoke. It is assumed that the frontal cloud mass, being unusually dense, caused the transmission to be reduced to 10 per cent. on account of waterdrops alone; this would leave 1 per cent. as the attenuation to be attributed to smoke alone (on the over-simplified assumption that the attenuation due to smoke and cloud can be considered separately).

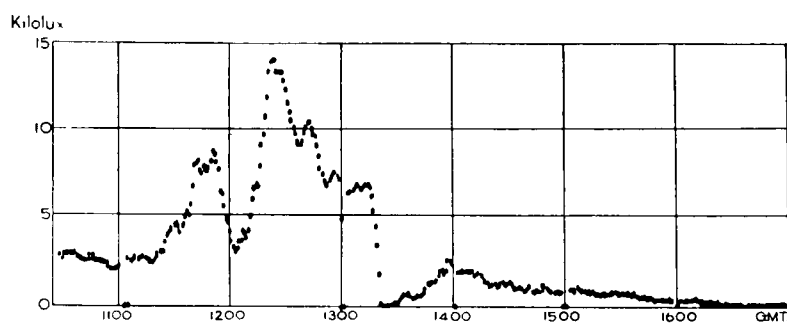


FIG. 5—DAYLIGHT ILLUMINATION RECORD AT KEW OBSERVATORY

The smoke-generating source area of London emits about  $0.025 \text{ gm./m.}^2/\text{hr.}$  of smoke<sup>2</sup>, and air drifting across the area took some 7 hr. to cover the 40-mile track. Such an accumulated smoke layer of  $0.175 \text{ gm./m.}^2$  would have a transmission of about 50 per cent. Thus the model envisaged would yield an overall transmission of 5 per cent. which exceeds the observed figure by a factor of 50.

The foregoing data on smoke attenuation are derived by correlating smoke-filter measurements with visibility observations at Kew. They are only valid for horizontal beam transmission in the absence of cloud or fog, but if allowance is made for the diffuseness of the radiation entering the smoke layer, the transmission is only reduced from 50 per cent. to about 35 per cent.

The observed darkness cannot be satisfactorily explained then by horizontal movement of the frontal cloud mass over the shallow layer of smoke, which has been hitherto confined by the low inversion. The remarkable drop in transmission is thought to be caused by some combination of the following two processes:—

- (i) Smoke-laden air, converging along several surface trajectories, entered the base of the frontal cloud, possibly assisted by a vertical circulation associated with a rolling movement at the base of the cloud. The lowest layers of cloud, augmented by smoke, would present a complex optical barrier with the smoke absorption effectively increased by the considerably

greater optical path length produced by scattering in the cloud. Such a layer might well reduce the overall transmission to the order of 1 per cent.

(ii) Marked vertical motion, due to the vigorous convergence and up-sliding movement at the front, might lift the smoke to a much greater height near the front. This process, occurring continuously while fresh smoke entered the base of the cloud, might increase the total smoke content over unit area by a factor of 10.

The fact that observed volume concentrations of smoke were of the order of 1 mg./m.<sup>3</sup>, while the area concentration was about 0.175 gm./m.<sup>2</sup>, gives a depth of about 175 m. for the original smoke layer. The observed transmission could only be obtained by vertical transport of the smoke until a total depth of 1,200 m. had been attained.

**Conclusion.**—It is difficult to assess the likelihood of a recurrence of the phenomena described here. It is thought that most of the following factors were of importance:—

(i) A vigorous depression with a weak pressure gradient in the centre and secondary formation near the triple point.

(ii) Very active fronts with marked air-mass contrast, giving dense cloud.

(iii) Warm-sector air passing over cold ground giving a shallow inversion layer.

(iv) Fog in the lowest layers.

(v) Marked convergence ahead of the cold front as well as near it, together with slow movement of the front, giving a large ratio of vertical to horizontal motion.

(vi) Initial north-westerly advection of smoke ahead of an eastward-moving centre, leading to concentration of smoke in a belt north-west of the centre, followed by freshening NW. winds bringing the smoke belt south-eastwards again.

**Acknowledgements.**—We wish to thank the Fuel Research Establishment at Greenwich for the data on smoke pollution.

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## METHOD OF OBTAINING THE GRADIENT WIND FROM THE GEOSTROPHIC WIND

By R. SILVESTER, B.A., B.E.  
(University of Western Australia)

The relation between the gradient wind and the geostrophic wind is

$$U_{gr} = U_{gs} \pm \frac{U_{gr}^2}{2 \omega r \sin \phi} \quad \dots \dots (1)$$

where  $U_{gr}$  is the gradient wind,  $U_{gs}$  is the geostrophic wind,  $\omega$  the angular velocity of the earth,  $r$  the radius of curvature of the isobars and  $\phi$  the latitude. The plus sign applies to anticyclonic curvature and the minus sign to cyclonic curvature. By introducing speed in knots, distances in nautical miles and time in hours, since  $2\omega = 1.454 \times 10^{-4} \text{ sec.}^{-1}$ , this equation becomes

$$U_{gr} = U_{gs} \pm \frac{1 \cdot 91 U_{gr}^2}{r \sin \phi} . \quad \dots \dots (2)$$

Dividing through by  $U_{gr}$  and substituting  $R = U_{gr}/U_{gs}$

$$1 = \frac{1}{R} \pm \frac{1 \cdot 91 U_{gr} R}{r \sin \phi} , \quad \dots \dots (3)$$

or, demonstrating the two cases separately

$$\left. \begin{array}{ll} \text{for cyclones} & \sin \phi = 1 \cdot 91 \frac{U_{gr}}{r} \left( \frac{R^2}{1-R} \right) \\ \text{for anticyclones} & \sin \phi = 1 \cdot 91 \frac{U_{gr}}{r} \left( \frac{R^2}{R-1} \right) . \end{array} \right\} \dots \dots (4)$$

The variations of the terms in brackets are shown in Fig. 1 for all values of  $R$ . Since, for cyclonic curvature only values of  $R$  between 0 and 1 need be considered the solution is unique. For anticyclones, where  $R$  is greater than 1, two solutions are obtained (except for  $R=2$  when  $R^2/(R-1) = 4$ ). This double solution has been cited elsewhere<sup>1</sup>, and an explanation has been given why only values of  $R$  between 1 and 2 should be used (i.e.  $2 U_{gs} > U_{gr} > U_{gs}$ ).

Fig. 2 has been obtained by plotting  $U_{gs}/r$  against  $\phi$  and using  $R$  as a parameter (limited between 1 and 2 as explained above). This diagram eliminates the necessity of calculating  $U_{gr}$  by successive steps of approximation<sup>2</sup>.

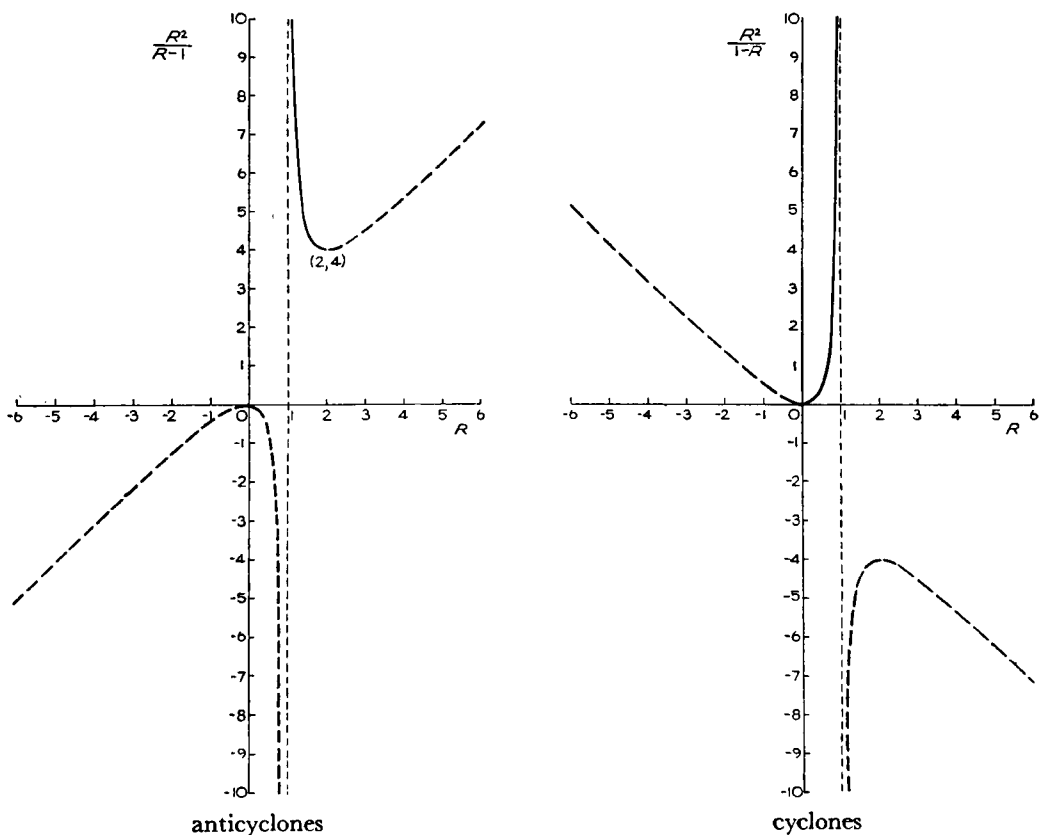


FIG. 1—VALUES OF  $R$  ( $=U_{gr}/U_{gs}$ ) FOR DIFFERENT VALUES OF  $\pm R^2/(R-1)$   
Useful values of  $R$  are given by full lines

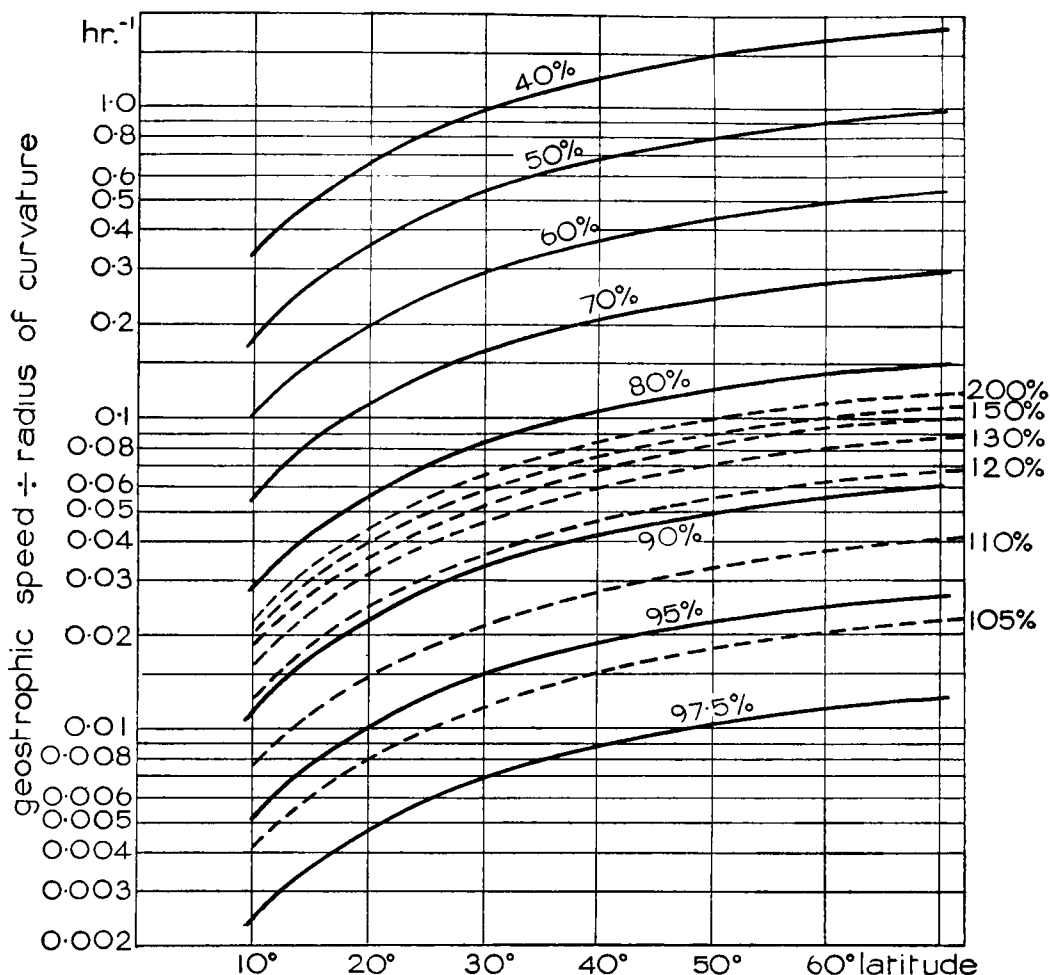


FIG. 2—GRAPH OF  $U_{gr}$  AS A PERCENTAGE OF  $U_{gs}$

The anticyclonic case is shown by broken lines, the cyclonic case by full lines

#### REFERENCES

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### VARIATION BETWEEN MEASUREMENTS OF RAINFALL MADE WITH A GRID OF GAUGES

By L. H. WATKINS, B.Sc.

Road Research Laboratory, Department of Scientific and Industrial Research.

**Introduction.**—Investigations are being carried out by the Road Research Laboratory into factors affecting the relation between the rate of rainfall and the rate of run-off from urban areas. In these investigations the rate of rainfall falling on an area is determined from measurements of rainfall made at either one or three points.

As there appeared to be little published information on the errors that would be incurred by assuming that the rainfall recorded at a single point is the same as that for a surrounding area, a start was made to explore this

problem by installing nine non-recording rain-gauges over a small area in the grounds of the Road Research Laboratory. This paper describes the results of this rainfall investigation.

**Details of experiment.**—A grid of nine standard Meteorological Office non-recording rain-gauges, each with a circular collecting area of 5 in. diameter, was installed in the Laboratory grounds in December 1952. Fig. 1 gives a plan of the site. The amount of rainfall collected by each gauge was measured daily at 0900 G.M.T., and also whenever possible separate measurements were made immediately after a heavy storm.

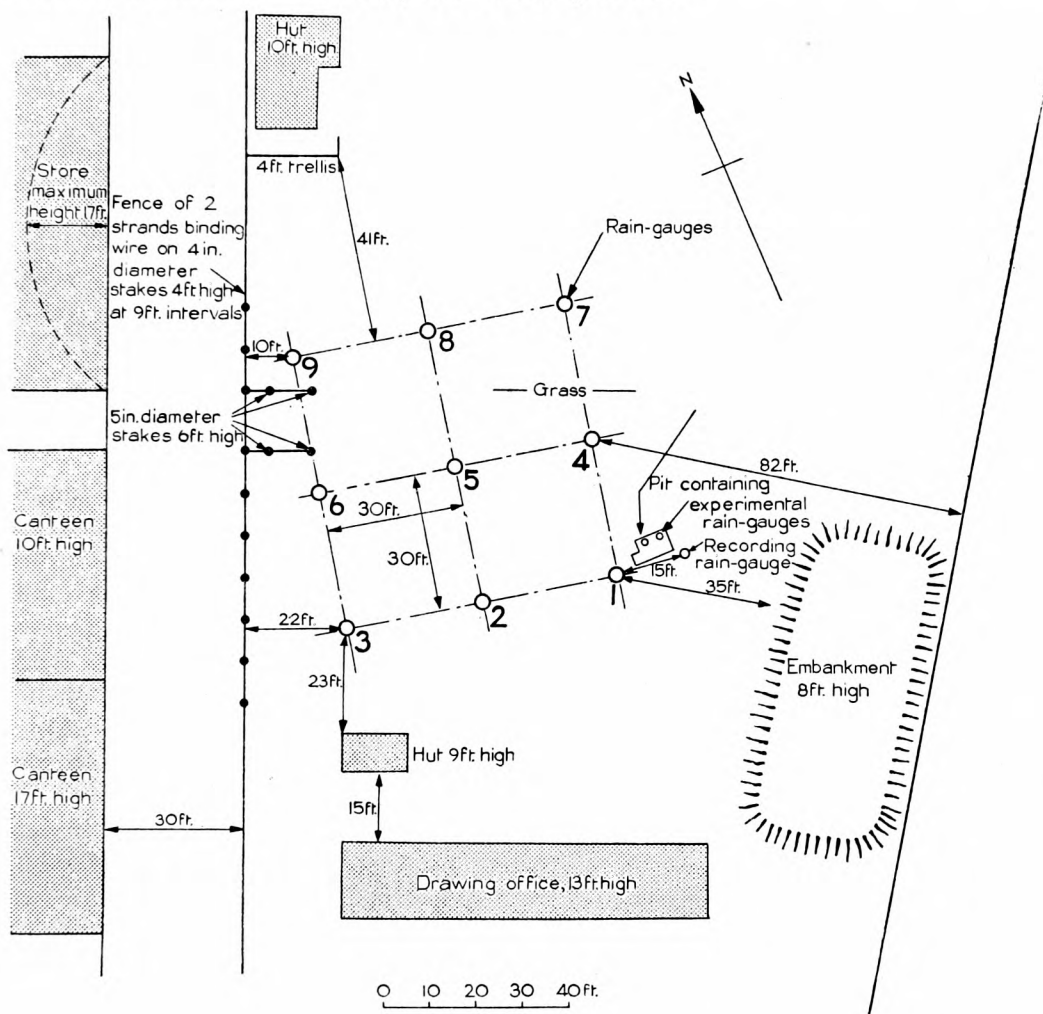


FIG. 1—SITING OF THE GRID OF 9 RAIN-GAUGES AT THE ROAD RESEARCH LABORATORY

**Results.**—Table I gives the monthly totals of rainfall measured with each instrument neglecting those days on which snow fell, and Table II gives the total rainfall collected by each gauge during five storms. Table III gives the monthly variation of each gauge from the mean value of all nine gauges, and Table IV gives the variation from the mean for the five storms. Although total rainfall is usually given by the Meteorological Office to the nearest 0.01 in., since the measuring cylinders can be read with a greater accuracy than this the figures given in Tables I and II are given to three places of decimals.

TABLE I—MONTHLY TOTALS OF RAINFALL

	Rainfall measured by gauges									Mean
	1	2	3	4	5	6	7	8	9	
	<i>inches</i>									
1952 December* ...	1·659	1·636	1·640	1·630	1·624	1·635	1·601	1·638	1·596	1·629
1953 January ...	0·334	0·342	0·331	0·339	0·329	0·349	0·326	0·331	0·324	0·331
February ...	0·727	0·733	0·747	0·747	0·752	0·750	0·725	0·747	0·741	0·741
March ...	0·220	0·237	0·236	0·235	0·224	0·227	0·216	0·229	0·222	0·227
April ...	2·120	2·142	2·130	2·165	2·131	2·153	2·083	2·120	2·095	2·127
May ...	1·288	1·323	1·292	1·317	1·296	1·282	1·288	1·294	1·282	1·296
June ...	1·511	1·554	1·539	1·550	1·533	1·554	1·540	1·536	1·537	1·539
July ...	3·157	3·189	3·174	3·191	3·138	3·159	3·115	3·164	3·113	3·156
August ...	1·532	1·521	1·482	1·505	1·457	1·487	1·456	1·481	1·463	1·487
September ...	2·022	2·022	2·016	2·030	1·977	2·016	1·991	2·017	1·980	2·008
October ...	2·703	2·690	2·692	2·691	2·691	2·709	2·679	2·700	2·683	2·693
November ...	1·157	1·115	1·132	1·151	1·120	1·148	1·115	1·138	1·112	1·132
December ...	0·627	0·618	0·619	0·626	0·620	0·625	0·619	0·617	0·618	0·621
1954 January ...	0·890	0·911	0·918	0·915	0·924	0·928	0·902	0·920	0·894	0·911
February ...	2·104	2·118	2·120	2·145	2·103	2·126	2·107	2·123	2·090	2·115
March ...	2·115	2·141	2·105	2·140	2·124	2·125	2·093	2·127	2·106	2·120
April ...	0·363	0·380	0·376	0·371	0·368	0·369	0·366	0·371	0·369	0·370
May ...	1·952	1·953	1·950	1·950	1·948	1·951	1·927	1·951	1·919	1·945
June ...	3·822	3·780	3·796	3·807	3·765	3·799	3·769	3·803	3·769	3·790
July ...	2·475	2·497	2·490	2·467	2·453	2·476	2·415	2·472	2·436	2·465
August ...	3·373	3·380	3·394	3·391	3·348	3·371	3·332	3·368	3·359	3·368
Total ...	36·151	36·282	36·079	36·363	35·925	36·139	35·665	36·147	35·708	36·051
No. of months with highest total ...	5	7†	1	4	1	4†	0	0	0	
No. of months with lowest total ...	3	0	0	0	2	1†	8	1	7†	

\* Last two weeks only

† Two gauges with same total

The areas of all the collecting funnels were measured, and it was found that although the areas were all in excess of the nominal value by between 0·8 and 1·3 per cent., the variation from the mean value was only from +0·2 per cent. to -0·4 per cent. Since the measurements of rainfall were all made with the same measuring cylinder, the differences between the gauges could not be explained by inaccurate calibration of the cylinder, and temperature had no effect on the differences between the gauges since all the gauges were read within a few minutes of each other every day. One graduation on the measuring cylinder corresponds to 0·01 in. of rain and the graduations are approximately 5/32 in. apart. Since the level of the meniscus can easily be read to within 1/32 in. errors in reading the measuring cylinder would not lead to variations of more than approximately 0·002 in. of rain, giving a possible variation ranging from 2 per cent. for 0·1 in. of rain to 0·2 per cent. for 1 in. of rain.

**Discussion of results.**—*Monthly rainfall.*—There is a general trend for the variation from the mean to decrease as the total rainfall increases. The maximum variation was 4·5 per cent. and occurred in January 1953 when the rainfall was only 0·331 in.; in June 1954 when the rainfall was 3·790 in. the maximum variation was only 0·8 per cent. Over this range of total rainfall

TABLE II—TOTAL RAINFALL DURING STORMS

Date	Duration of storm	Rainfall measured by gauges									Mean
		1	2	3	4	5	6	7	8	9	
	<i>min.</i>	<i>inches</i>									
July 14, 1953 ...	28	0·128	0·128	0·130	0·132	0·122	0·132	0·126	0·125	0·124	0·128
Aug. 24, 1953 ...	15	0·096	0·100	0·099	0·096	0·093	0·093	0·088	0·090	0·092	0·094
Jan. 13, 1954 ...	130	0·365	0·370	0·370	0·370	0·370	0·375	0·350	0·375	0·360	0·367
May 12, 1954 ...	90	0·380	0·385	0·390	0·380	0·385	0·390	0·375	0·390	0·370	0·383
May 26, 1954 ...	127	0·290	0·285	0·285	0·285	0·285	0·280	0·287	0·285	0·285	0·285





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FLOODED AIRFIELD AT SHARJAH, OMAN PENINSULA, NOVEMBER 1954  
(See p. 355)



*Reproduced by courtesy of S. A. C. James*

**FLOODED AIRFIELD AT SHARJAH, OMAN PENINSULA, NOVEMBER 1954**

(See p. 355)

TABLE III—MONTHLY VARIATION OF RAINFALL FROM THE MEAN VALUE

	Variation from mean									Maximum variation
	1	2	3	4	5	6	7	8	9	
1952										
December ...	+1.8	+0.4	+0.7	+0.1	<i>per cent.</i> -0.3	+0.3	-1.7	+0.6	-2.0	-2.0
1953										
January ...	0	+2.4	-1.1	+1.5	-1.5	+4.5	-2.4	-1.1	-3.0	+4.5
February ...	-1.9	-1.1	+0.8	+0.8	+1.5	+1.2	-2.2	+0.8	0	-2.2
March ...	-3.1	+4.4	+4.0	+3.5	-0.8	0	-2.1	+0.9	-2.2	+4.4
April ...	-0.3	+0.7	+0.1	+1.8	+0.2	+1.2	-2.1	-0.3	-1.5	+1.8
May... ..	-0.6	+2.1	-0.3	+1.6	0	-1.1	-0.6	-0.2	-1.1	+2.1
June... ..	-1.8	+1.0	0	+0.7	-0.4	+1.0	+0.1	-0.2	-0.1	-1.8
July ... ..	0	+1.0	+0.6	+1.1	-0.6	+0.1	-1.3	+0.3	-1.4	-1.4
August ...	+3.0	+2.3	-0.3	+1.2	-2.0	0	-2.1	-0.4	-1.6	+3.0
September ...	+0.7	+0.7	+0.4	+1.1	-1.5	+0.4	-0.8	+0.4	-1.4	-1.5
October ...	+0.4	-0.1	0	-0.1	-0.1	+0.6	-0.5	+0.3	-0.4	+0.6
November ...	+2.2	-1.5	0	+1.7	-1.1	+1.4	-1.5	+0.5	-1.8	+2.2
December ...	+1.0	-0.5	-0.3	+0.8	-0.2	+0.6	-0.3	-0.6	-0.5	+1.0
1954										
January ...	-2.3	0	+0.8	+0.4	+1.4	+1.9	-1.0	+1.0	-1.9	-2.3
February ...	-0.5	+0.1	+0.2	+1.4	-0.6	+0.5	-0.4	+0.4	-1.2	+1.4
March ... ..	-0.2	+1.0	-0.7	+0.9	+0.2	+0.2	-1.3	+0.3	-0.7	-1.3
April ... ..	-1.9	+2.7	+1.6	+0.3	+0.5	-0.3	-1.1	+0.3	-0.3	+2.7
May... ..	+0.4	+0.4	+0.3	+0.3	+0.2	+0.3	-0.9	+0.3	-1.3	-1.3
June... ..	+0.8	-0.3	+0.2	+0.4	-0.7	+0.2	-0.6	+0.3	-0.6	+0.8
July ... ..	+0.4	+1.3	+1.1	+0.1	-0.4	+0.5	-2.0	+0.3	-1.1	-2.0
August ... ..	+0.1	+0.4	+0.8	+0.7	-0.6	+0.1	-1.1	0	-0.3	-1.1
Total ... ..	+0.3	+0.6	+0.1	+0.9	-0.4	+0.2	-1.1	+0.3	-1.0	-1.1

the possible percentage errors in reading the measuring cylinder are very small, and also the errors are likely to cancel out during a month since each total is the sum of several daily readings. It is concluded, therefore, that the maximum variation of measured rainfall ranged from approximately 5 per cent. for the lowest monthly rainfall to approximately 1 per cent. for the highest. Over the whole period of 21 months the rainfall measured with the gauges varied over a range within approximately  $\pm 1$  per cent. of the mean value.

It can be seen from Tables I and II that gauge number 9 collected less than the mean every month and gave the lowest value on seven occasions; gauge number 7 collected less than the mean during 20 months out of the 21 and gave the lowest value on eight occasions; while gauges numbers 2, 4 and 6 usually collected more than the mean and between them gave the highest value 14 times. If the variations between the gauges were caused by variations in the true rainfall over the area it is thought that no such consistency would be found over the length of time considered, and it is thought, therefore that the variations in the monthly totals are likely to be due principally to the effect of local wind eddies round the gauges.

*Storm rainfall.*—The variation between the gauges during the storms was greater than for the monthly rainfall. The maximum variation from the mean was 6.4 per cent. on August 24, 1953, for a total rainfall of 0.094 in.; taking into account possible errors in reading the measuring cylinder this indicates a possible variation of approximately 8 per cent. There is the same indication

TABLE IV—VARIATION OF STORM RAINFALL FROM THE MEAN VALUE

Date	Variation from mean									Maximum variation
	1	2	3	4	5	6	7	8	9	
July 14, 1953 ...	0	0	+1.6	+3.1	-4.7	+3.1	-1.6	-2.3	-3.1	-4.7
Aug. 24, 1953...	+2.1	+6.4	+5.3	+2.1	-1.1	-1.1	-6.4	-4.3	-2.1	$\pm 6.4$
Jan. 13, 1954 ...	-0.5	+0.8	+0.8	+0.8	+0.8	+2.2	-4.6	+2.2	-1.9	-4.6
May 12, 1954...	-0.8	+0.5	+1.8	-0.8	+0.5	+1.8	-2.1	+1.8	-3.0	-3.0
May 26, 1954...	+1.8	0	0	0	0	-1.8	+0.7	0	0	$\pm 1.8$

as with the monthly totals that this variation is due principally to wind eddies, since gauges numbers 7 and 9 consistently gave less than the mean and gauges numbers 2, 4 and 6 tended to give more.

The variation between the gauges is large enough to have an important bearing on the accuracy with which the storm rainfall measured by a single gauge can be assumed to represent the rainfall over an area. However, since only five storms were measured it is considered that it would be desirable to continue the investigation using recording rain-gauges. This would enable more storms to be measured than was possible in the present investigation. With non-recording rain-gauges, no storm rainfall could be measured outside normal working hours, nor could a storm be recorded if it occurred after the gauges had already collected some rainfall.

**Conclusions.**—(1) Over an area of 60 ft. by 60 ft. there was a maximum variation from the mean value of 5 per cent. in the monthly rainfall as measured with nine rain-gauges.

(2) During five individual storms there was a maximum variation from the mean of 8 per cent.

(3) The variation between the gauges was considered to be due principally to local wind eddies round the gauges, and not to true variations in the rainfall over the area.

**Acknowledgements.**—The work described in this article was carried out as part of the programme of the Road Research Board of the Department of Scientific and Industrial Research. The article is published by permission of the Director of Road Research.

## LETTERS TO THE EDITOR

### Model depressions on the Thames

On misty autumn mornings one may sometimes see from the Embankment a surprisingly accurate model of a frontal depression which passes through a whole life cycle in a few seconds.

The best conditions seem to be with a very light westerly wind, and the best position, just at the stern of H.M.S. *Chrysanthemum*. The mist usually covers the water in an irregular layer a few inches deep and allows the air movements to be clearly seen.

The two streams of air which have flowed along the two sides of the ship, meet at the stern and generally continue side by side with little mixing. The "front" which separates them is quite distinctly seen as a gently waving line, sometimes 20 yd. long of denser and deeper mist. From time to time, a wave 2 or 3 ft. long with its crest towards the Embankment appears suddenly on the front. The amplitude rapidly increases, and within a second or two a counter-clockwise rotation is set up. The rotation increases in violence until, after a few seconds, the eddy breaks away from the front which reforms on the south side of it, while the eddy itself decays and disappears. One often sees distinctly the beginnings of the formation of an occlusion, and occasionally one has a momentary glimpse of a properly formed back-bent occlusion. The mist towers up above the eddy to a height of perhaps 2 or 3 ft., thus showing the part which surface convergence plays in the process; but indeed it is generally obvious that the depression is a result of convergence—a movement

of mist towards the front from the south can usually be observed before the first signs of the resulting wave. One can therefore generally anticipate the formation of a new depression by several seconds—not a bad standard of forecasting in relation to a life cycle of 5 or 6 secs. A feature which might conceivably have applications to real life is that the convergence which sets off the depression often starts well to the south—one sees it as a distinct patch of mist, possibly 3 or 4 yd. south of the front, moving slowly but remarkably steadily north or north-east. It seems to exercise no effect, or very little, till it actually reaches the front.

It is hard to estimate how frequent this display is, or how critical are the conditions. I have seen it twice really distinctly, and several times less so, during three years; but I pass that way very seldom at the right time, and infer that suitable occasions are not exceptional.

*London, September 1, 1955*

B. C. V. ODDIE

### **Thunderstorm at Sharjah on November 14, 1954**

A storm with unusual intensity of rainfall and lightning occurred at Sharjah, on the Oman Peninsula in the Persian Gulf, on the evening of November 14, 1954.

It had been noted that the ring of small isolated cumulonimbus clouds which had persisted most of the afternoon on the horizon were beginning to develop further. When dusk approached lightning became visible over the mountains to the east. As this increased in frequency and intensity it could be seen that considerable vertical development was taking place. This seems to have had a trigger effect on cloud to the west, south and north and by 2000 local zone time Sharjah was surrounded by towering cumulonimbus. Just before the storm broke at 2045, lightning was so frequent and intense as to appear one continuous vivid light, sufficient to read the small print of a newspaper in comfort. Rain, moderate at first, soon became violent turning to hail at 2100. The hailstones were up to 1 in. in diameter some of them of a flattened shape. Precipitation turned to rain at 2115 and stopped abruptly at 2130. In a period of 45 min. 56.0 mm. (2.21 in.) of rain fell. The barograph trace showed a rise of about 7 mb. followed by a fall of about 5 mb. in this period.

There is unfortunately no record of the strength of the wind in the squall which accompanied the storm, but considerable damage was done to barousti\* roofs. The whole area is sand with impervious consolidated coral beneath. The camp was quickly flooded and low-lying areas were under 30 in. of water (see photographs facing pp. 352 and 353). Some damage was done to a brick building by subsidence. The lightning was described by many observers as frightening, but seems to have done no damage.

A. C. THOMAS

[The average annual rainfall at Sharjah (25° 20'N. 55° 24'E.)† is 117 mm. (4.61 in.) and the average number of days in a year on which rain falls is 7; 108 mm. (4.29 in.) has been recorded in 24 hr. in November. Hail is very rare in the area.—Ed., *M.M.*].

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\* Of woven cane.

† See London, Meteorological Office. *Weather in the Indian Ocean*. Vol. II, Part 3, *The Persian Gulf and Gulf of Oman*. London, 1941.

## NOTES AND NEWS

### World maps of atmospheric water-vapour pressure

The World Climatology Branch of the Meteorological Office has produced world maps of mean atmospheric water-vapour pressure for the months of January, April, July and October. The maps, which are on a Mercator projection, measure 24 in.  $\times$  45 in. and extend from 75°N. to 60°S. The vapour-pressure values are as near as possible means of 24 hourly values per day reduced to sea level by a new formula. Between three and four thousand stations have been used.

It is hoped to publish these maps in the near future in sections with an explanatory text and with the limited amounts of arctic and antarctic data plotted on circumpolar maps. The complete lists of data and authorities will be available on microfilm.

A limited issue of the Mercator world maps is available. It is a set of full size photographic reproductions and has been sent to meteorological services who have supplied data and helped with the production of the maps. It is available for purchase at the cost of reproduction: 13s. 8d. per set of 4 charts (plus postage) on application to the World Climatology Branch of the Meteorological Office, Harrow, Middlesex. Postage in the United Kingdom is 1s. 3d.

### REVIEW

*Annual meteorological tables, Falkland Islands and Dependencies Meteorological Service, 1951-53, 13½ in.  $\times$  8½ in., iv + 40, iv + 52, viii + 112, Falkland Islands Dependencies Survey, Stanley. Prices: 3s. 6d., 3s. 6d., 10s.*

*Daily weather report of the Falkland Islands and Dependencies Meteorological Service. Part I: Synoptic section, Part II: Upper air section. 14 in.  $\times$  8½ in., Illus., Falkland Islands Dependencies Survey, Stanley.*

The *Annual meteorological tables*, started in 1951, present a wide range of statistics for each month and each year for all the British-operated observing stations in the Falkland Islands and Dependencies. The most southerly station is at present the Argentine Islands at 65°S. in west Grahamland. The tables cover all the usual items, even including monthly frequencies of various visibility ranges, cloud heights, wind speeds and directions and temperature ranges at the surface and aloft. Average temperature, humidity and cloud amount are given in most cases for eight different times of the day. Rainfall (or its equivalent in melted snow) is quoted for those months for which it was judged that reliable figures could be given.

The *Daily weather report* lists the surface observations in international code; winds and temperatures aloft are given in plain language. Radio-sonde observations are available for Stanley and, since January 1955, for the Argentine Islands.

The published weather-map analysis covers the southern part of Argentina, most of the Weddell Sea and the seas west of South America and Grahamland as far as about 80°W., showing plotted observations of wind, weather, cloud cover and temperature.

These productions will be generally welcomed for the sake of the documentation they provide for climatic reference libraries of weather in the region

covered and by workers engaged in research on southern-hemisphere meteorology.

H. H. LAMB

### OBITUARY

*Frank M. Dean, M.B.E.*—We regret to announce the death of Frank Dean which occurred on September 15, 1955. He was widely known as a member of the staff of the Meteorological Office and, on account of his staff association and Whitley work, throughout the Air Ministry and Civil Service.

Frank Dean, who was born on March 31, 1894, entered the Meteorological Office at the beginning of 1920 after having served throughout the first world war in the Corps of Royal Engineers. He spent most of his career at Meteorological Office Headquarters in Branches dealing with the organization of meteorological services for civil and service aviation. In his early days with the Office he received rapid promotion, and in the re-organization following the last war became a Senior Experimental Officer. During the war, the Branch in which he served was responsible for organizing meteorological services for the Royal Air Force, and Dean's unremitting energy and organizing ability were of the greatest value in ensuring that the Royal Air Force requirements were met to the fullest possible extent.

From the time he entered the Civil Service Frank Dean took an active part in the staff association movement, which grew at an astonishing rate immediately after the 1914-18 war. He was largely instrumental in raising interest in the Civil Service Clerical Association amongst what were then known as the non-professional grades of the Meteorological Office, and before long was their acknowledged leader and representative within the Association. His interests, however, were not confined to Meteorological Office affairs, and he soon became well known in the Air Ministry Whitley movement, and indeed throughout the whole of the Civil Service staff association organization.

In 1935, the Meteorological Office was re-organized as the result of the Carpenter Committee Report, and the non-professional grades were firmly recognized as scientific staff. In due course, Dean, who realized that the best interests of these grades would not be served by an organization representing clerical staffs, led the Meteorological Office members of the Civil Service Clerical Association into the ranks of the Institution of Professional Civil Servants. The Meteorological Office Branch of the Institution then became fully representative of all the scientific staff within the Office. Dean was elected Chairman of the Branch in 1943, a position which he held continuously until his death.

He was soon as well known throughout the Institution as he had been in the Civil Service Clerical Association. He held many Institution offices and was a member of its Executive Committee from the time of its formation in 1942 until his death. In the activities which at the end of the last war led to a new Government policy for Civil Service scientific staffs he was well to the fore. The implementation of this policy produced a period of intense departmental and national negotiation in which he took a full part, and his work on behalf of Civil Service scientific staffs in general, and the Meteorological Office staff in particular, will always be remembered with gratitude.

Dean, who for so many years had been well known for his work on the Air Ministry Departmental Whitley Council was elected Chairman of the Staff

Side of the Council in 1946, and he continued to hold this office until he died. As Chairman he achieved great success, and was held in high esteem by the varied interests he represented, and also by the Official Side members of the Council and by all establishment officers in the Air Ministry.

As a public speaker, Dean could be superb. He rarely referred to notes, and scorned the use of the new-fangled microphone, and his powerful voice could be heard throughout the largest conference hall. His short pithy sentences drove home his points with force, and he was particularly successful in dealing with a proposition not entirely to the liking of his audience. Many executive committees, trying to persuade members to adopt policies which had aroused opposition, have breathed sighs of relief on hearing the applause at the end of a speech by Frank Dean.

He will be sorely missed in the Meteorological Office, where everyone will remember his readiness to help and advise those with personal problems, and to put at their disposal his great store of experience and sound common sense.

Frank Dean was appointed a Member of the Order of the British Empire in the Birthday Honours List of 1954.

T. W. V. JONES

### METEOROLOGICAL OFFICE NEWS

**Retirement.**—Mr. N. H. Smith, Principal Scientific Officer, retired on September 30, 1955. He joined the Office in March 1919 after service in the Meteorological Section, Royal Engineers from January 1916. Mr. Smith has worked at Headquarters and aviation outstations as well as at the Observatories at Kew and Valentia. In 1934 he was transferred to Malta and he was the Senior Meteorological Officer there during the worst part of the siege of the island. Since his return from Malta in 1942 he has served at Headquarters, and from 1948, until his retirement, as Head of the Branch of the Office providing meteorological services for civil aviation on air routes within the United Kingdom and those with destinations in Europe. During the past two years he has been the Chairman of the Meteorological Office Social and Sports Committee.

At a ceremony in the Conference Room in Victory House on October 13, Mr. W. H. Bigg presented Mr. Smith with a cheque subscribed by his colleagues.

Mr. Smith has accepted a temporary appointment in the Meteorological Office.

**Academic successes.**—To the lists published in the October number should be added:

*Intermediate B.Sc.*—Pure mathematics, A. E. M. Maddox.

*City and Guilds.*—Telecommunications, Principles II and Mathematics II, D. G. Wilkinson.

### WEATHER OF SEPTEMBER 1955

The month was perhaps chiefly remarkable for the normality of the weather sequences over most of North America, the North Atlantic Ocean and western Europe. Pressure gradients were however greater than normal in the Atlantic sector. The Azores anticyclone and the



usual September ridge over the Bay of Biscay were shifted slightly north and 2-4 mb. more intense than normal. The low-pressure centres near Iceland and both sides of south Greenland were near their normal positions but 7-10 mb. deeper than usual on the monthly mean map. The pressure-anomaly isopleths over a very wide region were nearly concentric with the deepened Iceland low, leaving normal values over most of North America but pressures 3-6 mb. above normal in a great ridge across the Arctic from the European side. The usual September low-pressure trough in the Barents Sea was missing.

Temperatures were near normal over most of the northern hemisphere, though with a small increase in the latitudinal temperature gradient over North America and a warm patch with anomaly +3 to +4°C. over Finland.

Rainfall amounts were excessive (2-4 times the normal) in some areas in the Indian monsoon and in parts of the United States devastated by tropical storms. There were rainfall anomalies of the same order west of the central Rockies and in Jan Mayen and north-east Greenland.

In the British Isles the weather was rather changeable but on the whole conformed to the average although somewhat sunnier. It was rather warm in the north.

Troughs of low pressure in a general westerly air stream crossed the country during the first five days, but most of the accompanying rain fell in west Scotland, north-west England and Northern Ireland; Aldergrove had more than 1 in. of rain during the night of the 4th-5th and Prestwick not much less. Weather during the first few days was rather warm generally with variable cloud amounts and sunshine most days; temperature reached 80°F. at London Airport and Cromer on the 2nd. An anticyclone developed over Russia on the 5th and a cold front intensified as it slowly crossed the country, giving heavy rain in places with thunderstorms in East Anglia and the London area. A ridge of high pressure formed over the British Isles the following day, moved to the North Sea on the 7th and later joined up with the anticyclone still over Russia. Apart from fairly widespread fog around dawn, these two days were generally fine and warm with 11-12 hr. sunshine in many areas. Pressure remained low in the Iceland-south Greenland region until the 12th with associated troughs moving slowly across the British Isles; weather became rather changeable with showers and sunny periods and temperature nearer the normal. There were occasional thunderstorms and these became widespread on the 13th and 14th with the arrival of cold air from Greenland in the rear of a depression which moved south-east from Iceland to the North Sea; temperature fell generally in the north-westerly air stream; early on the 15th the screen minimum at Prestwick was only 37°F. and elsewhere there was slight ground frost locally for several nights. From the 17th to the 20th an anticyclone moved eastward from the Atlantic along the English Channel to northern Germany and brought several days of settled and progressively warmer weather with temperature rising to or a little over 70°F. by the 20th, though early morning fog and some ground frost occurred in places. An unusually deep depression developed in the central Atlantic on the 18th; associated fronts, which subsequently crossed the country, were mainly weak in the south, but an active cold front produced thunderstorms in the Channel Islands and south-east England on the 22nd, where about 2 in. of rain fell at Sevenoaks and Brighton in 24 hr. and Croydon had its second wettest September day since records began in 1920. From the 25th an anticyclone became established south-west of the British Isles, and, although there was some occasional slight rain chiefly in the north, the weather was mostly fine with variable cloud and sunny periods in all areas until the end of the month. On the 29th more than 10 hr. sunshine was recorded at many places in south and south-east England and temperature rose to the middle seventies in parts of north-east England and east Scotland. Average temperature for the month was near to the normal over south-east England and higher than usual elsewhere. Sunshine exceeded the average except over the Hebrides and the extreme east of Norfolk. Rainfall was less than the average over most of the eastern half of Scotland, over County Down, Ireland and over the major part of England and Wales except for a belt from Suffolk to Sussex. Less than half the average was recorded in east Lincolnshire and east Kent.

The general character of the weather is shown by the following provisional figures.

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	81	33	+1·1	80	0	117
Scotland ...	79	34	+2·1	115	+2	114
Northern Ireland ...	74	42	+2·2	140	+4	123

# RAINFALL OF SEPTEMBER 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	2·34	129	<i>Glam.</i>	Cardiff, Penylan ...	2·00	66
<i>Kent</i>	Dover ...	0·96	42	<i>Pemb.</i>	Tenby ...	2·66	84
<i>"</i>	Edenbridge, Falconhurst	2·95	130	<i>Radnor</i>	Tyrmynydd ...	4·14	107
<i>Sussex</i>	Compton, Compton Ho.	2·51	90	<i>Mont.</i>	Lake Vyrnwy ...	2·39	66
<i>"</i>	Worthing, Beach Ho. Pk.	3·02	141	<i>Mer.</i>	Blaenau Festiniog ...	6·62	84
<i>Hants.</i>	St. Catherine's L'thouse	1·49	62	<i>"</i>	Aberdovey ...	3·32	104
<i>"</i>	Southampton (East Pk.)	1·69	78	<i>Carn.</i>	Llandudno ...	1·19	56
<i>"</i>	South Farnborough ...	1·78	93	<i>Angl.</i>	Llanerchymedd ...	2·72	93
<i>Herts.</i>	Harpenden, Rothamsted	1·71	88	<i>I. Man</i>	Douglas, Borough Cem.	3·00	92
<i>Bucks.</i>	Slough, Upton ...	1·48	84	<i>Wigtown</i>	Newton Stewart ...	3·45	101
<i>Oxford</i>	Oxford, Radcliffe ...	1·51	88	<i>Dumf.</i>	Dumfries, Crichton R.I.	2·32	86
<i>N'hants.</i>	Wellingboro' Swanspool	1·52	84	<i>"</i>	Eskdalemuir Obsy. ...	4·65	126
<i>Essex</i>	Southend, W. W. ...	2·74	165	<i>Roxb.</i>	Crailing ...	1·93	95
<i>Suffolk</i>	Felixstowe ...	0·90	54	<i>Peebles</i>	Stobo Castle ...	2·92	116
<i>"</i>	Lowestoft Sec. School ...	1·26	64	<i>Berwick</i>	Marchmont House ...	1·72	71
<i>"</i>	Bury St. Ed., Westley H.	2·19	110	<i>E. Loth.</i>	North Berwick Gas Wks.	1·41	68
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·58	76	<i>Mid'n.</i>	Edinburgh, Blackf'd. H.	1·21	59
<i>Wilts.</i>	Aldbourne ...	1·09	52	<i>Lanark</i>	Hamilton W. W., T'nhill	3·59	134
<i>Dorset</i>	Creech Grange ...	2·18	80	<i>Ayr</i>	Prestwick ...	2·88	112
<i>"</i>	Beaminster, East St. ...	1·98	78	<i>"</i>	Glen Afton, Ayr San. ...	5·48	141
<i>Devon</i>	Teignmouth, Den Gdns.	1·04	53	<i>Renfrew</i>	Greenock, Prospect Hill	5·18	115
<i>"</i>	Ilfracombe ...	1·97	73	<i>Bute</i>	Rothsay, Arden Craig ...	5·16	127
<i>"</i>	Princetown ...	5·23	102	<i>Argyll</i>	Morven, Drimnin ...	8·04	142
<i>Cornwall</i>	Bude, School House ...	1·34	54	<i>"</i>	Poltalloch ...	6·29	138
<i>"</i>	Penzance ...	2·10	72	<i>"</i>	Inveraray Castle ...	9·70	151
<i>"</i>	St. Austell ...	2·03	64	<i>"</i>	Islay, Eallabus ...	6·94	166
<i>"</i>	Scilly, Tresco Abbey ...	0·92	36	<i>"</i>	Tiree ...	6·43	173
<i>Somerset</i>	Taunton ...	1·48	75	<i>Kinross</i>	Loch Leven Sluice ...	2·18	85
<i>Glos.</i>	Cirencester ...	0·72	32	<i>Fife</i>	Leuchars Airfield ...	0·96	50
<i>Salop</i>	Church Stretton ...	1·58	75	<i>Perth</i>	Loch Dhu ...	6·48	113
<i>"</i>	Shrewsbury, Monkmore	1·67	102	<i>"</i>	Crieff, Strathearn Hyd.	2·12	74
<i>Worcs.</i>	Malvern, Free Library...	1·66	86	<i>"</i>	Pitlochry, Fincastle ...	2·16	86
<i>Warwick</i>	Birmingham, Edgbaston	1·37	70	<i>Angus</i>	Montrose, Sunnyside ...	2·06	104
<i>Leics.</i>	Thornton Reservoir ...	1·91	106	<i>Aberd.</i>	Braemar ...	1·55	62
<i>Lincs.</i>	Boston, Skirbeck ...	1·29	73	<i>"</i>	Dyce, Craibstone ...	2·11	87
<i>"</i>	Skegness, Marine Gdns.	0·77	43	<i>"</i>	New Deer School House	2·08	83
<i>Notts.</i>	Mansfield, Carr Bank ...	0·80	43	<i>Moray</i>	Gordon Castle ...	1·57	63
<i>Derby</i>	Buxton, Terrace Slopes	2·86	88	<i>Nairn</i>	Nairn, Achareidh ...	1·67	79
<i>Ches.</i>	Bidston Observatory ...	1·82	76	<i>Inverness</i>	Loch Ness, Garthbeg ...	3·73	121
<i>"</i>	Manchester, Ringway...	1·89	83	<i>"</i>	Glenquoich ...	...	...
<i>Lancs.</i>	Stonyhurst College ...	3·71	97	<i>"</i>	Fort William, Teviot ...	9·10	142
<i>"</i>	Squires Gate ...	2·54	94	<i>"</i>	Skye, Broadford ...	10·11	146
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·33	83	<i>"</i>	Skye, Duntuilum ...	8·32	181
<i>"</i>	Hull, Pearson Park ...	0·89	52	<i>R. &amp; C.</i>	Tain, Mayfield... ..	1·60	70
<i>"</i>	Felixkirk, Mt. St. John...	1·38	76	<i>"</i>	Inverbroom, Glackour...	5·77	131
<i>"</i>	York Museum ...	1·26	77	<i>"</i>	Achnashellach ...	10·72	156
<i>"</i>	Scarborough ...	1·26	70	<i>Suth.</i>	Lochinver, Bank Ho. ...	5·90	170
<i>"</i>	Middlesbrough... ..	1·22	73	<i>Caith.</i>	Wick Airfield ...	3·25	130
<i>"</i>	Baldersdale, Hury Res.	2·05	80	<i>Shetland</i>	Lerwick Observatory ...	3·71	123
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	1·13	57	<i>Ferm.</i>	Crom Castle ...	4·04	145
<i>"</i>	Bellingham, High Green	2·18	91	<i>Armagh</i>	Armagh Observatory ...	3·61	147
<i>"</i>	Lilburn Tower Gdns. ...	1·64	69	<i>Down</i>	Seaforde ...	2·15	78
<i>Cumb.</i>	Geltsdale ...	2·72	97	<i>Antrim</i>	Aldergrove Airfield ...	4·52	182
<i>"</i>	Keswick, High Hill ...	4·14	98	<i>"</i>	Ballymena, Harryville...	4·69	151
<i>"</i>	Ravenglass, The Grove	3·10	92	<i>L'derry</i>	Garvagh, Moneydig ...	4·38	148
<i>Mon.</i>	A'gavenny, Plás Derwen	1·28	50	<i>"</i>	Londonderry, Creggan	4·41	133
<i>Glam.</i>	Ystalyfera, Wern House	4·27	98	<i>Tyrone</i>	Omagh, Edenfel ...	4·18	137

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METEOROLOGICAL OFFICE

# THE METEOROLOGICAL MAGAZINE

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## SNOW SURVEY OF GREAT BRITAIN

### Season 1954-55

As in previous years the basic material for this report has been derived from the returns made by voluntary observers who have provided, month by month, daily records of snowfall and of any snow-cover within their range of vision. These records, from a network of stations distributed over the country, are augmented by data extracted from the regular monthly returns from official weather stations and also from voluntary climatological stations reporting to the Meteorological Office. Without the co-operation of all those responsible for these voluntary observations it would have been impossible to have prepared this report in anything like its present detail.

Measurements of depth of snow in the following pages refer, in general, to 0900 G.M.T. or thereabouts.

**Summary of 1954-55 season.**—The season may be classed as one of more than average snowfall. Data for ten representative stations\* in Great Britain at altitudes between 400 and 1,200 ft., which have been used for seasonal comparison since the survey of 1946-47, give a mean of 51 days with snow lying at the hour of morning observation. This compares with an average of 36 such days over the past eight seasons; the great variability of snowfall in the British Isles is shown by the fact that during these seasons the mean number of days ranged from 13 in 1948-49 and 1949-50, to 66 in the severe winter 1946-47. The snowfall during the season under review may be compared generally with that of 1946-47, although the worst conditions were largely confined to northern districts, whereas during the 1946-47 season they were more evenly distributed over the country. In February 1955 undrifted snow accumulated to a depth of over 24 in. over a wide area in Scotland, and Drummair, Banffshire, reported a depth of 36 in. on the 21st, whereas in the Pennines at Forest-in-Teesdale during February 1947 the depth of level snow increased from 44 in. on the 6th to 53 in. on the 18th. The number of days on which snow fell was also less this season than in 1946-47.

**Notes on the months.**—*September 1954.*—Temperature during the month was below normal for the time of the year, and sleet showers fell locally in Scotland on the 16th-18th and 24th-29th. Snow lay on the summit of Ben Nevis throughout the month, and on some other high peaks in Scotland, notably the Cairngorms on the 17th-20th and 26th-30th, and on some of the higher peaks in Cumberland and Westmorland on the 27th-28th.

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\* These stations are:—Dalwhinnie, Braemar, West Linton, Eskdalemuir, Huddersfield (Oakes), Buxton, Whipsnade, Little Rissington, Princetown and Rhayader.

*October 1954* was a very mild month, particularly in England and Wales where the average temperature was 3°F. above the seasonal normal. Snow or sleet showers were reported locally on the 17th, 21st–25th, 27th, and 30th. Snow lay on some of the Scottish hills, mainly at 2,500 ft. and above, from the 10th onward, and on the higher hills in Cumberland and Westmorland, including Cross Fell on the 24th–29th.

*November 1954.*—Mean temperature during the month was about the seasonal normal. Snow or sleet fell locally on most days, but there were no really heavy falls, though snow lay several inches deep on high ground in Scotland on the 24th; for example, 2½ in. at Glenlivet in the Cairngorms and at Glengavel in the northern foothills of the Southern Uplands, Lanarkshire, 4 in. at Dalwhinnie in the Grampians and 5 in. at Leadhills in the Southern Uplands. Snow also lay on the higher ground of north-west England on the 5th–9th, 12th and 23rd–27th including Moorland Cottage and Cross Fell in the Pennines and on Helvellyn and Scafell in the Lake District.

*December 1954* was exceptionally mild in England and Wales, where the mean temperature for the month was nearly 4°F. above normal in spite of a rather cold period from the 5th to the 12th and again from the 23rd to the 24th. Snow fell fairly frequently north-west of a line, Bristol Channel to the Wash, particularly in parts of Scotland where heavy falls blocked roads for several days. At 2,400 ft. near Leadhills, Lanarkshire, there were drifts 12 ft. deep. Snow was widespread on the 8th, 12th, 23rd and 24th; it lay to a depth of 22 in. at Braemar and 18 in. at Balmoral, both in Aberdeenshire, on the 8th, and 14 in. at Achnagoichan and Glenmore Lodge, both in Invernessshire, on the 9th. Further south at Moor House, Westmorland, there was 6 in. of level snow with drifts 3 ft. deep on the 9th–12th; 4 in. at Buxton, Derbyshire, on the 8th–10th and 5 in. at Cae Llwyd, Denbighshire, on the 8th.

*January 1955*, in marked contrast with December, was very cold except for the last week. In Scotland local falls of snow or sleet occurred throughout the month, and there was snow in most areas from the 10th to the 18th, the main falls occurring from the 11th to the 14th and from the 16th to the 18th. At Glenrossal, Sutherland, level snow lay to a depth of more than 12 in. from the 14th to the 21st and was 18–20 in. deep on the 18th; on the same day it was also 18 in. deep at Achnagoichan near the Cairngorms and at Adit 3 near Loch Lochy on the Caledonian Canal. Gales piled the snow into deep drifts—30-ft. drifts were reported at some places—and many farms and villages, thus isolated, were supplied with food by aircraft. In England and Wales snow or sleet fell fairly frequently up to the 19th, and was widespread on the 4th, 5th, 15th and 18th. It was lying to a depth of 6–9 in. on the 17th in Northumberland, Durham, the North and West Ridings of Yorkshire, south Lancashire and north Wales.

*February 1955* was an exceedingly cold month, the coldest in the British Isles since February 1947 with average temperatures 5–6°F. below normal. In Scotland, snow or sleet fell daily with moderate or heavy falls on most days from the 9th to the 22nd. As in January, the north and north-east were severely affected with undrifted snow in places more than 24 in. deep; Drummair, Banffshire, reported a level depth of snow of 36 in. on the 21st. In England the north-east was badly affected; in parts of Northumberland level snow lay over a foot deep from the 22nd till the end of the month, while at Buxton,

Derbyshire, undrifted snow was 20 in. deep from the 25th to the 28th. Further details of the snowfall of January and February are given in an earlier article<sup>1</sup>.

*March 1955.*—This was another cold month with mean temperature everywhere below the average. In Scotland, snow and sleet fell chiefly during the first week and from the 16th to the 24th though there were local snow showers until the 29th; at Reay Forest, Sutherland, snow lay 16 in. deep on the 20th and 21st. In England and Wales snow fell to a depth of 6 in. in parts of East Anglia and Kent on the 6th, and to a similar depth in places in northern England on the 20th; there were also scattered snow showers, particularly in eastern England, throughout the major part of the month.

*April 1955* was dry, sunny and mild with very little snow. Snow fell locally in Scotland, however, on the 20th and 24th, and in parts of Bedfordshire and Buckinghamshire on the 17th–19th.

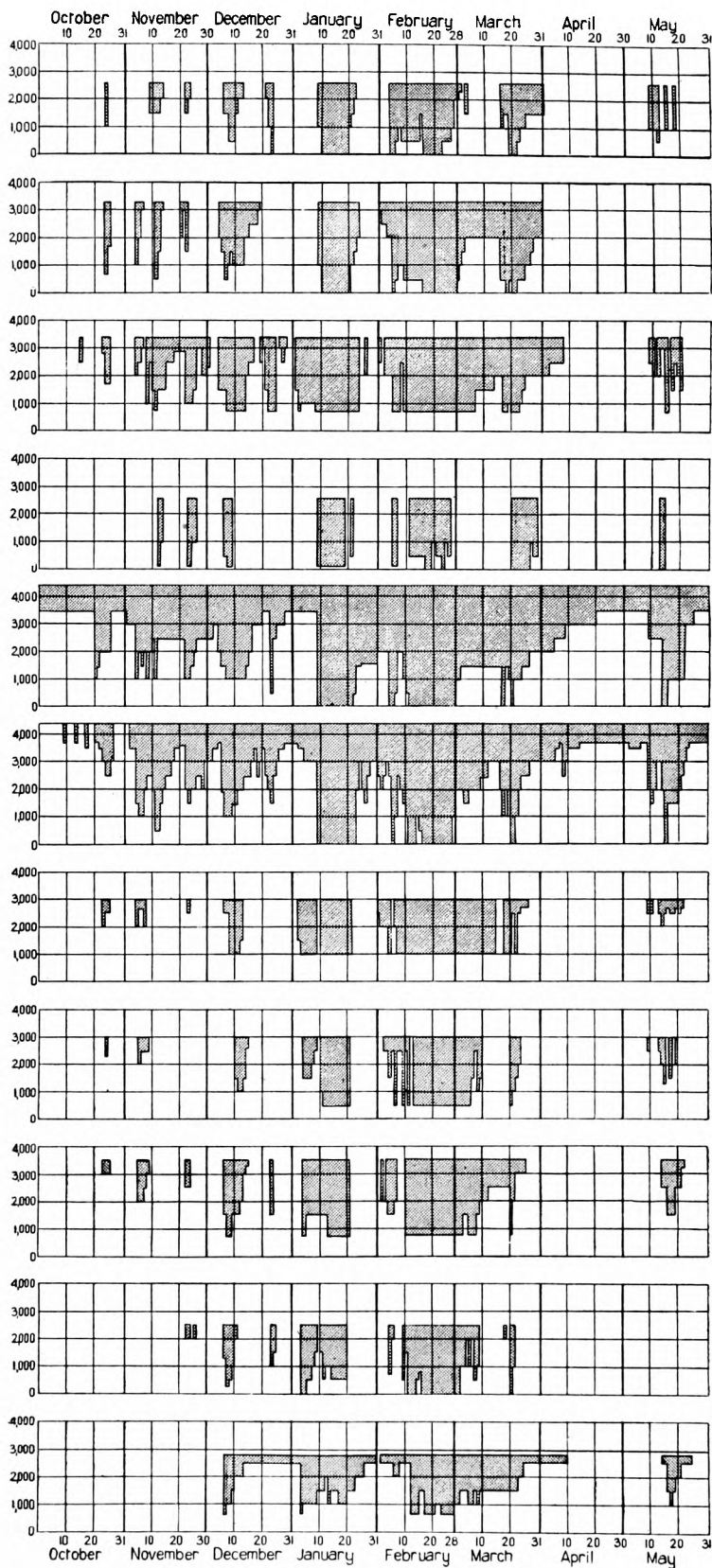
*May 1955.*—The mean temperature was again considerably below the normal. Snow and sleet fell almost daily for the first three weeks of the month in Scotland and on the 10th and 14th–21st in England and Wales. Snow fell on 8 days at Malham Tarn, West Riding of Yorkshire, where it lay to a depth of 4 in. on the 17th. On this day snow was fairly widespread; 3–4 in. lay extensively in the Merthyr, Brecon and Neath districts of south Wales; 3 in. were measured in parts of Wiltshire and Dorset after an unusually heavy snowstorm for mid May, and many parts of east Yorkshire and the east midlands had a cover of 1 in. Further details of snowfall in May are given in an earlier article<sup>2</sup>.

**Duration of snow-cover on British mountains.**—The mean number of days of snow-cover at 2,500 ft. on four mountain groups used as indices was 93 compared with an average of 81 for the past eight seasons. The stations used were Glenbrittle (Cuillin Hills 3,300 ft.), Meggernie Castle (mountains round Glen Lyon 3,400 ft.), Capel Curig (Snowdonia 3,500 ft.), and Tairbull (Brecon Beacons 2,800 ft.). Diagrams showing the distribution of snow-cover relative to height for eleven stations are given in Fig. 1.

Harris, in the Outer Hebrides, reported snow-cover on 1 day in October and 8 days in November; in December it was covered from the 7th to the 13th and from the 22nd to the 24th. Snow-cover was also observed during January 9–23 and from February 4 to the end of the month, most of which time the snow-line was down to sea level. There was snow-cover for 3 days at the beginning of March and during the whole of the second half of the month, extending to April 1, and for 6 days during the middle of May.

The Cuillins of Skye were occasionally covered during the last week of October and the first 3 weeks of November. The summits were also covered during December 4–19, January 10–24 and during the whole of February and March, most of which time the snow extended down to 2,000 ft. The snow-line came down to sea level during the middle of January, the last half of February and for 3 days towards the end of March.

The peaks around Glen Lyon had snow-cover for a few days during October, most of November and December and continuously from January 1 to March 8, except for 5 days at the end of January. There was also snow-cover during mid May. Snow came down to station level (760 ft.) frequently from December to March, and on November 12 and May 14.



**CLISHAM and RONEVAL**  
Station: Leverburgh,  
Harris (Height: 25 ft.)

**CUILLIN HILLS**  
Station: Glenbrittle,  
Skye (Height: 30 ft.)

**Mountains round GLEN LYON**  
Station: Meggernie  
Castle, Perthshire  
(Height: 760 ft.)

**PAPS OF JURA**  
Station: Colonsay,  
Argyll (Height: 150 ft.)

**BEN NEVIS**  
Station: Corpach,  
Inverness-shire  
(Height: 30 ft.)

**BEN NEVIS**  
Station: Banavie,  
Inverness-shire  
(Height: 50 ft.)

**CROSS FELL**  
Station: Alston,  
Cumberland  
(Height: 1,070 ft.)

**HELVELLYN**  
Station: Patterdale,  
Westmorland  
(Height: 520 ft.)

**SNOWDONIA**  
Station: Capel  
Curig, Caernarvonshire  
(Height: 700 ft.)

**SOUTH SNOWDONIA**  
Station: Llanfrothen,  
Merionethshire  
(Height: 475 ft.)

**BRECON BEACONS**  
Station: Tairbull,  
Brecknockshire  
(Height: 660 ft.)

FIG. 1—DISTRIBUTION OF SNOW-COVER IN RELATION TO HEIGHT

The Paps of Jura were covered for 5 days in November, three days at the beginning of December, January 10–19, January 22, February 6–7, February 12–27, March 22–30 and May 17–18, most of which time the snow-line was down to station level (150 ft.) except for a week in mid February.

The summit of Ben Nevis was observed to be covered continuously from the beginning of September to the end of June and snow was seen in gullies down to 3,200 ft. even as late as August 8. Snow-cover came down to 1,000 ft. during each month from September to May, except April, and down to sea level January 10–22, most of February, 2 days in March and 2 days in April.

Cross Fell was snow-capped for 3 days in October, 5 days in November, and 7 consecutive days in December, during which time the snow-line came down to station level (1,070 ft.) on December 9, 10 and 12. The summit was covered on January 2–7 and 9–21, the whole of February, March 1–4, 6–14, and 18–26; during most of this period snow extended down to station level. Snow was also observed on 12 days during mid May.

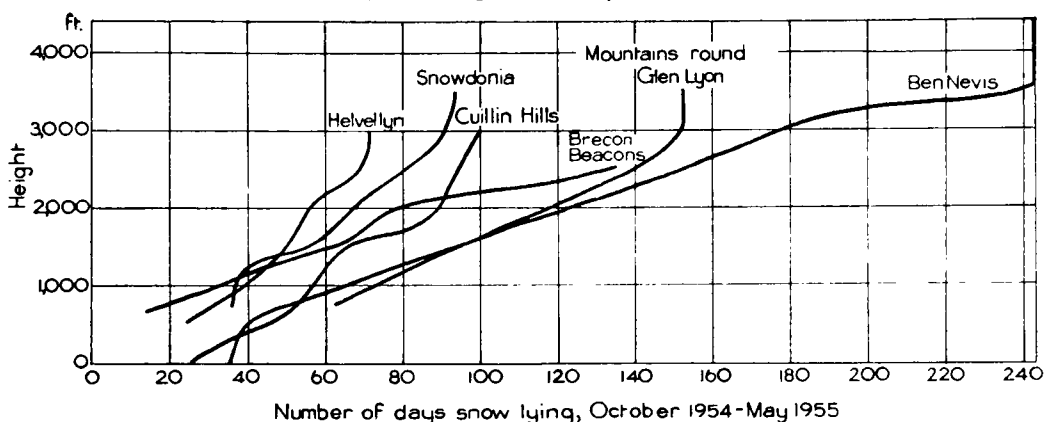


FIG. 2—SEASONAL DURATION OF SNOW-COVER

Helvellyn was snow-covered for 1 day in October, 4 days in November and 5 consecutive days in December when the snow came down to 1,000 ft. on December 11 and 12. Snow-cover was also observed on January 3–9, 11–21, February 3–12, February 14–March 10 and March 21–24; snow was down to station level (520 ft.) on January 12–21, February 7, 10, February 14–March 6 and March 21. Snow was also observed on 6 days during mid May.

The peaks near Capel Curig had snow-cover above 3,000 ft. on 3 days during the last week of October and were occasionally covered above 2,000 ft. in November. Snow-cover was observed on December 6–16, about half of January and from February 2 to March 26 except for February 3 and February 8–10, most of which time snow extended down to 2,000 ft. Snow was also observed on 8 consecutive days during mid May.

In south Snowdonia there was snow-cover at 2,500 ft. on November 23–25, December 6–11, 24 and 25, January 3–20 (except 10), February 5 and 6, from February 10 to March 9 and March 19, 21 and 22; most of this time snow was down to station level at 475 ft.

The Brecon Beacons were under continuous cover above 2,500 ft. from December 7 to April 10 except for one day, February 1, and during May 14–25. Snow came down to station level (660 ft.) on December 7, January 4 and February 13–15, 18–21, and 24–28.

Curves showing total seasonal duration for six stations are drawn in Fig. 2; 200 days' snow-cover was exceeded on Ben Nevis above 3,500 ft., and 100 days' cover was exceeded on the mountains about Glen Lyon above 1,600 ft., on the Brecon Beacons above 2,500 ft. and at the summit of the Cuillin Hills.

#### REFERENCES

1. BOOTH, R. E.; The snow of January and February 1955. *Met. Mag., London*, **84**, 1955, p. 129.
2. BOOTH, R. E.; An exceptionally cold day in May. *Met. Mag., London*, **84**, 1955, p. 293.

## THE OCCURRENCE OF SPELLS IN LONDON RAINFALL AND TEMPERATURE

By D. H. McINTOSH, M.A., B.Sc.

**Introduction.**—In a spell of disappointing weather, such as that experienced in the British Isles in the summer of 1954, there is a tendency for the expression of the lay opinion—or perhaps it is merely the hope—that the future weather is likely to atone to some extent for the past by being better than average for the period in question, the “law of averages” usually being invoked in vague support of this belief. The corresponding belief, that the chance that the future weather will be as good as average is somewhat decreased if the weather in the immediate past has been exceptionally favourable, is also fairly generally held though less widely expressed. Professional meteorological opinion does not appear to be unanimous on these points which have apparently lacked systematic investigation in the past; no doubt the view most widely held is that, following a rather indefinite period of persistence of the existing tendency, the most probable course of events, in any particular case, is a return to average without any “compensating” period. This is the conclusion that would reasonably be drawn from what various investigations have shown concerning the general character of the meteorological elements. But such a conclusion can hardly be reached with certainty without a special investigation, which appears the more necessary because Glasspoole<sup>1</sup> has recently reported a type of result which accords with the more popular belief; namely that if in a run of four very dry months there has been only about a third of the average rainfall, then the next four months are likely to redress the deficit to some extent.

Attention is confined in this investigation to the monthly values of rainfall and temperature published<sup>2</sup> for Greenwich for the period 1841–70, and for Kew from 1871 to 1949; to these were added the Kew observations for 1950 to 1953. The data thus covered a period of 113 yr. The two elements were considered separately.

**Rainfall.**—The rainfall of each of the  $12 \times 113$  months was expressed as a departure from the appropriate monthly mean for the whole period; the annual variation of rainfall amount was thus eliminated. The data were then examined for evidence of secular change or changes during the period. This was done by averaging the monthly departures in successive groups of 10 yr. (13 yr. in the last group), and then examining the progression of these averages and also their magnitude, in terms of the standard deviation. As a result it was concluded that there was no clear evidence of any secular change in rainfall over the period, and that the data could safely be regarded as comprising a homogeneous set.



Wet and dry spells were then defined as follows:

*Wet spell.*—Any three successive months, each with a positive rainfall departure and having an aggregate rainfall more than 150 per cent. of the average taken over the whole period for the corresponding three months.

*Dry spell.*—Any three successive months each with a negative rainfall departure and having an aggregate rainfall less than 50 per cent. of the average taken over the whole period for the corresponding three months.

With these definitions it was found that there were 53 wet and 61 dry spells. The rainfall departure was noted for each month from 6 months before to 12 months after the middle month of each selected wet or dry spell and the average departures were calculated for the months:  $-6, -5 \dots +12$  (month "0" being the middle month of the spell) for the two contrasting groups separately. Since it was considered possible that there might be a seasonal variation in the effect found, such that the effect might diminish or cancel out over the year as a whole, the results were first subdivided according to the middle one of each three months comprising a spell. The number of cases for each month was however too small for adequate discussion, and the results were therefore paired successively—middle month January or February, March or April, etc.—and are shown graphically in Fig. 1. Finally, the figures were combined for the six summer months April to September, the six winter months October to March, and for the year as a whole; these results are also shown in Fig. 1.

Standard errors of various plotted means are shown in each graph. These were calculated from the close approximation to the "population" standard deviation of monthly rainfall amount obtained from the whole series. There is in London monthly rainfall an annual variation of the variability of amount, which runs approximately parallel to the annual variation of rainfall amount itself. This results in small differences in the standard errors of the various plotted means; maximum and minimum values are shown for each curve where this is warranted by the scale of the plotted differences between these values. In each graph the number of cases comprising the mean is shown.

In the absence of the association of any effect, in subsequent or preceding months, with the occurrence of the selected spell, the departures at months other than 0,  $+1$ ,  $+2$  will be merely random fluctuations about the zero line. The method of analysis therefore consists simply in examining whether any of these plotted means differ from zero by an amount which is significant in relation to the general variability, as defined by the standard error of the mean values. For months  $+11$ ,  $+12$  (also  $+13$  as used later with the temperature data), the mean value appropriate to "no effect" differs slightly from zero, which is the appropriate value for all the other months considered. This arises because, with months  $+11$ ,  $+12$ ,  $+13$  the same months of the previous year were specially selected for their large departures ( $+D$  say) from the whole period means, but are naturally excluded from making a contribution to the means found for months  $+11$  and  $+12$ . Where the long period mean is  $M$ , and the number of cases comprising it  $N$ , the appropriate mean for "no effect" at months  $+11$  and  $+12$  is  $(NM - D)/(N - 1)$  which is approximately  $M - D/N$  for large  $N$ , i.e. the mean is moved by an amount  $D/N$  in the sense opposite to that of the selected feature. In the present case  $D = 50$  mm. and  $N = 113$ ; the

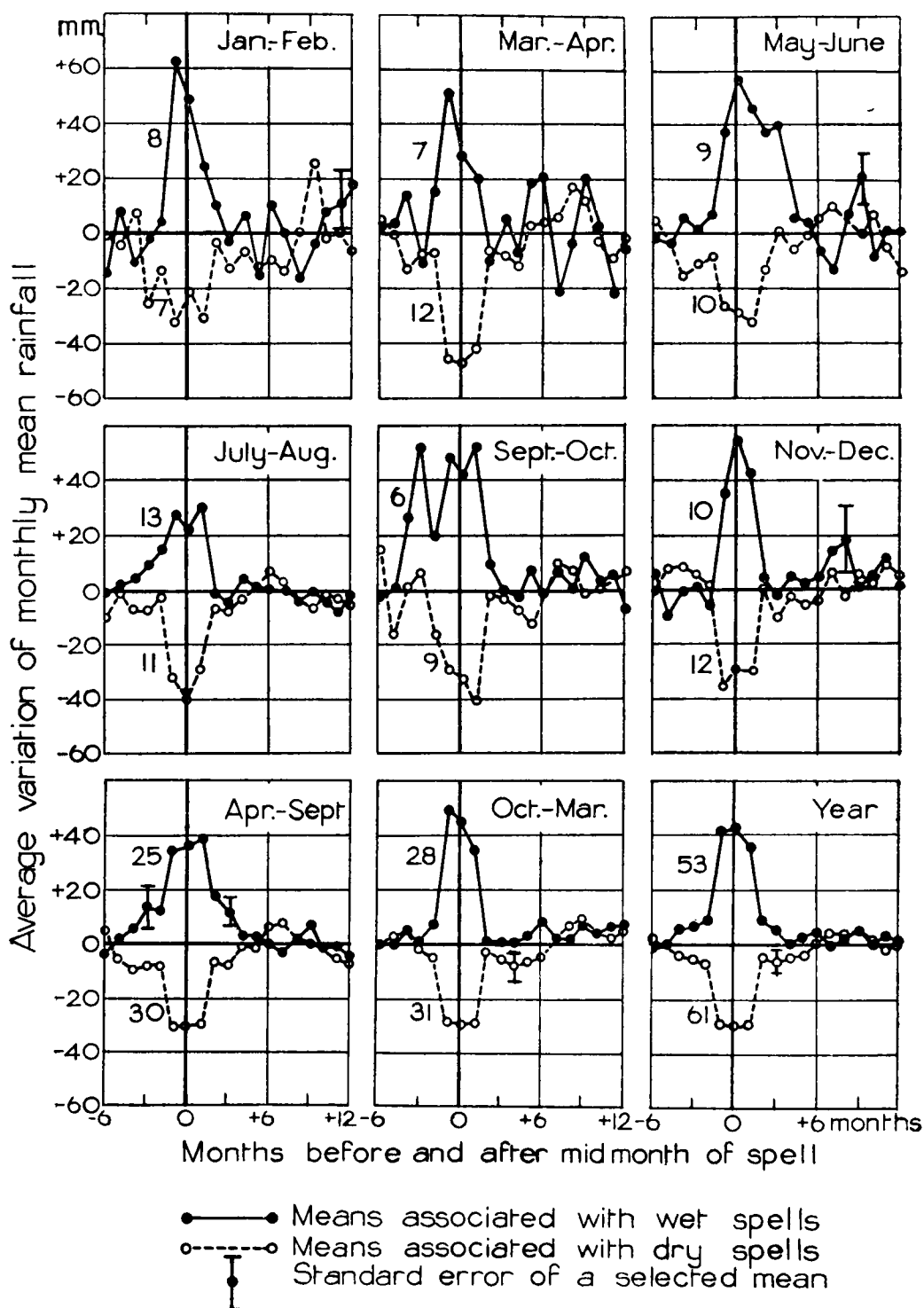


FIG. 1—AVERAGE VARIATION OF MONTHLY MEAN RAINFALL IN LONDON ASSOCIATED WITH WET AND DRY SPELLS LASTING 3 MONTHS

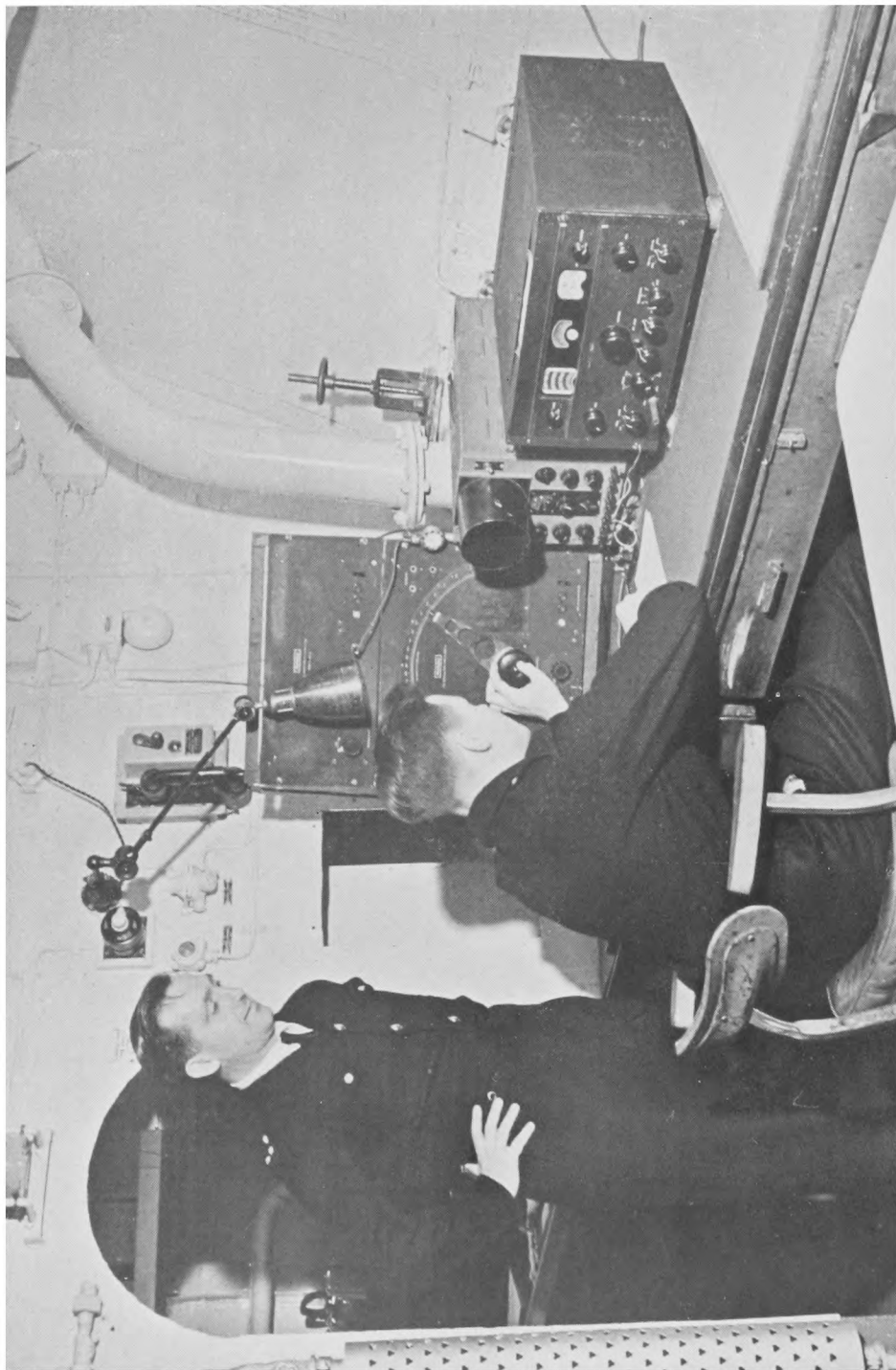
Month "0" is the middle month of spell and the number of spells in each average is given against each curve.



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### THE METEOROLOGICAL OFFICE ABOARD O.W.S. *Weather Explorer*

The instruments along the far wall are, from left to right, three marine barometers, each with a Gold slide (two are check barometers), indicating dials for the relative wind speed and direction, sea-temperature recorder (from the engine-room intake), wet-bulb and dry-bulb distant-reading thermograph, and an oil-damped barograph on an anti-vibration mounting. The dial almost directly above the wind-direction indicator gives the ship's speed. The meteorologist is working out an ascent using a pilot-balloon slide-rule; above him, on a folding arm is the microphone for communication with the ship's radar room.



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**FOLLOWING A RADIO-SONDE ABOARD O.W.S. *Weather Explorer***

In this corner of the meteorological office are the standard surface instruments for a Meteorological Office radio-sonde, consisting of oscillator, cathode-ray oscillograph and radio receiver.

appropriate mean is thus changed by about 0.5 mm. which may be seen to be quite negligible. The effect is also negligible in the temperature data considered later.

The following interpretation is made of the results shown in Fig. 1; some weight is given in this interpretation to the general progression of the mean departures and to the results obtained with the two contrasting groups as well as to the absolute size of the departures.

(a) In the average of the six "summer" months wet and dry spells, as defined above, follow, and are followed by, months of the same average rainfall characteristic as the type of spell concerned. The effect lasts for two to four months on either side of the spell. The data are insufficient for determining the precise months during which the persistence tendency is at a maximum.

(b) In the six "winter" months there is no significant persistence tendency associated with wet spells; the long-period average becomes at once the most probable value. Following a dry spell in these months, the rainfall probably tends to remain below average for some four months.

(c) There is no evidence of any compensation effect, either immediately following a wet or dry spell or after a time lag. In particular the effect reported by Glasspoole is absent from these London data. In the 61 dry spells distributed throughout the year the succession of three dry months had an aggregate rainfall about 40 per cent. of normal; the four following months were all dry on the average, and aggregated 90 per cent. of normal. The calculated probability that this persistence of a dry tendency is other than a real feature is only 0.007.

**Temperature.**—As with the rainfall data, the effect of the annual variation of temperature was eliminated by expressing the temperature of each month as a departure from the whole-period average for the corresponding month. When this was done it was very soon apparent that there was a secular change or changes in the data. Thus it was found that in the first thirty years (1841–70) the "summer" months April to September comprised 65 positive and 115 negative departures; while in the last 23 years (1931–53) they comprised 96 positive and 42 negative departures. These particular periods were not specially selected, the data being worked in three batches each of 30 yr. and a final one of 23 yr. The over-all value of the autocorrelation coefficient  $r_1$  was found to be +0.24; 6 consecutive terms (April to September) were thus calculated as being equivalent to 4.1 random terms so that the early period comprised  $30 \times 4.1$  or 123 independent months, divided between 44 positive and 79 negative (retaining the percentage frequency of positive and negative actually found); and the later period comprised 94 independent months, divided between 66 positive and 28 negative. Application of the  $\chi^2$  test to these figures left no doubt that from April to September the temperatures in the later period were significantly higher than in the earlier period. In connexion with this secular change it may be noted that the data for the early years were for Greenwich and those for the later years were for Kew. Comparison over a common period gives the result for April to September, Greenwich minus Kew = +0.4°F. Elimination of the site difference would therefore magnify still further the summer warming of more recent years.

In this particular investigation it was necessary to eliminate or minimize the effect of secular changes in the data. Thus, for instance, in a selection of

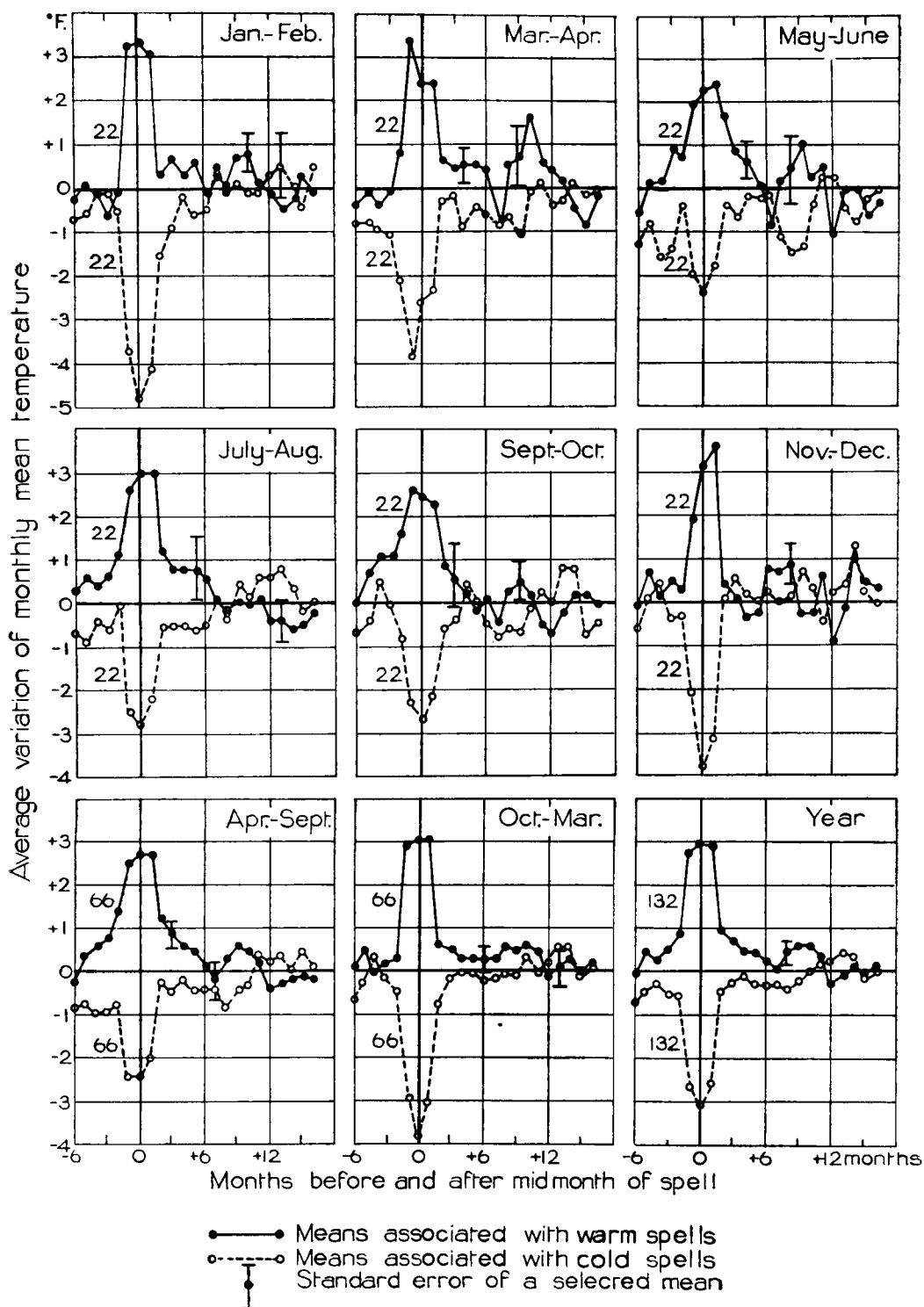
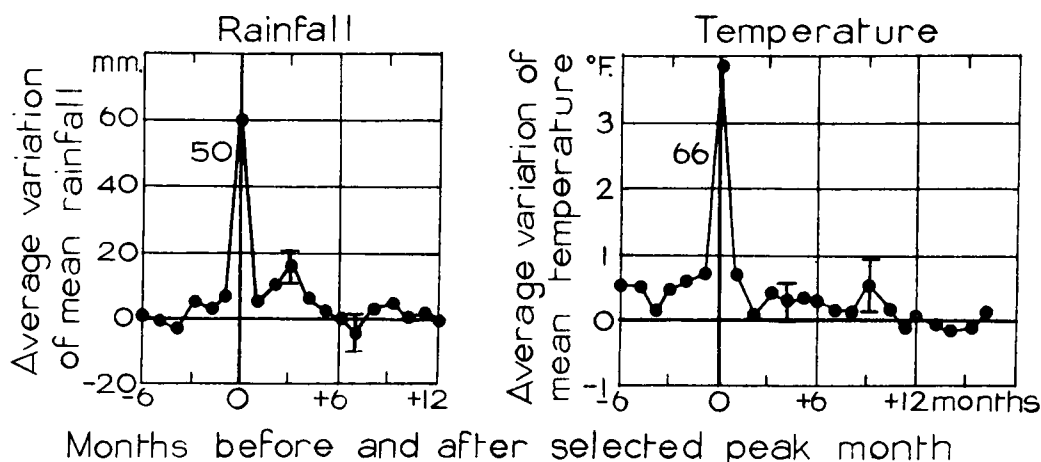


FIG. 2—AVERAGE VARIATION OF MONTHLY MEAN TEMPERATURE IN LONDON ASSOCIATED WITH WARM AND COLD SPELLS LASTING 3 MONTHS

Month "0" is the middle month of spell and the number of spells in each average is given against each curve.

warm summer months made from the data considered as a whole, the later years would be over represented as compared with the earlier years and the average progression of temperatures round the selected months would be biased in a certain way. Elimination of this effect could be achieved by using departures from some form of running means. This method was rejected as too laborious and approximate elimination of the effect of secular changes was achieved as follows. For the purpose of selection the temperature data were divided into three consecutive groups of 30 years and a final one of 23 years. For each group of consecutive three months, January–February–March, February–March–April, etc., the three highest and three lowest temperature aggregate months in each 30-yr. period (two highest and lowest in the final shorter period) were selected. The work thereafter progressed as already described for the rainfall data, except that it was subsequently considered advisable to extend the investigation beyond month +12 to month +16; subdivision into the four periods was not maintained beyond the initial selection. The plotted results are shown in Fig. 2 for the same groupings of months as before. The application of criteria of “suitable” stringency yielded more temperature than rainfall cases, mainly because, as may be seen from the plotted results, monthly temperature characteristics are rather more persistent than those of rainfall.



Standard error of a selected mean

FIG. 3—AVERAGE VARIATION OF MONTHLY MEAN RAINFALL AND TEMPERATURE IN LONDON ASSOCIATED WITH WET MONTHS AND WARM MONTHS, APRIL–SEPTEMBER. Month “o” is the wet or warm month, and the number of wet or warm months in each average is given against each curve.

The conclusions drawn from Fig. 2 are as follows:

(a) Warm and cold spells, as here defined, have a definite tendency to follow months of the same temperature characteristic as the type of spell concerned, and the occurrence of such spells has a systematic average effect of the same sense in subsequent months. The magnitude of the effect is larger with “summer” than with “winter” spells. The indications—hardly amounting to proof—are that the after-effect lasts as long as 8 or 9 months. This period is so surprisingly long, and the apparent rate of decrease of the effect so slow, that

it can hardly be accepted without clearer proof than available data are yet able to provide.

(b) Following the after-effect mentioned above, the long-period average remains in all months the most probable value; the data were extended to month + 16 to confirm this.

**General.**—Attention has so far been confined to the effects associated with spells lasting at least three months, mainly because it is the longer-lived spells that give rise to the type of general comment referred to earlier. There is, however, no reason to doubt that the types of effect found have a more general application. This is confirmed by the results shown in Fig. 3 which refer to one-month spells of warmth and of wetness, obtained from a selection of the most conspicuous cases evenly distributed over the six months April to September; it is clear that the types of effect found with these one-month spells are similar to the corresponding effects found with the three-month spells.

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2. MARSHALL, W. A. L.; A century of London weather. London, 1952.

### UPPER WINDS IN THE SOUTH-EAST ASIA–WEST AUSTRALIA REGION

By B. RAMSEY

**Summary.**—A survey of upper winds centred along the meridian of  $110^{\circ}\text{E}$ . was carried out for the months of April, July and October 1953 and January 1954. This shows a well defined seasonal movement and change in the broad west and east flowing air streams in the area in the height range from 10,000 to 50,000 ft.

The strongest easterly flow was in summer, but, although winter westerlies were strong, the strongest westerlies coincided with the spring in each hemisphere. During the summer of each hemisphere the broad belt of easterlies was interrupted by a deep monsoon flow the SW. monsoon of India which extends over the South China Sea and occasionally the Philippines, and the westerly monsoon of Java and other Indonesian islands.

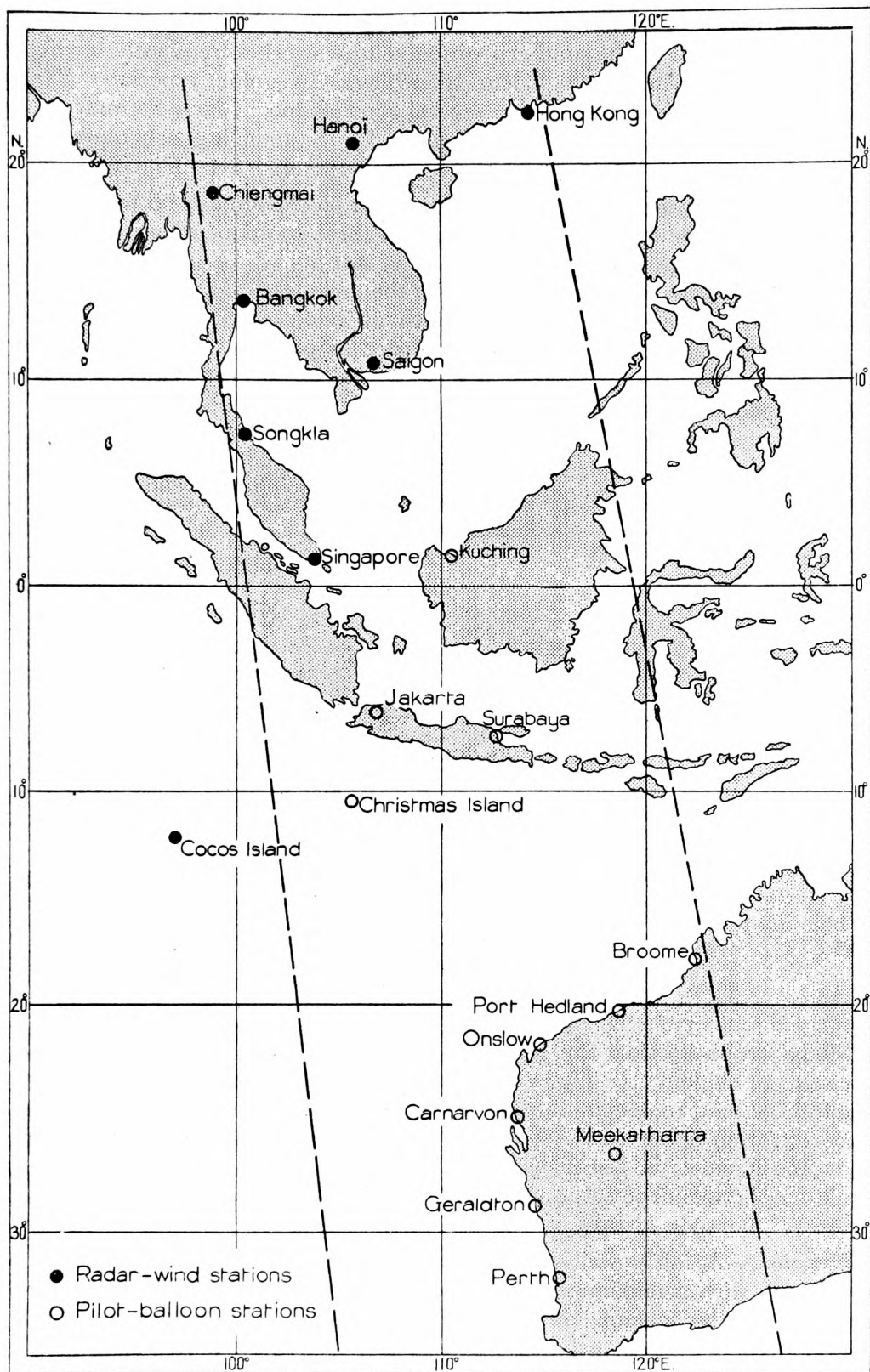
It is emphasized that this summary was derived from the single months only and was not averaged over a period of years.

**Period of investigation and data used.**—Upper winds were plotted as routine at the meteorological office, R.A.F. station, Changi, Singapore, twice daily up to 50,000 ft. During 1952–53 increased upper wind data became available from south-east Asian territories, and vertical cross-sections could be constructed showing zonal flow over the area from China to south-west Australia. On general grounds it was considered January and July could be regarded as typical monsoon months, and April and October as transitional months. Cross-sections of interzonal flow were therefore prepared for April, July and October 1953 and January 1954.

Radar winds were available during that period from Hong Kong, Hanoi, Saigon, Chiangmai (Thailand), Bangkok, Songkla (Malay–Thai border) and Singapore on most days. Winds were available up to 80,000 ft. at times, but the frequency was rather low above 50,000 ft. However, in extracting the data, days with poor representation at high levels were ignored, and although figures of the number of occasions per month are not available, there were about 20 days per month when there was good coverage to 50,000 ft.

Pilot-balloon reports were frequent from Western Australia and in good weather heights up to 60,000 ft. were attained. Ascents from Kuching (Sarawak), Christmas Island and Indonesia unfortunately rarely exceeded 20,000 ft. and, being pilot-balloon ascents, they tended to give a bias toward





**FIG. 1—SOUTH-EAST ASIA AND WEST AUSTRALIA**  
The approximate limits of the cross-sections are given by broken lines

good weather. This was especially true in Indonesia where cloud in the W. monsoon and haze in the southern winter south-easterlies frequently restricted ascents. Radar winds from Cocos Island were irregular, especially during January 1954, but in compensation several good ascents in early February 1954 were used. The area between the equator and 15°S., then, is poorly represented throughout, with winds above 20,000 ft. available only from Cocos Island.

For each observation, and at each 10,000-ft. level from 10,000 to 50,000 ft. the east-west component was computed and these components were averaged for the month. Fig. 1 shows the positions of stations whose data were used in the survey with the approximate limits of the cross-sections. Table I gives the average W. components for each month at each height and at each 10° latitude, westerly components being regarded as positive, in conformity with other investigations<sup>1,2</sup>. The table was derived directly from the cross-sections of Figs. 2-5.

TABLE I—MEAN WESTERLY COMPONENT ALONG 110°E.

	Height	Latitude					
		20°N.	10°N.	0°	10°S.	20°S.	30°S.
	ft.	<i>knots</i>					
January 1954	50,000	40	— 8	—42	—30	8	25
	40,000	55	—10	—20	—20	12	34
	30,000	55	—10	—15	— 5	12	30
	20,000	40	—12	— 9	0	0	20
	10,000	20	—12	0	8	— 3	5
April 1953	50,000	55	— 5	—10	12	33	35
	40,000	60	—11	—18	6	33	40
	30,000	52	— 9	—12	— 1	22	35
	20,000	35	— 8	— 9	0	11	28
	10,000	20	—12	— 3	6	— 3	12
July 1953	50,000	—50	—55	—38	—10	35	55
	40,000	—35	—30	—38	—10	40	82
	30,000	—20	—15	—25	— 2	40	56
	20,000	— 5	— 5	—15	0	28	44
	10,000	6	10	— 2	—12	9	25
October 1953	50,000	0	—35	—30	10	50	75
	40,000	6	—18	—25	10	55	88
	30,000	10	—10	—18	5	50	56
	20,000	5	— 8	—12	— 5	25	34
	10,000	5	— 8	— 3	—12	15	18

**Mean cross-section for January 1954.—Westerlies.**—Two main westerly streams are evident (see Fig. 2), the stronger being in the northern (winter) hemisphere. At 10,000 ft. the latter is continuous from about 17°N. and at 50,000 ft. from about 12°N. The westerlies in the southern hemisphere begin at 10,000 ft. at 24°S. but at 30,000 ft. at 12°S. There is another westerly, a weak one, between the equator and 14°S. which appears to be the upper limit of the W. monsoon of Java.

**Easterlies.**—A fairly well defined equatorial easterly stream is centred at about 2°S. with a maximum about 50,000 ft. At this time of year the inter-tropical convergence zone varies between 6° and 12°S. at this meridian.

**Mean cross-section for April 1953.—Westerlies.**—Again two main streams are evident (see Fig. 3). That of the northern hemisphere is a little stronger than in January with about the same geographical limits. The southern westerlies have increased as autumn advances, and although at 10,000 ft. they

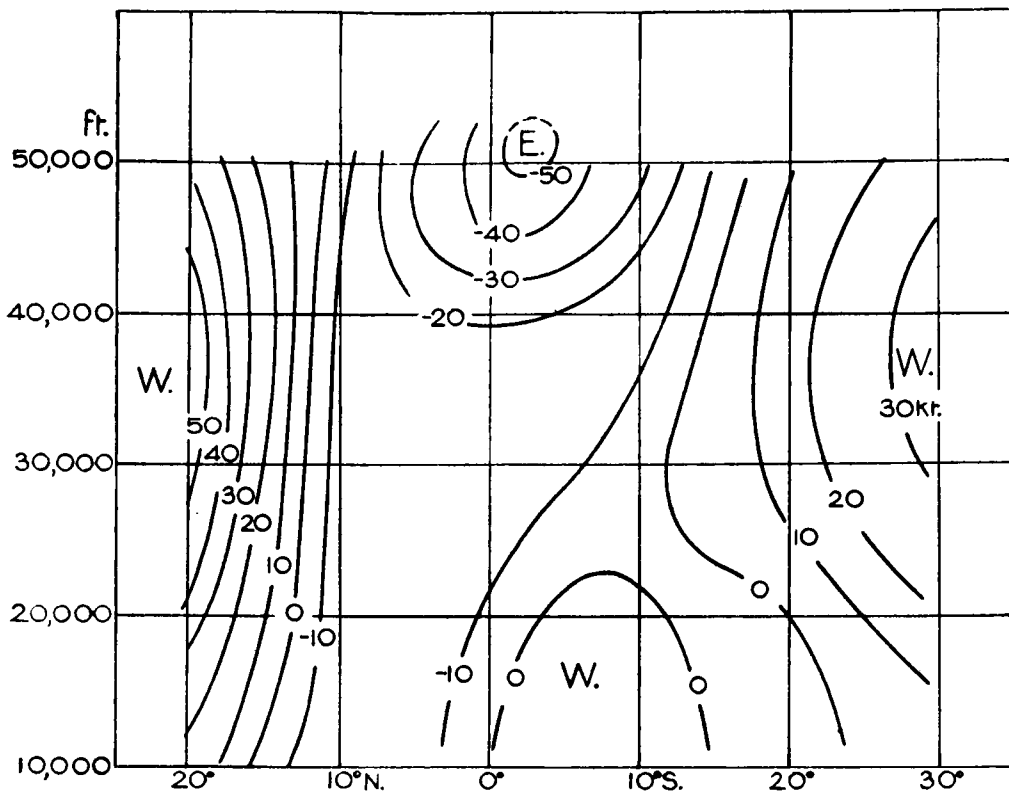


FIG. 2—MEAN CROSS-SECTION AT 110°E. FOR JANUARY 1954

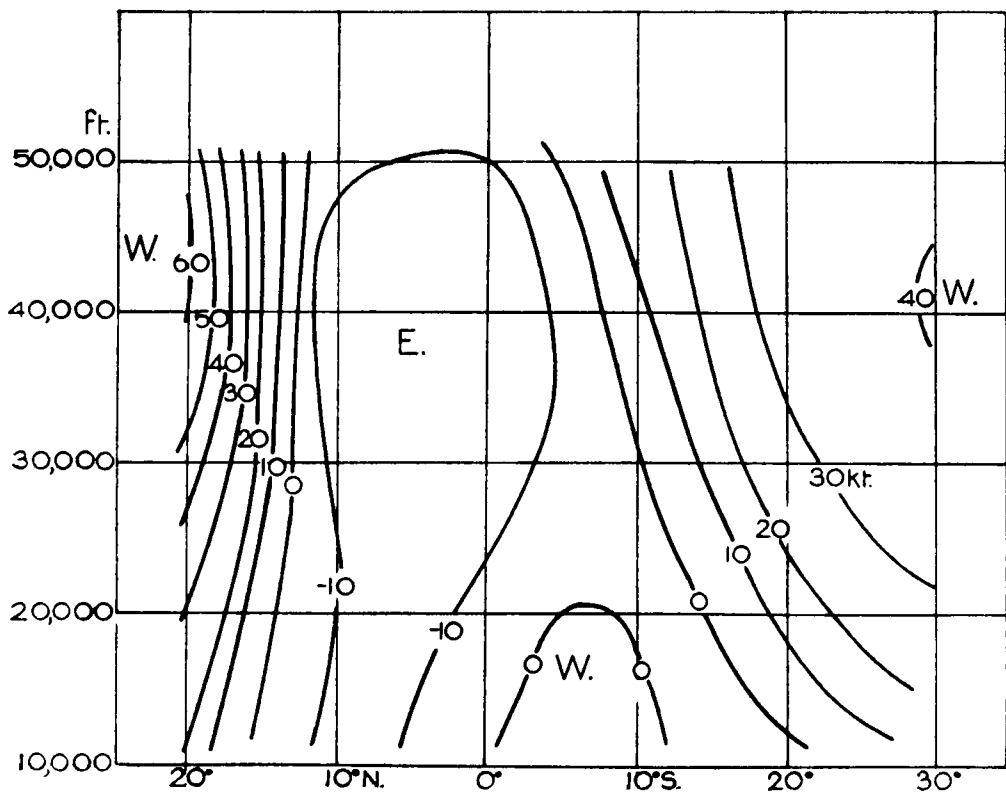


FIG. 3—MEAN CROSS-SECTION AT 110°E. FOR APRIL 1953

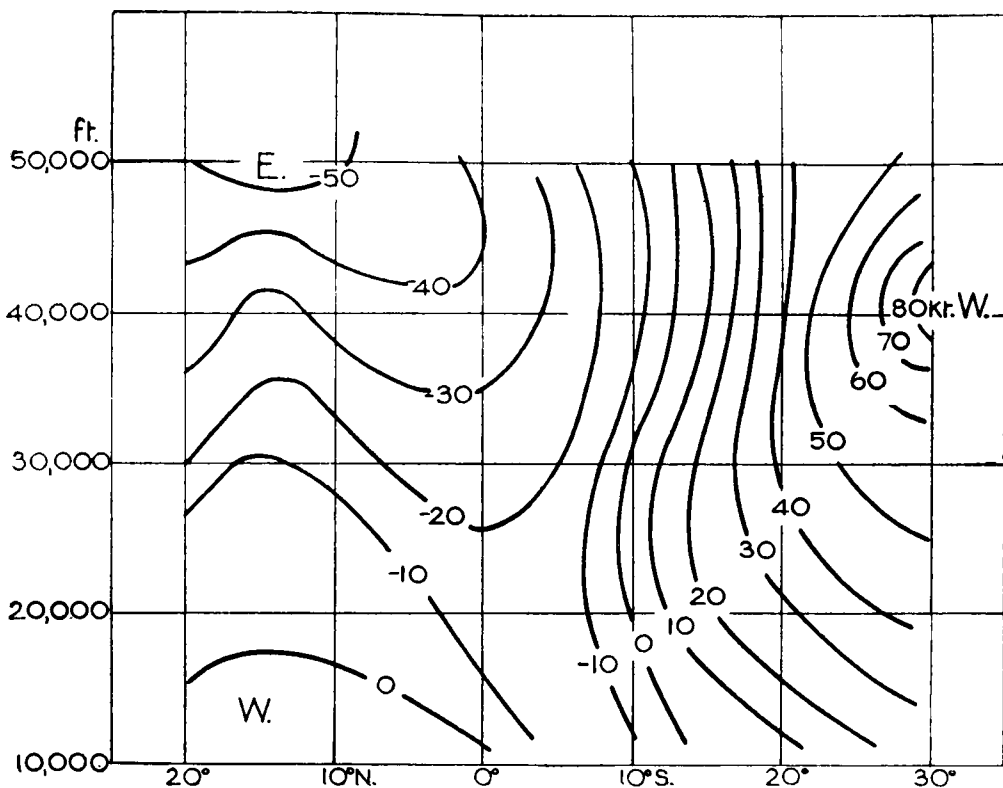


FIG. 4—MEAN CROSS-SECTION AT 110°E. FOR JULY 1953

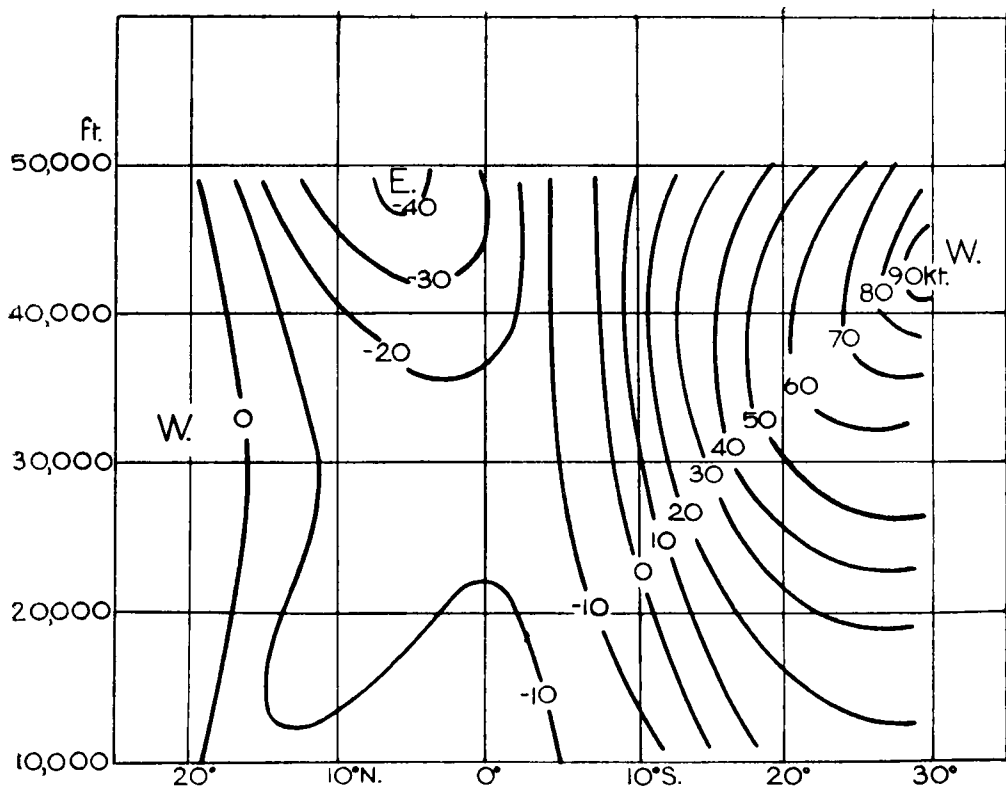


FIG. 5—MEAN CROSS-SECTION AT 110°E. FOR OCTOBER 1953

still appear at  $22^{\circ}\text{S}$ ., their northward limit at 50,000 ft. appears to be in the region of  $5^{\circ}\text{S}$ . However, this is in the area of scarcity of data. The weak remnant of the W. monsoon still occupies the area from  $1^{\circ}\text{S}$ . to  $12^{\circ}\text{S}$ . at 10,000 ft.

*Easterlies*.—The strong easterly flow of January has faded into a broad weak flow between the great westerlies of either hemisphere. The intertropical convergence zone still south of the equator at the beginning of April, begins to penetrate into Malaya from about the middle of the month.

**Mean cross-section for July 1953.**—*Westerlies*.—A great change has taken place since April. The only westerlies now in the northern hemisphere are below 17,000 ft. (see Fig. 4). These are the upper limit of the SW. monsoon which now occupies the whole northern hemisphere from the equator to  $20^{\circ}\text{N}$ . at the surface. The winter westerlies of the southern hemisphere have strengthened considerably. Their northern limit has retreated a little southward to  $12^{\circ}\text{S}$ . at 50,000 ft., but at 10,000 ft. they extend to  $15^{\circ}\text{S}$ .

*Easterlies*.—There is now a very broad deep easterly flow from about  $10^{\circ}\text{S}$ . to beyond  $20^{\circ}\text{N}$ . above the monsoon, and the maximum is in the region of  $15^{\circ}\text{N}$ . The intertropical convergence zone at this season has moved north into China.

**Mean cross-section for October 1953.**—*Westerlies*.—During the month the northern-hemisphere westerlies re-appear south of  $20^{\circ}\text{N}$ . and the upper limit of the SW. monsoon is no longer evident (see Fig. 5). The southern hemisphere “jet stream” shows a slight increase, with the advance of spring, as happened in the north in April. Again, as the cross-section applies to a single month only, no conclusions as to the significance of this increase can be drawn.

*Easterlies*.—A more restricted but still fairly strong flow, especially at high levels, has moved south from the July position to about  $5^{\circ}\text{N}$ . The intertropical convergence zone is now at about  $5^{\circ}\text{N}$ . at this time of year.

**Comparison with other meridional cross-sections.**—Gilchrist<sup>1</sup> and Gibbs<sup>2</sup> have produced similar cross-sections for other meridians, two of them being  $45^{\circ}\text{E}$ . and  $150^{\circ}\text{E}$ .

Comparing the above cross-sections with those of Gibbs for  $150^{\circ}\text{E}$ ., there is good general agreement. However, there is at  $150^{\circ}\text{E}$ . no parallel to the monsoon flow above 10,000 ft., and no well marked broad easterly flow in July. No increase in the southern westerlies is apparent in the spring, nor in April in the north. However, this apparent discrepancy may be removed with investigation into other years.

Gilchrist's cross-sections for  $45^{\circ}\text{E}$ ., which unfortunately extend to  $2^{\circ}\text{S}$ . (Nairobi) only, show similar trends, and they, too, are for single months only. In January 1954 at  $110^{\circ}\text{E}$ . westerlies and easterlies are both stronger than in 1951 at  $45^{\circ}\text{E}$ . In April the westerlies at  $110^{\circ}\text{E}$ . are much stronger, and there is little or no component from the east at  $45^{\circ}\text{E}$ . In July there is great similarity, with an even stronger easterly at  $45^{\circ}\text{E}$ . The westerly monsoon flow is evident at both meridians, but it is deeper at  $110^{\circ}\text{E}$ . Similar agreement is shown in October with lighter easterlies at  $45^{\circ}\text{E}$ . and westerlies re-appearing down to  $15^{\circ}\text{N}$ .

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1. GILCHRIST, A.; Winds between 300 and 100 mb. in the tropics and subtropics. *Met. Rep.*, London, 2, No. 16 (in the press).
2. GIBBS, W. J.; A comparison of hemispheric circulations with particular reference to the western Pacific. *Quart. J. R. met. Soc.*, London, 79, 1953, p. 121.

## OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

*The Annual Report of the Director of the Meteorological Office*, presented by the Meteorological Committee to the Secretary of State for Air, for the year April 1, 1954, to March 31, 1955.

The Report describes the activities of the Meteorological Office as the State Meteorological Service and includes a full account of the vigorous research programme which has been maintained.

Meteorological services have been provided for civil and military aviation, for shipping and directly for the general public by telephone, television, radio, and through the Press, and indirectly by special forecasts for electricity and gas undertakings, farmers, and River Board and road engineers.

Considerable progress in the study of numerical forecasting—the process whereby forecast pressure maps are produced by the use of an electronic computer—has been achieved, and a long series of carefully controlled trials of the possibility of increasing rainfall by cloud seeding has been undertaken. The Meteorological Research Flight has continued its high-altitude research and much effort has been directed at the problems which result from the increasing heights at which aircraft now operate.

The Report includes financial and staff details, and indicates the continued shortage of scientific staff and difficulties produced by the continuing high rate of turnover of assistants.

### GEOPHYSICAL MEMOIRS

No. 96—*The free atmosphere in the vicinity of fronts*. By J. S. Sawyer, M.A.

During the period 1950 to 1952 some 20 flights were made by aircraft of the Meteorological Research Flight from Farnborough in order to explore the structure of fronts. The results indicate the great complexity of the atmosphere in frontal regions. Although the observations confirm that a sloping baroclinic zone exists it is clear that no idealized frontal model can adequately represent an individual front. Small-scale irregularities of temperature are sufficient to prevent any clear delimitation of the frontal zone.

Some very dry air was often found in frontal regions in close juxtaposition to cloud and rain. Its presence can be adequately explained by large-scale air movements which are primarily horizontal. Cloud structure and turbulence in frontal regions were also observed.

## ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on October 19, 1955, the President, Dr. R. C. Sutcliffe, in the Chair, the papers read were all on the subject of rainfall.

*Lewis, W. A. and Watkins, L. H.—Investigation into the accuracy of four types of rainfall recorder\**

Messrs. W. A. Lewis and L. H. Watkins (Road Research Laboratory) described an investigation into the accuracy of four types of rainfall recorder. They required a rate-of-rainfall recorder for measuring high rates of rainfall in connexion with drainage design. The Meteorological Office standard total rainfall recorder was found unsuitable because the variations in rate did not stand out sufficiently clearly on the curve of total fall, and the periods, 1 min. or more, over which the Meteorological Office standard rate-of-rainfall recorder averaged its records were too long for their purposes. Two new recorders were designed by the

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\* *Quart. J. R. met. Soc., London*, **81**, 1955, p. 449.

speakers. One, the channel-flow recorder, was not successful. The other, now in use, records both total fall and rate of rainfall. The principle of the rate-of-rainfall part is the weighing of a cylinder through which the rain passes. A variable orifice at the foot opposes the flow so that a column of water builds up in the cylinder. The length of this column is steady so long as the rate of fall is steady, but if the rate changes the length of water column changes and the weighing mechanism moves to operate a pen in the usual way. Variations in rate lasting for only a few seconds can be measured. A number of records obtained from the instrument were shown. Queries raised in the discussion related to the difficulties of filtering solid matter without interfering with the flow of rain and the accuracy in very light rain. The authors described the filtering mechanism and said they were interested in the heavier rates of rainfall; small rates could be read from the gradient of the total-fall curve.

Turner, J. S.—*The salinity of rainfall as a function of drop size\**

The next paper was read by J. S. Turner of Sydney, Australia. He found that raindrops falling at Sydney and at a station 45 miles inland 2,880 ft. above M.S.L. from clouds extending above the freezing level and so presumably from the melting of ice crystals formed by the Bergeron process had a salinity in drops in any one fall of rain independent of the radius when the cloud base was low but proportional to (radius)<sup>-n</sup>, where *n* might be as high as 2.6, when the cloud base was high. He showed that this distribution could be quantitatively explained on the supposition that the salt content was collected below the cloud, collection of salt particles and evaporation of the drop both increasing the salinity, and inferred that the salt content played no essential part in the formation of the rain. On the other hand the salt content in raindrops falling at Hawaii from clouds with tops well below freezing level in which the primary condensation is believed to occur on salt nuclei had a minimum salinity in drops in the middle of the size range with appreciable increases in smaller and larger drops. The large drops were the first to fall, and he believed the large salinity was due to them having been formed on giant salt nuclei. The salinity of the small drops had values intermediate between those which would be obtained by supposing the raindrops were formed by coalescence of equally saline cloud particles and by supposing them formed on salt particles falling through a mass of pure water droplets or droplets formed on nuclei other than sea salt. The results suggest that if the primary process is condensation on salt nuclei the later growth of the drop takes place by collection of smaller droplets which are not pure water but have a mean salinity about equal to that in the final rain. The general result suggests that salt nuclei play an essential part in the formation of rain in "warm" clouds, but are not essential in the formation of rain from clouds extending above the freezing level. Observations of the salt content of cloud particles are needed for further progress.

Questions raised in the discussion related to whether the distribution in "warm" rain could be due to differential sweeping up of the drops, doubt whether measurement of sodium content alone, as was done in this work, to measure salt content was satisfactory in view of the known variations in the sodium:chlorine ratio in raindrops, and whether the method gave any indication of the mass of the nucleus.

D'Albe, E. M. Fournier, Lateef, A. M. A., Rasool, S. I. and Zaidi, I. H.—*The cloud-seeding trials in the central Punjab, July–September 1954†*.

Finally Mr. Ludlam read a paper on the cloud-seeding trials in the central Punjab in July–September 1954. These trials were made by spraying fine salt particles into the air from two places, it being believed that showers in the monsoon period in this area fell mainly from clouds whose tops did not reach freezing level and so were entirely produced by condensation on hygroscopic particles. Samples showed the surface air in the Punjab contained 5–10 hygroscopic particles per cubic metre of a mass exceeding the critical one of 10<sup>-9</sup> gm., and it was hoped by dispersal of salt particles to at least double this; 5 × 10<sup>9</sup> particles ground to the right size were dispersed per second. It was found that the rainfall in a down-wind sector of 100 Km. radius comprising 72 per cent. of the wind directions was significantly higher than in other areas round the seeding points, various combinations of the logarithms of the ratios of area rainfalls being used to establish this. Rainfall in the sector mentioned was about normal for the season and in the others below normal. In the course of the discussion it was asked if the clouds were deep enough for a chain reaction to be set in motion to which the reply was "no"; it was stated there were no orographic effects. It was pointed out that it would have been advisable to deal separately with each day, and state rainfalls along the trajectory from the point of seeding in relation to other areas to eliminate possible natural fluctuation in rainfall over the sector believed to have been seeded; and that it would be desirable to measure the nucleus content of the air in the cloud.

## ERRATA

October 1955, PAGE 300, line 34; after "h the height" insert "and d the diameter".

November 1955, PAGE 345; interchange the diagrams without altering the captions or figure numbers

\* *Quart. J. R. met. Soc., London*, **81**, 1955, p. 418.

† *Quart. J. R. met. Soc., London*, **81**, 1955, p. 574.

## LETTERS TO THE EDITOR

### Effect of a wind-break on the speed and direction of wind

One or two statements in Mr. Lawrence's interesting re-analysis of the Manby wind-screen data in the August *Meteorological Magazine* invite further comment.

In the first place, his consideration of the effects of thermal stability on the efficiency of protection involves a procedure which is surely unsound. The velocity-profile formulae apply to flow over surfaces with small roughness elements and in conditions when a "steady state" in respect of the interchange of momentum, appropriate to the surface roughness and the thermal stability of the air stream, has been achieved. Nor can the formulae be applied through, what are effectively, two distinct fields of flow—that above the surface of separation, and that below, i.e. in the turbulent wake. In any event field evidence suggests that the protective efficiency of a barrier is less with an unstable turbulent stream than with a stable one—although the differences are usually of "second-order" in magnitude. Physically it is reasonable to suppose that the more rapid vertical interchange of "eddies" in unstable conditions compared with that in stable conditions results in the incident flow being re-established nearer the barrier. This argument is frequently used to reconcile results obtained from models subjected to the steady flow in the wind tunnel and those for the actual barriers placed in the naturally turbulent wind. Again the re-establishment of a velocity profile can be used as a means of defining the extent of the "zone of influence" of a barrier.

Secondly, presumably, we are to assume from the lowest diagram in Fig. 2 that the flow is symmetrical about the centre line—implying an equal net mass flow from each of the ends converging towards the centre (but below  $0.7H$  according to the statement on p. 248). This, it appears, can very easily be disturbed since if the incident direction deviates by  $5^\circ$  from the normal (strictly apparently  $2\frac{1}{2}$ – $7\frac{1}{2}^\circ$ ) the direction of mass flow is parallel to the barrier and in one sense only. In view of the range of variation in direction of the natural wind, it would seem that in practice there would be a series of pulses or surges alternately from either end, and that over an extended period (say 30 min.) the net mass flow parallel to the barrier would tend to zero when the mean incident direction over the same period was normal to the barrier. This is not the place to raise the difficult problem of the measurement of air flow in the open, but Mr. Lawrence may care to comment on the specific point suggested by his diagrams.

R. W. GLOYNE

*Edinburgh, September 1, 1955*

[Regarding the first point in the above letter, Mr. Gloyne appears to have misunderstood the procedure. Sutton's formulae have been applied only to the free atmosphere and not to the disturbed air around the wind-break. Also, the "shelter" isopleths are not intended to represent any "efficiency of protection" under each type of lapse rate as it occurs naturally in the atmosphere. Unfortunately, the data available did not permit this, as no temperature ascents were made.

As far as his second point is concerned, the large area of "variable wind direction" when the wind is normal or nearly normal to the barrier, is sufficient testimony to the occurrence of "pulses and surges". The convergence



immediately behind the barrier is presumably associated with a "suction effect" which balances the "down-draught" further down stream behind the barrier.—E. N. LAWRENCE].

### **Lunar rainbow**

A lunar rainbow was seen by Mr. W. Duncan, auxiliary observer at Glenlivet at 2040 G.M.T. on October 3. The bow, which was complete, was faintly coloured, yellow and green being predominant. At the time the visibility was six miles in slight rain. There were seven oktas of cumulus and cumulonimbus cloud, patches of nimbostratus at 1,800 ft. being the lowest clouds.

P. E. PHILLIPS

*Pitreavie, Fife, October 6, 1955*

## **NOTES AND NEWS**

### **The sunny weather of July 1955**

Except for the first three days high pressure persisted throughout July extending from the Azores across the British Isles to the region of Scandinavia. For much of the month the weather over England and Wales followed the same pattern day after day; easterly or north-easterly winds brought cloud inland at night, but this cleared from most areas during the morning to give fine sunny days. As this cloud did not cross the Pennines and rarely penetrated far into the Midlands, sunshine totals were usually larger in the west of the country than in the east. Fairly frequent thunderstorms reduced the total amount of sunshine recorded during the month in the south Midlands and south and south-east England, and sunshine in the north of Scotland was reduced by weak frontal systems associated with small disturbances which, from time to time, passed north-eastward between Iceland and Scandinavia. Elsewhere the sunshine of July 1955 was outstanding. In south and east Scotland, north-west England, north and west Wales, Northern Ireland, the Republic of Ireland, and in parts of the Midlands there was more sunshine than during any previous July since records became available.

Much of southern Scotland had 100–150 hr. of sunshine in excess of the average. Renfrew, with sunshine records dating back to 1921, registered 291 hr. during the month, 56 hr. more than the previous highest July total in 1952. Eskdalemuir, with records since 1910, registered 40 hr. more than its previous best July total of 217 hr. in 1935. Glasgow's total of 292 hr. exceeded that of any July since their records began in 1880. Aberdeen, with a similar long period of sunshine records, enjoyed 263 hr., the most ever registered in July and 24 hr. more than during the July of the brilliantly fine summer of 1911. Leuchars, with observations since 1922, recorded 262 hr., 18 hr. more than their previous July record of 244 hr. in 1935.

At Southport, in north-west England, July 1955 was the sunniest of any month since observations began in 1896. The total of 329 hr. was approximately 65 per cent. of the total possible sunshine for the latitude, 135 hr. more than the average and 14 hr. above the previous monthly record set up in June 1940. An even higher total of 336 hr. was registered at Squires Gate, Blackpool, and this too was higher than all previous monthly sunshine totals available for Squires Gate since records were first taken there in 1942. Keswick with 294 hr.—more than twice the average amount—and Stonyhurst with

285 hr. each had more sunshine than in any other July since observations were first made in 1919 and 1881 respectively.

In Wales, the total of 295 hr. at Hawarden was the best for July since records began in 1923 and 50 hr. better than the previous highest in 1934. At Llandudno, with 332 hr., it was the sunniest month in their records which date back to 1909; the previous best monthly total was 304 hr. in June 1940. Holyhead with observations dating back to 1914 recorded 341 hr., 67 per cent. of the possible duration and an average of 11 hr. sunshine a day compared with the usual daily average of just under 6 hr. The total was 156 hr. above their July average and 86 hr. more than their previous best July total in 1934. There were 14 days during the month with more than 13 hr. sunshine.

In Northern Ireland, Aldergrove, with 274 hr., registered more sunshine than in any other July since their records began in 1923; this was 54 hr. above their previous highest July total in 1954 and 138 hr. more than their monthly average.

In the Republic of Ireland records at Birr Castle and Valentia date back to 1881. The total of 266 hr. at Birr Castle was 46 hr. better than their next best total for July in 1911. In spite of there being five days during the month with 3 hr. sunshine or less, Valentia registered 311 hr., 154 hr. above the average and 76 hr. more than the previous sunniest July in 1918.

Among the places in the west Midlands which had the sunniest July on record, Ross-on-Wye enjoyed 275 hr., 4 hr. more than their previous highest total for July in 1942; sunshine records were started there in 1880.

Of all these stations Southport and Holyhead are usually the most sunny with an average of nearly 6 hr. sunshine daily in July—1955 totals were 184 and 178 per cent. of their averages; the least sunny are Eskdalemuir and Keswick with a daily average of sunshine of just below and just above  $4\frac{1}{2}$  hr.—the totals for July 1955 were 187 and 204 per cent. of the average respectively. Most of the stations quoted recorded more than 180 per cent. of their July average.

At Southport, Squires Gate and Llandudno, July 1955 was the sunniest month ever recorded and no station mentioned above had ever before recorded so much sunshine in July though in some cases observations cover a period of more than 70 years.

R. E. BOOTH

### **Bibliography on the history of terrestrial magnetism**

The late Dr. A. Crichton Mitchell published in *Terrestrial Magnetism and Atmospheric Electricity* a series of articles entitled "Chapters in the history of terrestrial magnetism"\* . His daughter has now presented to the Edinburgh Meteorological Office, papers which show that Dr. Mitchell had planned a more extensive work on this subject. The papers consist of a card index bibliography of almost 10,000 cards and a considerable volume of Dr. Mitchell's notes. These notes are not in a state which permits easy editing for publication, but they would undoubtedly be valuable to a research worker on the history of terrestrial magnetism. They can be consulted by arrangement with the Superintendent of the Meteorological Office, 26 Palmerston Place, Edinburgh.

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\* *Terr. Magn. atmos. Elect.*, Baltimore, **37**, 1932, p. 105, **42**, 1937, p. 241, **44**, 1939, p. 77 and **51**, 1946, p. 323.

### **New units for upper air observations**

With effect from January 1, 1956, the Meteorological Office will use the degree Celsius for measuring temperature and geopotential metres for measuring height in all upper air observations. The new units will be used in the daily international exchange of upper air observations, in the *Daily aerological record* and in *Climatological summaries of upper air data*.

Contour lines and thickness lines on charts in the *Daily aerological record* and in broadcasts from the Central Forecasting Office will be given at 60 m. intervals. The interval for the tropopause will be 1,000 m.

Whenever, for special purposes, it is necessary to provide upper air observations with temperatures expressed in degrees Fahrenheit and heights in feet, this will be done.

The height of base of low cloud will continue to be measured and expressed in feet.

### **Fog patches at Tilbury**

The photographs facing p. 384 and p. 385 illustrate the nature of the fog of November 15-16, 1949. A deep depression passed eastwards across Scotland on November 12 reaching Denmark at 0000 on the 14th. The cold winds behind the depression swept over the whole country on the 14th and, as the depression entered the Baltic and began to fill up, first a ridge of high pressure and then a small anticyclone developed over the British Isles. The wind dropped rapidly to calm over south-east England and, with clear skies, fog formed over the London area during the evening, the visibility falling to 100 yd. at London Airport at midnight. There were local and temporary clearances during the late morning and afternoon of the 15th, and when these pictures were taken over Tilbury about 1000 the sky could be seen through the fog in many parts. The fog formed again during the late afternoon and finally dispersed on the afternoon of the 16th. By this time a large anticyclone had developed over Scandinavia and the Baltic Sea.

### **REVIEWS**

*Lake Eyre, South Australia: The great flooding of 1949-50.* Report of the Lake Eyre Committee. 9½ in. × 7 in., *Illus.*, pp. xii + 75. Royal Geographical Society of Australasia, South Australian Branch, Adelaide. Price: £A1 1s.

Several articles have already appeared dealing with various aspects of the filling of Lake Eyre in 1949-50 and of the subsequent drying up which lasted until the end of 1952. Here is a comprehensive report which, with the aid of references to previous articles and to earlier literature, provides a compact guide to all that is known about the "lake".

Beginning with the explorations of E. J. Eyre in 1840, investigations spread over more than a century, including the use of aircraft since 1922, had led to opinions that Lake Eyre rarely contained much water and would probably never fill again. It was known that in recent decades the lower reaches of one of the main potential feeders, the Cooper, had become blocked by wind-formed sand ridges, and there were strong suspicions that sporadic flood flows down the creeks were inadequate to counteract continuing dessication in the lake area. But flood waters began to pour into Lake Eyre North during the first half of 1949, the sand hills across the Cooper were reported to be breached in June,

and at the beginning of November observation from the air established that the mouth of the Cooper was discharging, with water from it already joining the then main body which had entered the lake from the Warburton. The Cooper was flowing at its strongest in August 1950, and by the end of September Lake Eyre North, covering an estimated area of rather more than 3,000 square miles, was completely full. Lake Eyre South, with an estimated area of little more than 500 square miles, is joined to the main lake by a slightly raised channel and did not fill.

The occurrence aroused much interest, not least one suspects, because of a persistent reluctance to accept conclusions that the region is all but useless and incapable of economic development beyond the maintenance of a sparse pastoral population. The scientific activities of the specially formed Lake Eyre Committee were accompanied by the less scientific resurrection of schemes for irrigation, or for joining the lake to Spencer Gulf by means of a canal 250 miles long, which would keep an enlarged lake of about 5,000 square miles permanently full, and perhaps transform the climate of the area. No such scheme receives any encouragement from the Committee's report. As for possible modifications of the climate, the discussion of the drying up of 1951-52 includes the remark, "It is interesting to note that the high evaporation had virtually no effect on the climate of the surrounding country, for this was to suffer a drought even while the lake evaporated fast into the dry continental air." A land expedition to the shores of the drying lake in the summer of 1951-52 found the humid heat almost intolerable: "to everyone's relief the next day, December 7, dawned cloudy and it proved rather cooler. (The maximum measured at the lake was  $100.5^{\circ}\text{F.}$ )". On some days any form of activity was out of the question during the period 10.30 a.m. to 6.30 p.m. and "the enervated party could do little work even after the sun had set". It is impossible to escape the conclusion that even if there was a modification of some of the elements of climate, due to the presence of the large area of water, there was no appreciable improvement in terms of human comfort.

The main appeal of the report is to the hydrologist. For instance, the description of the "Channel Country" of Cooper's Creek, south of Windorah, Queensland, presents a picture of a river system in reverse. The main creek in flood does not spread laterally as the flood rises, but breaks up into several smaller channels, which in turn branch out into a multiplicity of distributaries, until eventually (with only moderate flood) the final streamlets disappear into the dry ground. The analysis of the rainfall of 1949-50 shows the sequence of events, with heavy rainfall in one part of the drainage system, followed after an interval by heavy rainfall in another part, which so modified ground moisture conditions that very high floods reached Lake Eyre without losing themselves, or suffering great reduction, in the Channel Country. It is apparent, without giving further details, that this was a very special case in the hydrology of flood discharges.

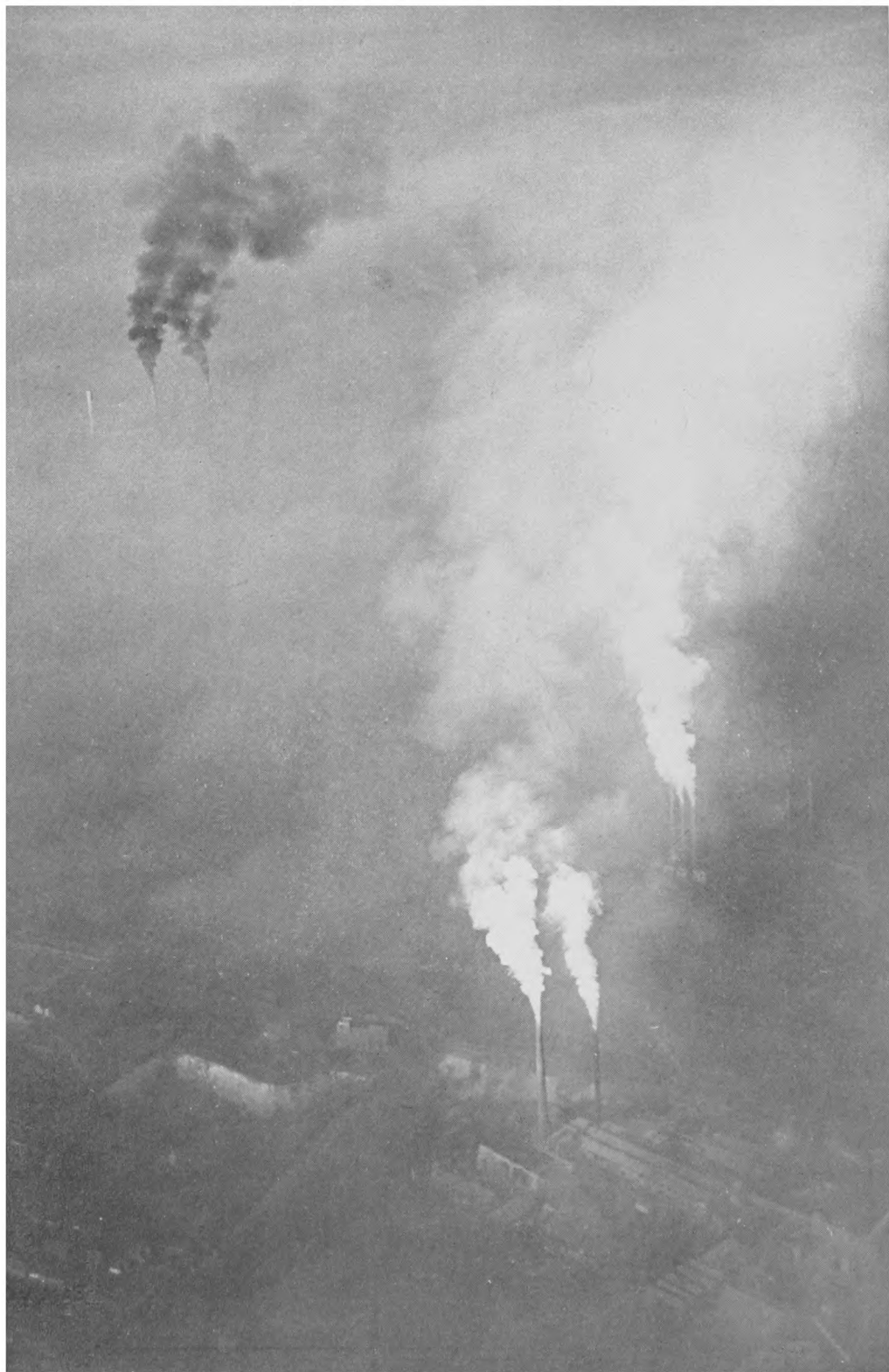
A short account is given of a partial filling and subsequent drying of Lake Eyre North in 1953, and a brief mention of yet another filling, as the report was going to press, in March 1955, in which it appears that Lake Eyre South filled independently and probably contributed to the flood in Lake Eyre North. There seem to be interesting new features in this latest flood, and perhaps we shall hear more of Lake Eyre in the near future.



*Photograph by Mirrorpic*

**FOG PATCHES AT TILBURY, NOVEMBER 15, 1949**  
(see p. 383)

*To face p. 385]*



*Photograph by Mirrornpic*

FOG PATCHES AT TILBURY, NOVEMBER 15, 1949  
(see p. 383)

Meanwhile the sections of the report which are potentially of the greatest general values are those dealing with evaporation, and it is a great pity that the observations were severely restricted by the difficulties which the land expeditions had to face. The data could have been of very wide application because of their value as a check, for extreme conditions, on theoretical estimates, and it is to be hoped, if the 1955 filling has proved to be as complete as the early reports suggested, that further expeditions will be organized and attempts made to obtain fuller data. In the circumstances the close agreement between observed and estimated values obtained by Penman, who took part in the December 1951 expedition, must be regarded as surprising rather than gratifying. In his own contribution to this report he says that "the agreement . . . cannot be regarded as a confirmation of the theoretical basis". Nevertheless the results are worth quoting. Three estimates of the total evaporation for the year 1951 were obtained:—

By C. Warren Bonython	...	77 in.
By H. L. Penman	...	86 in.
From lake-level observations	...	94 in.

The first two estimates were made by extrapolating from two brief periods of observation at the lake—the first by reconstructing monthly mean values of the elements used in the computation for the lake area by reference to the data obtained at the nearest climatological stations (50–100 miles away); the second by calculating evaporation at the lake for the two periods of observation, and then fitting to these two values the seasonal cycle observed at the nearest station with a standard evaporation pan (200 miles away). Optimistic as these methods may appear to be, it does not follow that the third estimate is necessarily the most accurate (it is given elsewhere in the report as 7.5 ft.). This "measured" value neglects the possibility of seepage from or into the lake, and though this was carefully judged to be negligible it was not proved beyond doubt to be small. Also the measurements of lake level were subject to some error because of seiches which caused fluctuations from day to day. An overnight fall of 15 in. was observed in February 1951 on the cessation of a strong northerly wind; a rapid rise of at least 2 ft. (maximum not observed) occurred with a north-westerly squall in December 1951; and in the same month, a few days later, there was a "spectacular fall" of 20 in. produced by a strong S. wind. Although the relatively calm periods were used to estimate the mean static level, there is some doubt, in particular, about the December 1951 value. Perhaps the best that can be said is that open-water evaporation at Lake Eyre is now known to the nearest foot, and, making a small deduction from the 1951 value to correct to the normal year, it is probably nearer to 7 ft. than to 8 ft. which was roughly the value previously assumed.

A. BLEASDALE

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*Klima und Bioklima von Wien. I Teil. Ergebnisse der langjährigen Messreihen an der Zentralanstalt für Meteorologie und Geodynamik in Wien, Hohe Warte.* By Prof. Dr. F. Steinhauser, Dr. O. Eckel and Dr. F. Sauberer. 9½ in. × 6½ in., pp. 120, *Illus.*, Verlag: Österr. Gesellschaft für Meteorologie, Wien XIX, 1955.

This is the first part to be published of a climatology of Vienna for use in town planning, building design and industry.

The observations summarized were made at three sites, two in the built-up city between 1775 and 1872 and since 1872 at one in a park area to the north-west. The elements covered are radiation (direct solar, sky, global, and long-wave radiation and daylight illumination), temperature, earth temperature, humidity and evaporation, total amount of cloud, fog, sunshine, precipitation, thunderstorms, wind, and air pressure. The temperature observations summarized are for the period 1775–1950, the radiation data are for 1938 to 1944, and the others for intermediate periods, precipitation being for 1851–1950.

The publication gives a great amount of information on means, extremes, diurnal and annual variations, frequencies of special periods, such as ice days, dates of earliest and last occurrence of snow in the year, highest gusts, and on combinations, such as frequencies of wind strength, and direction at low temperatures, of importance in building. Interesting combinations, frequencies of which were new to the reviewer, are those of sunless days with precipitation and the amount of sunshine on days of precipitation. The probability in winter that the sun will not shine on a day with precipitation is about  $\frac{1}{2}$  but in late summer it is only  $\frac{1}{20}$ .

While much information on rainfall is given there is none on frequencies of high rates of rainfall which are of great importance in drainage design; no other omissions were obvious to the reviewer. Tables of the individual monthly means of temperature, cloud amount, of amounts of rain and extremes of temperature are given in appendices. In view of the purpose of the work no application of the data to study of secular change was to be expected.

G. A. BULL

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*Climates in miniature.* By T. Bedford Franklin.  $8\frac{1}{2}$  in.  $\times$   $5\frac{1}{2}$  in., pp. 138, *Illus.*, Faber and Faber Ltd., London, 1955. Price: 15s.

This is an attractive and useful addition to the relatively small number of books devoted to exploring and explaining the complicated interaction between plants and animals and their climatological environment. The author presupposes some familiarity on the part of the reader with physical concepts and techniques, and obviously brings to his task considerable scientific knowledge, and, equally welcome, a wealth of results from personal observation and experiment.

The first four chapters, respectively entitled "What a microclimate is" "Warmth and hibernation", "Cranberry marshes", and "Soils", are mainly introductory. In Chapter III some of the problems encountered in the subject are illustrated from the classical work of H. J. Cox on methods of reducing frost damage on plantations of cranberries in Wisconsin, whilst in Chapter IV special attention is paid to soil temperature—a topic dealt with more formally in Chapter V "Taking earth temperatures". Chapter VI, "What happens to the rain", introduces the subject of evaporation, and in Chapter VII, "Nature's way", some interactions between soil temperature, soil moisture and soil cover are discussed with special reference to the freezing of soil.

Chapter VIII, "Frost", includes information on artificial methods of reducing damage and some empirical forecasting rules. The following chapter, "Air temperatures", covers considerable ground and contains interesting remarks on temperatures in walled gardens.



Chapter X, "Humidity and dew", includes some of the author's instrumental measurements of dew deposit, and first-hand observations are also quoted in Chapter XI, "Wind and shelter", although the experimental set-up used by the author needs careful noting before the result illustrated in Fig. 9 (p. 99) can be assessed. Chapter XII, "Light and shade", deals satisfactorily with a subject notoriously difficult to explain in simple terms.

The last three chapters, "Cloches and frames", "Microclimates on the farm", "Microclimates in the home", illustrate the application of principles and results mentioned earlier.

The author dismisses the Rothamsted work on evaporation rather too hastily in Chapter VI, and in the course of estimating "transpiration ratios" (i.e. mass of water needed to produce unit mass of dry matter) implies that the water loss from an area covered with vegetation can be separated into two easily computed components: that lost from the soil and the surface of the vegetation and that transpired by the vegetation; the consistently low values he finds for the above ratio may arise from these assumptions. Regarding frost risk—does it follow (p. 29) that if one soil plot experiences a greater diurnal temperature range than a neighbouring one then the frost risk in the former case is the smaller? Snow does not "disobey the law that a good reflector is a poor radiator" (p. 62), and, contrary to the statement on p. 78, "air frost" as well as "ground frost" are recorded officially (although only the latter is published in the *Monthly Weather Report*). The statement on p. 84 that 92 per cent. of bright sunshine is used in transpiring water is incorrect—the correct estimate is given on p. 103. It might also have been wise to mention explicitly the distinctions between photosynthesis and photoperiodism (pp. 107–109).

There are other points one could criticize, but none of these make the book less worth reading and purchasing—one feels impelled to try and emulate the author's enthusiasm and ingenuity; for a start some of the empirical rules on, for example, pp. 48–49, 61–62, 70–72, 76 might be tried out.

R. W. GLOYNE

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*Sun, sea and sky: Weather in our world and in our lives.* By Irving P. Krick and Roscoe Fleming. 8½ in. × 5½ in., pp. 248, *Illus.*, Victor Gollancz Ltd., London, 1955. Price: 16s.

This is a most unusual book, in which, according to the "blurb", "a distinguished meteorologist and a skilled writer combine . . . to present the drama of the weather". The meteorologist in the combination is well known to many as possessing unusual enthusiasms, and these combined with the literary style of an American journalist give the book its character.

The book is crammed full of similies and metaphors which are used to such an overbearing extent as to be a real burden to the reader, proving how wise is the use of the ordinary, formal style of writing used in scientific papers. Whole paragraphs of entirely unnecessary similies are to be found everywhere; sometimes even a whole page can be consumed without advancing the argument any further, while on a smaller scale even the better, simpler, paragraphs are marred by the use of pictorial but scientifically unnecessary adjectives. If all this is the work of a skilled writer then we must rejoice that so many scientists are unskilled.

From a scientific point of view the book is of very mixed quality, bearing too heavily the signs of meteorological eccentricity, but at the same time often showing real wisdom and learning. It begins with an account of the conversion of the earth's atmosphere from one of carbon dioxide into its present composition, and then there is a good account of the working of the earth's atmosphere, and how it transports heat and water, using the energy of the sun. Most of this is very good but there is a serious lapse on p. 47 where a very woolly and loose account is given of a theory that the heat absorbed in the ozone layer of the atmosphere drives the general circulation of the atmosphere. This is a theory that would require careful presentation to be acceptable, and it is doubtful whether even those most interested in ozone would accept it easily. From this we proceed to an account of the structure of clouds and depressions. This is followed by an account of the history of forecasting and of the latest developments, with special reference to the analogue technique in which Dr. Krick is very interested. Having regard to the limited acceptance of this method it would seem to be greatly over-emphasized.

Next, in Chapter V, the book gives an account of the ordinary weather systems of the atmosphere, and in Chapter VI the changes of the climate of the globe are reviewed. From this point, except for parts of the last chapter, the book degenerates into what is almost entirely an account of the activities of analogue forecasters and of modern rain-makers and their claimed successes; and in the reviewer's opinion the accounts are usually biased and misleading. There are some good parts, but these are few. There is a lot of politics.

The last chapter is devoted mainly to mankind's pollution of the air, rivers and sea and his consumption of the world's resources of clean water and fertile land. Perhaps because the reviewer agrees with the views expressed, these are rated very high, and although there is nothing very new it is always well to have it said.

The book by its style invites actual quotation, but two are specially selected. The first, from the chapter on atmosphere pollution (p. 227), because it ought to be read by many English people: "Most of the pollution is unnecessary and wasteful. Better ways of burning, more complete combustion, would for example give Britain an ample supply of coal in the amount she now digs from the ground, rather than the chronic shortage which she must supplement from abroad though she can hardly afford it. But her inertia, more than her poverty prevents reform." The second from p. 92—because many readers of the *Meteorological Magazine* will like it—"The ablest forecasters are humble men. . . ."

A. W. BREWER

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*The observer's book of weather.* By R. M. Lester. 5 $\frac{3}{4}$  in.  $\times$  3 $\frac{3}{4}$  in., pp. viii + 152, *Illus.*, Frederick Warne & Co. Ltd., 1955. Price: 5s.

This neat little volume is presumably intended to give the amateur weather observer some knowledge of the physical processes of the atmosphere and the problems confronting a forecaster. It is not possible to recommend it because the author has a most awkward style, the sequence of his thought is confused, and the uninformed reader may easily be misled at many points by implication if not by positive mis-statement. For example, referring to oxygen in the composition of the atmosphere, the author states: "This is a variable gas that

decreases with altitude. . . ." and follows this immediately by: "The other variable gas in the atmosphere is water vapour. . . ." Again, the description of fronts and of the formation of a frontal depression makes difficult reading, and the definition of a cold front, given in the glossary, is more than misleading. In fact, several of the definitions in the glossary are inaccurate. It is difficult at times to decide whether the author intends his statements to apply to the British Isles only or more generally. Indeed, in his chapter on "Weather lore" he appears to treat certain Biblical quotations on weather as if they applied to the British Isles. The book is well illustrated by numerous plates, some in colour. The cloud photographs are good and their captions in most cases accurate.

H. HEASTIE

### BOOKS RECEIVED

*Natural water and its use in S. Rhodesia.* Minister of Agriculture and Lands, Rhodesia. *Rhod. agric. J.*, Salisbury, 49, 1952, pp. 203-211, 272-279, 384-391, 50, 1953, pp. 54-67, 255-262, 486-490, 51, 1954, pp. 193-196, 478-488. 9½ in. × 6 in., *Illus.*

*Resumen de Labores, Año 1954.* No. 3, 10 in. × 7½ in., pp. 44, *Illus.* Universidad Mayor de San Andres, Laboratorio de Física Cósmica, La Paz, Bolivia, 1955.

### AWARDS

**The L. G. Groves Memorial Prize for Meteorology** has been awarded this year to Dr. F. J. Scrase, O.B.E., M.A., Sc.D., Senior Principal Scientific Officer, Meteorological Office. Dr. Scrase is a world authority on meteorological instrumentation and an inspiring leader of the Instrument Development Division of the Meteorological Office. As President of a Sub-Commission of the World Meteorological Organization Dr. Scrase has been in very large measure responsible for the new "Guide to International Meteorological Instrument Practice", a comprehensive work of reference. His recent personal research work includes further studies of turbulence in the upper atmosphere and an important theoretical investigation of the errors, due to radiation and lag, of radio-sondes. These studies are also closely related with practical problems of aviation and air navigation.

**The L. G. Groves Memorial Award for Meteorological Air Observers** has been awarded to Flight Lieutenant J. Formby, R.A.F.R.O. Since September 1952 Flt-Lt Formby has been engaged in carrying out the meteorological ascents which are performed daily from the R.A.F. station at Woodvale. He has made over 450 such flights and during one period he was called upon to make the ascent every day for five weeks. Throughout his period of service he has shown marked enthusiasm for this task and exceptional ability both as a pilot and as a meteorological observer. Flt-Lt Formby's keenness and devotion to duty have contributed much to the remarkable regularity with which these flights have been carried out at Woodvale.

### METEOROLOGICAL OFFICE NEWS

**Ocean weather ships.**—The following extracts are taken from reports of Masters of ocean weather ships:

*o.w.s. Weather Explorer.*—At station K in the Bay of Biscay, August 31–September 24, 1955:

"Weather on station was mainly very good, almost subtropical; the air temperature averaging 68°F. and sea temperature about 69°F. led to a considerable amount of sea bathing. Two small turtles which swam round the

ship caused considerable excitement to those of the ship's company who had never seen such a thing before."

The Meteorologist-in-Charge aboard o.w.s. *Weather Explorer* says, "The mean temperature was some twenty degrees higher than on our previous voyage and we were able to indulge in such recreations as swimming, sailing, sun-bathing and the indigenous form of cricket."

**o.w.s. *Weather Observer*.**—At station J, August 25–September 18, 1955:

The number of transatlantic aircraft to which navigational aids and meteorological information was given reached the very high total of 911.

The increasing use which is being made of weather ships by transatlantic aircraft at ocean station J, which is very near the great-circle track from London Airport to Gander, is indicated in the following table which shows the average per voyage of the number of aircraft to which assistance was given:—

1947 ...	30	1952 ...	321
1948 ...	185	1953 ...	348
1949 ...	237	1954 ...	417
1950 ...	235	1955 (to date)...	605
1951 ...	228		

**Social activities.**—In celebration of the Meteorological Office Centenary, the staff of the Central Forecasting Office held a very successful dinner and dance at the Leicester Arms Hotel, Luton, on October 25. Attendance, including wives and friends, was over 100, all branches and grades at the Central Forecasting Office being represented. Mr. S. P. Peters presided and introduced Dr. and Mrs. Sutcliffe as the guests of the evening. Dr. Sutcliffe gave a short historical survey of the Meteorological Office with special light-hearted references to what had been achieved since he joined the staff in 1927. The evening undoubtedly justified the faith of the organizers, and a desire that a similar function should be held before the next centenary was strong and unanimous.

**Sports activities.**—*Lawn Tennis.*—In the Air Ministry annual lawn tennis competition for 1955, Miss U. J. Murray won the Ladies' Singles Championship and Miss B. M. Edwards and Miss N. M. Edwards won the Ladies' Doubles Championship.

*Swimming.*—In the Air Ministry Swimming Championships held at the Chelsea Baths on November 2, the Meteorological Office gained first place in the Ladies' Relay and second place in the Men's Relay. In the Ladies' Championship Miss L. Carter and Miss G. A. Morgan were second and third respectively. Mr. J. V. Evling gained second place in both the Men's Free Style and Backstroke Championships and Mr. I. Ridgway was third in the Breaststroke Championship.

## WEATHER OF OCTOBER 1955

Pressure anomaly features over the northern hemisphere were remarkably nearly inverse to those in September 1955. In October there were negative departures all over northern North America culminating in a maximum anomaly of  $-11$  mb. over north-west Canada. This was associated with noteworthy deepening of the North Pacific depressions which spread in over Alaska and travelled across northern Canada. Pressure was also far below normal over Finland and Scandinavia, and eastern and central Europe, with anomalies of  $-9$  mb. near the White Sea. The monthly mean pressures were up to 6 mb. above normal between Iceland and South Greenland and the Azores anticyclone appeared weak, though these anomalies reflect an unsteady régime with considerable variability in the positions of the main centres of action in the Atlantic sector, especially in the second half of the month. The Siberian anticyclone was

intensely above normal along an axis in 50°N., whilst depressions travelled east near the Arctic coast.

Temperature was below normal over the Arctic Ocean and in Alaska. There were also smaller negative anomalies over the North Sea and western half of Europe and over north-easternmost Siberia. Eastern Europe, central and western Siberia, nearly all North America and Greenland were 1·4°C. warmer than normal.

The complex pattern of rainfall anomalies was chiefly remarkable for large areas of deficiencies over Alaska, north-west Canada and also the southern Rockies, moderate excesses of rain around the Baltic and North Sea and some great excesses in south-east Europe. There were again great excesses in northern and central India but deficiencies in East and West Pakistan.

In the British Isles the first week ended with widespread rain; during the second week, mainly anticyclonic conditions prevailed while the third was unusually wet in the south. Sunny weather with cold northerly winds predominated during the last week of the month.

There were outbreaks of thundery rain with sunny periods during the first few days as troughs slowly crossed the country, but on the 5th the first major depression of autumn developed off north-west Ireland; winds reached gale force on western coasts and rain was widespread, and in many places heavy, as the depression crossed southern Scotland to reach the North Sea on the 6th. Behind the depression, squally showers with strong north-westerly winds, which reached gale force at times, became general—a gust of 74 kt. was registered at Bidston Observatory. An anticyclone from the Azores moved to the Bay of Biscay on the 8th and later to southern Russia; warm Atlantic air spread over the British Isles accompanied by widespread rain and a general rise in temperature. Weather was fine and warm from the 9th to the 12th with light south-easterly winds and temperature often in the upper sixties, although widespread fog night and morning persisted all day in many places. An anticyclone became established over southern England from the 13th to the 15th; winds veered to a south-westerly direction with temperature generally somewhat lower than of late although it reached 70°F. at many places in eastern England on the 15th. An influx of polar air on the 16th caused a sharp and general fall of temperature of about 15°F.; at Rotherham, Yorkshire, the minimum temperature, which was 53°F. on the 15th, fell to 26°F. on the 16th, while London, with a maximum temperature of only 48°F. on the 16th, had its coldest day since March. On the 18th a depression deepened considerably as it moved southward from Iceland; it was centred over Ireland by midday the following day, afterwards turning north-east and 24 hr. later was over the northern North Sea. Rain was widespread over the British Isles for two days with exceptionally heavy falls in places; in 24 hr. Poole recorded more than 4 in. and Swanage and Bournemouth each had over 3 in., while Southampton registered 1½ in. on both the 18th and 19th. A cold front associated with the main depression moved slowly across the country with occasional rain on the 20th, but a wave on this front developed into an active depression which remained quasi-stationary over the southern North Sea during the 20th and 21st; northerly gales developed along the east coast with heavy and prolonged rainfall in south-east England; several stations again registered more than 2 in. in 24 hr. while at Hastings rain fell continuously for more than 30 hr. The last week of the month was mainly anticyclonic and became progressively colder as arctic air spread southwards. On the night of the 28th, 30th and 31st air frost occurred over much of the country.

It was one of the coldest Octobers of recent years with temperature more than 2°F. below normal on the East Anglian coast. The average night minimum temperature at Croydon was the lowest during October since 1926. The sudden and severe frosts on the night of the 15th-16th caught many growers by surprise and had quite an appreciable effect on the cut-flower trade. Sunshine was about the average, but rainfall was very variable; over much of the country, rainfall was well below the average but parts of south-east England had twice the normal amount. The dry conditions, especially in the north and west, made ploughing extremely difficult with the result that the acreage of winter sown corn to date is very small in places. Harvesting generally has been satisfactory although root crops have been lighter than usual owing to the dry summer.

The general character of the weather is shown by the following provisional figures.

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	73	17	-1·3	77	-5	121
Scotland ...	71	18	-1·2	108	0	101
Northern Ireland ...	68	26	-1·0	86	-2	112

# RAINFALL OF OCTOBER 1955

## Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.
<i>London</i>	Camden Square ...	2·79	106	<i>Glam.</i>	Cardiff, Penylan ...	2·26
<i>Kent</i>	Dover ... ..	6·17	159	<i>Pemb.</i>	Tenby ... ..	2·23
<i>"</i>	Edenbridge, Falconhurst	4·87	135	<i>Radnor</i>	Tyrmynydd ... ..	4·67
<i>Sussex</i>	Compton, Compton Ho.	3·93	86	<i>Mont.</i>	Lake Vyrnwy ... ..	3·62
<i>"</i>	Worthing, Beach Ho. Pk.	2·37	65	<i>Mer.</i>	Blaenau Festiniog ...	7·53
<i>Hants.</i>	St. Catherine's L'thouse	2·03	54	<i>"</i>	Aberdovey ... ..	2·98
<i>"</i>	Southampton (East Pk.)	4·67	119	<i>Carn.</i>	Llandudno ... ..	2·14
<i>"</i>	South Farnborough ...	4·17	130	<i>Angl.</i>	Llanerchymedd ...	1·83
<i>Herts.</i>	Harpenden, Rothamsted	3·05	97	<i>I. Man</i>	Douglas, Borough Cem.	3·25
<i>Bucks.</i>	Slough, Upton ... ..	3·90	139	<i>Wigtown</i>	Newton Stewart ...	2·30
<i>Oxford</i>	Oxford, Radcliffe ...	1·57	54	<i>Dumf.</i>	Dumfries, Crichton R.I.	3·47
<i>N'hants.</i>	Wellingboro' Swanspool	1·70	67	<i>"</i>	Eskdalemuir Obsy. ...	3·11
<i>Essex</i>	Southend, W. W. ...	4·10	164	<i>Roxb.</i>	Crailing... ..	1·92
<i>Suffolk</i>	Felixstowe ... ..	4·31	188	<i>Peebles</i>	Stobo Castle ... ..	2·81
<i>"</i>	Lowestoft Sec. School ...	4·41	158	<i>Berwick</i>	Marchmont House ...	2·15
<i>"</i>	Bury St. Ed., Westley H.	4·47	165	<i>E. Loth.</i>	North Berwick Gas Wks.	1·39
<i>Norfolk</i>	Sandringham Ho. Gdns.	2·56	84	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	1·44
<i>Wilts.</i>	Aldbourne ... ..	2·20	62	<i>Lanark</i>	Hamilton W. W., T'nhill	2·34
<i>Dorset</i>	Creech Grange... ..	5·69	112	<i>Ayr</i>	Prestwick ... ..	1·72
<i>"</i>	Beaminster, East St. ...	2·85	64	<i>"</i>	Glen Afton, Ayr San. ...	4·38
<i>Devon</i>	Teignmouth, Den Gdns.	2·08	54	<i>Renfrew</i>	Greenock, Prospect Hill	5·04
<i>"</i>	Ilfracombe ... ..	2·76	61	<i>Bute</i>	Rothsay, Arden Craig ...	4·37
<i>"</i>	Princetown ... ..	4·85	58	<i>Argyll</i>	Morven, Drimnin ...	8·31
<i>Cornwall</i>	Bude, School House ...	2·48	61	<i>"</i>	Poltalloch ... ..	5·68
<i>"</i>	Penzance ... ..	5·46	117	<i>"</i>	Inveraray Castle ...	8·73
<i>"</i>	St. Austell ... ..	4·21	80	<i>"</i>	Islay, Eallabus ... ..	6·59
<i>"</i>	Scilly, Tresco Abbey ...	3·41	89	<i>"</i>	Tiree ... ..	6·52
<i>Somerset</i>	Taunton ... ..	1·32	41	<i>Kinross</i>	Loch Leven Sluice ...	2·58
<i>Glos.</i>	Cirencester ... ..	1·63	48	<i>Fife</i>	Leuchars Airfield ...	1·69
<i>Salop</i>	Church Stretton ...	2·06	56	<i>Perth</i>	Loch Dhu ... ..	5·94
<i>"</i>	Shrewsbury, Monkmore	1·24	44	<i>"</i>	Crieff, Strathearn Hyd.	3·21
<i>Worcs.</i>	Malvern, Free Library...	1·32	44	<i>"</i>	Pitlochry, Fincastle ...	2·78
<i>Warwick</i>	Birmingham, Edgbaston	1·66	54	<i>Angus</i>	Montrose, Sunnyside ...	2·33
<i>Leics.</i>	Thornton Reservoir ...	1·51	54	<i>Aberd.</i>	Braemar ... ..	3·25
<i>Lincs.</i>	Boston, Skirbeck ... ..	1·65	60	<i>"</i>	Dyce, Craibstone ...	5·08
<i>"</i>	Skegness, Marine Gdns.	1·49	54	<i>"</i>	New Deer School House	6·35
<i>Notts.</i>	Mansfield, Carr Bank ...	1·67	55	<i>Moray</i>	Gordon Castle ... ..	5·07
<i>Derby</i>	Buxton, Terrace Slopes	4·03	82	<i>Nairn</i>	Nairn, Achareidh ...	3·62
<i>Ches.</i>	Bidston Observatory ...	2·01	61	<i>Inverness</i>	Loch Ness, Garthbeg ...	5·46
<i>"</i>	Manchester, Ringway...	2·11	68	<i>"</i>	Glenquoich ... ..	...
<i>Lancs.</i>	Stonyhurst College ...	3·65	81	<i>"</i>	Fort William, Teviot ...	8·80
<i>"</i>	Squires Gate ... ..	2·22	63	<i>"</i>	Skye, Broadford ... ..	11·55
<i>Yorks.</i>	Wakefield, Clarence Pk.	1·64	57	<i>"</i>	Skye, Duntuilim ... ..	7·64
<i>"</i>	Hull, Pearson Park ...	2·07	69	<i>R. &amp; C.</i>	Tain, Mayfield... ..	3·10
<i>"</i>	Felixkirk, Mt. St. John...	1·64	57	<i>"</i>	Inverbroom, Glackour...	7·00
<i>"</i>	York Museum ... ..	1·45	54	<i>"</i>	Achnashellach ... ..	12·81
<i>"</i>	Scarborough ... ..	2·72	87	<i>Suth.</i>	Lochinver, Bank Ho. ...	8·33
<i>"</i>	Middlesbrough... ..	1·49	50	<i>Caith.</i>	Wick Airfield ... ..	4·08
<i>"</i>	Baldersdale, Hury Res.	2·29	62	<i>Shetland</i>	Lerwick Observatory ...	4·78
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	1·40	55	<i>Ferm.</i>	Crom Castle ... ..	2·76
<i>"</i>	Bellingham, High Green	2·21	56	<i>Armagh</i>	Armagh Observatory ...	1·47
<i>"</i>	Lilburn Tower Gdns. ...	2·47	67	<i>Down</i>	Seaforde ... ..	2·39
<i>Cumb.</i>	Geltsdale ... ..	2·32	62	<i>Antrim</i>	Aldergrove Airfield ...	2·67
<i>"</i>	Keswick, High Hill ...	3·44	61	<i>"</i>	Ballymena, Harryville...	3·54
<i>"</i>	Ravenglass, The Grove ...	...	...	<i>L'derry</i>	Garvagh, Moneydig ...	3·89
<i>Mon.</i>	A'gavenny, Plás Derwen	2·48	54	<i>"</i>	Londonderry, Creggan	3·80
<i>Glam.</i>	Ystalyfera, Wern House	4·24	62	<i>Tyrone</i>	Omagh, Edenfel ... ..	2·92