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ESTIMATION OF THE PROBABILITIES OF GIVEN EXTREME MINIMUM TEMPERATURES

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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[1], 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[2] 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 $T_1, T_2, T_3 \ldots T_n$. By considering values of temperature a little greater than and a little less than that of the rth value of the series, we know[3] 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[4] defined by $r/(n+\frac{1}{2})$ or $(r-\frac{1}{2})/n$.

Gumbel curves[5] were plotted of the corresponding values of T and $y[=-\log_e \log_e (1/P)]$ for values of P (probability) equal to $\frac{1}{2}/n, 1\frac{1}{2}/n \ldots (n-\frac{1}{2})/n$. 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[6] 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 $T=\overline{T}-R\sigma_1$, where $\overline{T}$ is the average monthly extreme minimum temperature, R is given in Table I, and σ_1 and σ_2 are the standard deviations for 1-yr. and 2-yr. minima.

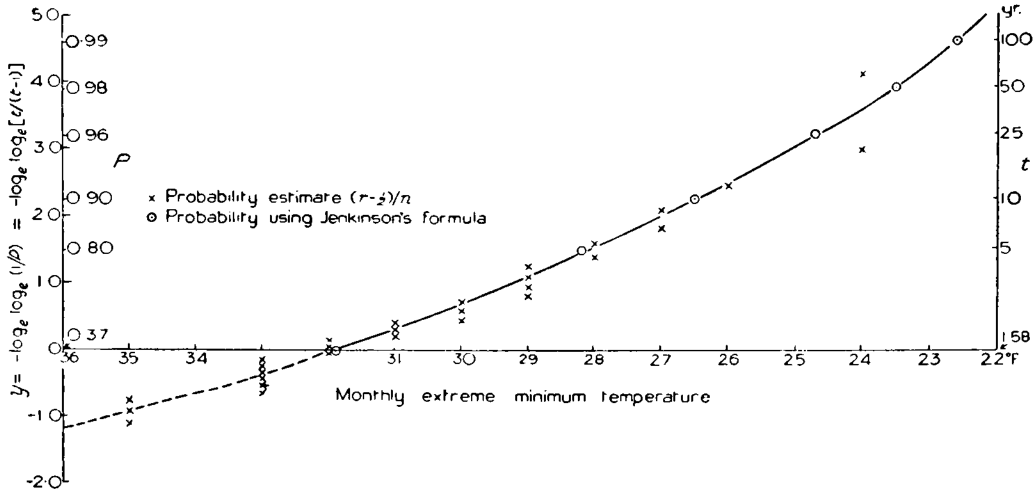


FIG. 1—PROBABILITY CURVE FOR MONTHLY EXTREME MINIMUM TEMPERATURES

Cambridge, May

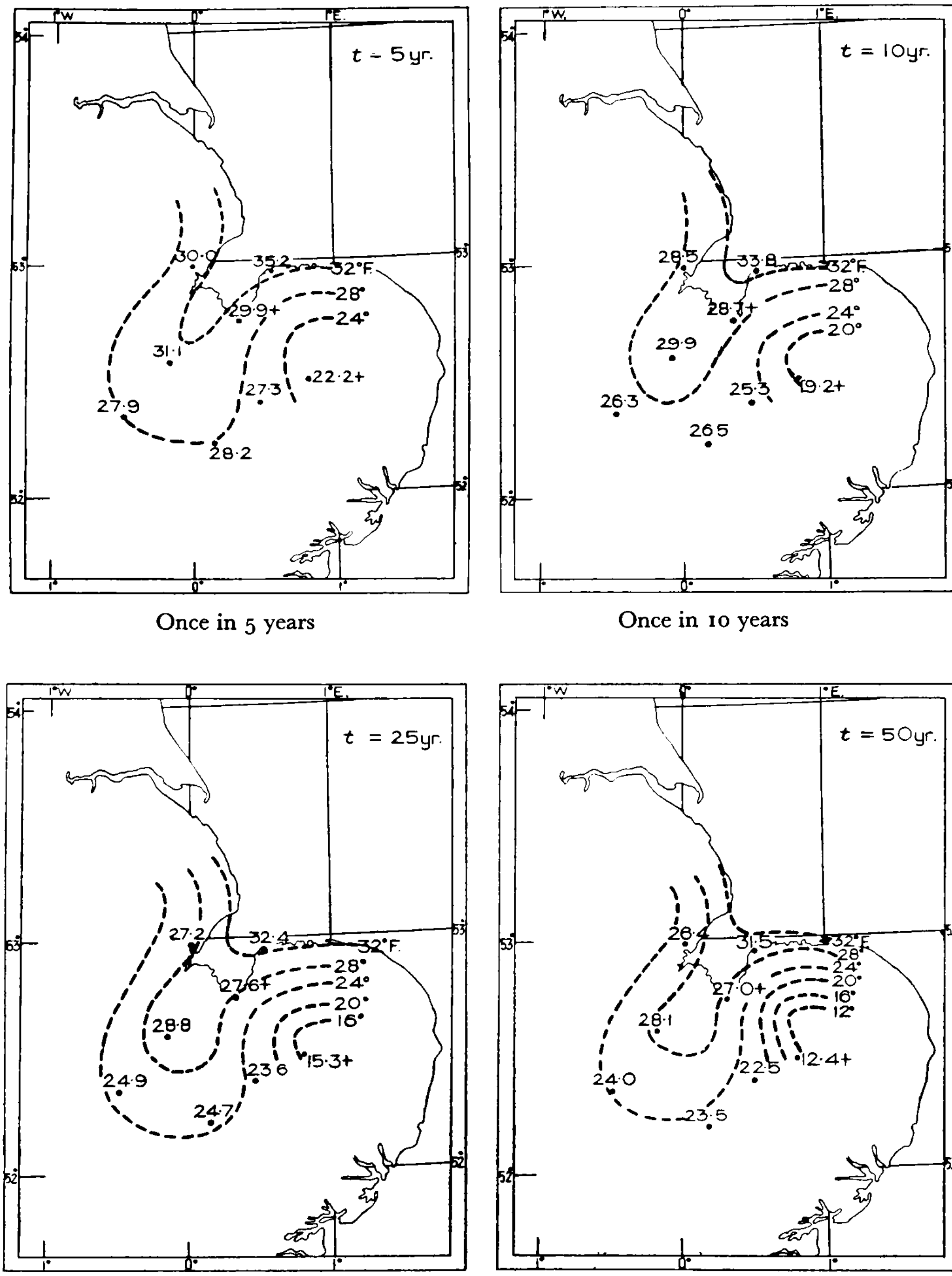
In calculating σ_2 the two-year periods are not necessarily consecutive. By taking all possible pairs of years, the value of T_1 (the highest minimum temperature in the series) would not enter into the calculation but it can be shown[6] that by considering an infinite number of similar but infinitesimally different samples, each minimum temperature is used $(2r-1)$ times. Thus each value of T_r is weighted by this factor when calculating σ_2 (see Appendix).

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

t / y / σ_1/σ_2	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[2]). 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

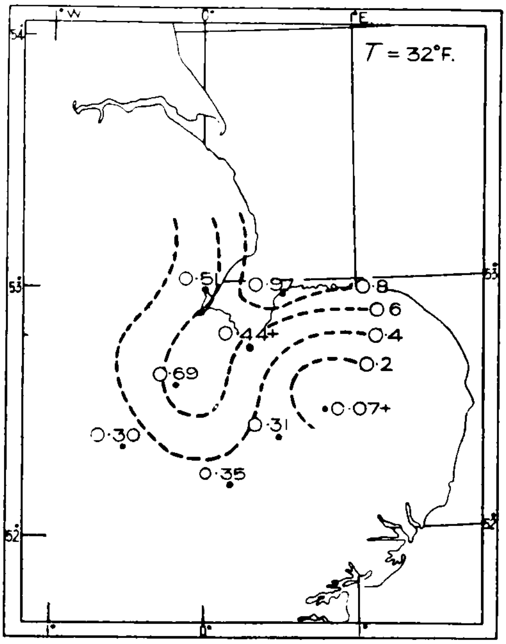
Once in 25 years

Once in 50 years

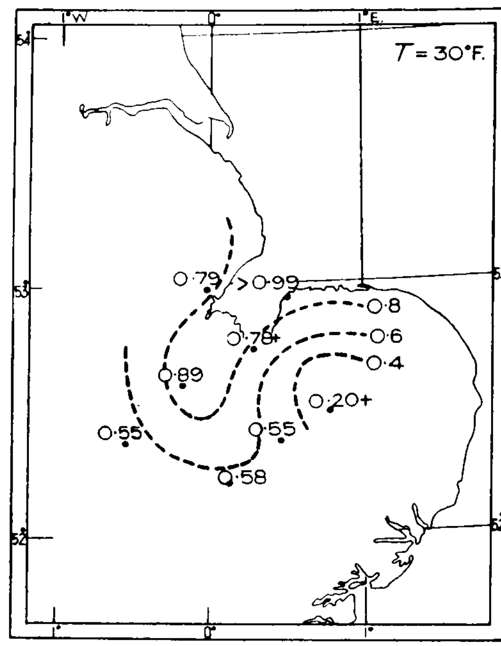
FIG. 2—PROBABLE EXTREME MONTHLY MINIMUM TEMPERATURES IN MAY

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.

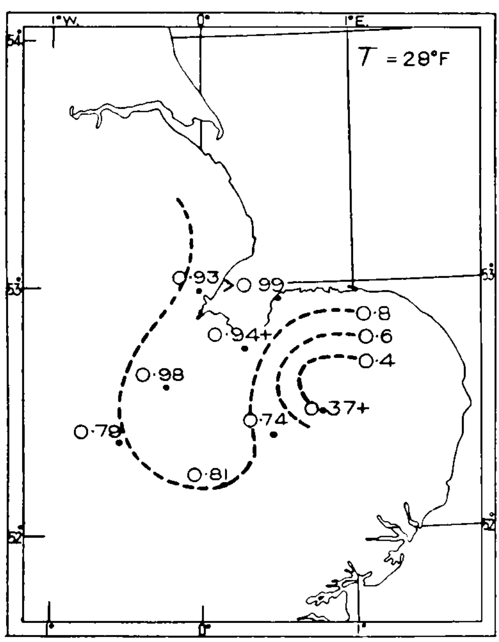
The chart method of obtaining even a very approximate idea of the frequency of frosty Mays cannot be employed in hilly country. In such irregular territory, a technique similar to that of the previous paper[1] may be employed.



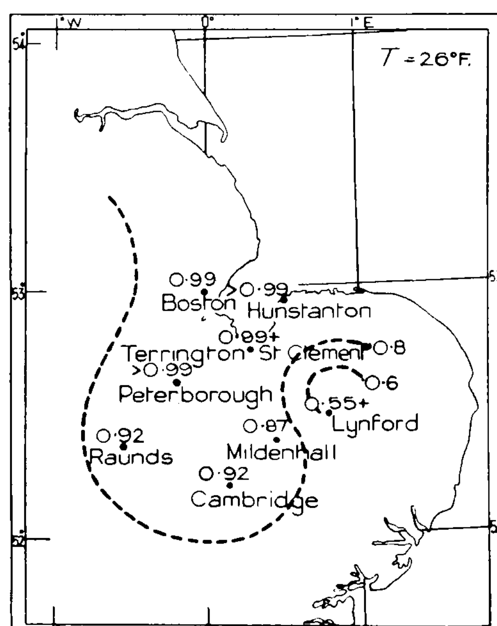
Minimum temperature 32°F.



Minimum temperature 30°F.



Minimum temperature 28°F.



Minimum temperature 26°F.

FIG. 3—ISOPLETHS OF PROBABILITY THAT THE MINIMUM SCREEN TEMPERATURE IN MAY WILL NOT FALL TO VARIOUS VALUES (T°F.)

Before proceeding it is necessary to examine further the properties of the temperature-probability curves. With minimum temperatures σ_1 is normally greater than σ_2 and the temperature probability curve is concave towards increasing y. This and other properties of the ratio σ_1/σ_2 are illustrated in Table II. The distribution of the values of σ_1/σ_2 is shown in Table III.

TABLE II—VALUES OF σ_1/σ_2

	Period	σ_1/σ_2 April	May		Period	σ_1/σ_2 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 St. Clement	12	1·06	1·46	Perdiswell ...	25	1·08	1·31
				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-on-Avon	16	1·10	1·43	Hereford ...	30	1·13	1·26
				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 σ_1/σ_2

σ_1/σ_2	All sites April	May	Total	Sites with period of 25 yr. or more 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 σ_1/σ_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 σ_1/σ_2 lay between 1·10 and 1·34 which suggests that the range for σ_1/σ_2 would be considerably decreased if the periods of the samples were longer. For example, of the six sites with the high value of $\sigma_1/\sigma_2 \geqslant 1{\cdot}35$, 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 σ_1/σ_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 $(\overline{T}-T)/\sigma_1(=R)$ would not generally be significantly lower than for the normal distribution, that is if it is assumed that the maximum value of σ_1/σ_2 is 1·20, we obtain the mean value of σ_1/σ_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:—

$$T = \overline{T} - R(1{\cdot}15, t)\,\sigma_1. \qquad \ldots\ldots (1)$$

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

$$T = \overline{T} - 0{\cdot}79\,\sigma_1.$$

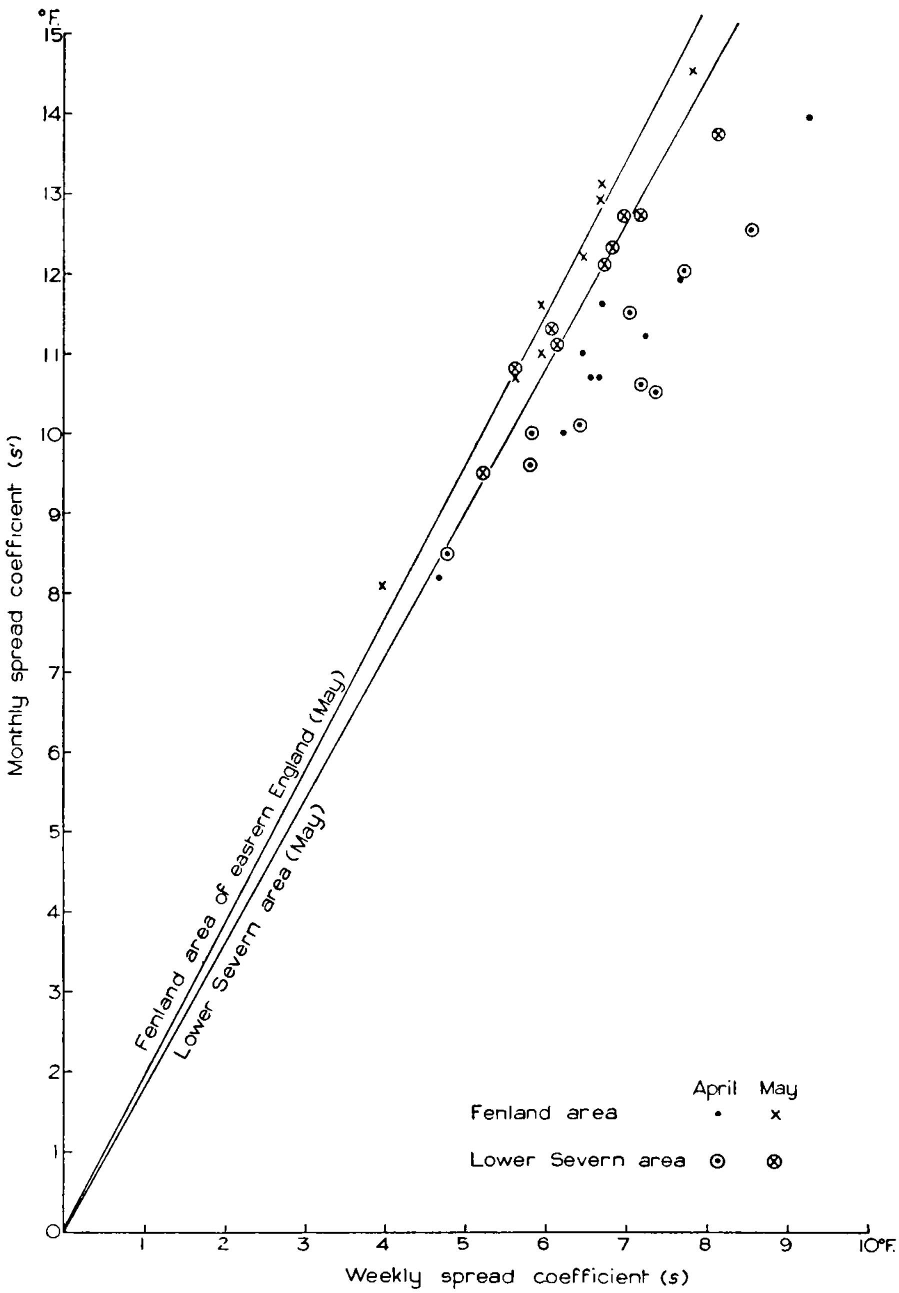


FIG. 4—RELATIONSHIP BETWEEN MONTHLY SPREAD COEFFICIENT s' AND WEEKLY SPREAD COEFFICIENT s

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[1] between standard deviation σ_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:—

$$T = \overline{T} - R(1 \cdot 15, t).\, s'.\, \left[\frac{\sigma_1}{s'}\right]_m \quad \ldots\ldots \quad (2)$$

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:—

$$s' = bs \qquad \ldots\ldots (3)$$

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[7] 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[7] 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:—

$$T = \overline{T} - R(1 \cdot 15, t).\, s. \left[\frac{\sigma_1}{s}\right]_m \qquad \ldots\ldots (4)$$

$$\text{or} \quad T = \overline{T}_d - s' - R(1 \cdot 15, t).\, s. \left[\frac{\sigma_1}{s}\right]_m \qquad \ldots\ldots (5)$$

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

$$\text{or} \quad T = \overline{T}_d - bs - R(1 \cdot 15, t).\, s. \left[\frac{\sigma_1}{s}\right]_m . \qquad \ldots\ldots (6)$$

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[1] 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[1].

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

(6) Using the values of $\overline{T}_d$ 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' [$\Sigma 2r-1$]	x [$T-$approx.$\overline{T}$]	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

$$\frac{\Sigma mx}{\Sigma m} = -\frac{12}{30} = -0{\cdot}40$$

$$\sigma_1^2 = \frac{292}{30} - (0{\cdot}40)^2 = 9{\cdot}56$$
$$\sigma_1 = 3{\cdot}09$$
$$\sigma_2^2 = \frac{11034}{900} - \left(\frac{1930}{900}\right)^2 = 7{\cdot}66$$
$$\sigma_2 = 2{\cdot}77.$$

Therefore $\sigma_1/\sigma_2 = 1{\cdot}12$

and $\overline{T} = 31 - 0{\cdot}4 = 30{\cdot}6$.

Substituting for σ_1 and $\overline{T}$ in the formula $T = \overline{T} - R\sigma_1$

$$T = 30{\cdot}6 - 3{\cdot}09R. \qquad \ldots\ldots (7)$$

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

σ_1/σ_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):—

σ_1/σ_2 \ t / y	1·58 / 0	5 / 1·50	10 / 2·25	25 / 3·20	50 / 3·90	100 / 4·61
			degrees Fahrenheit			
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 $\sigma_1/\sigma_2 = 1{\cdot}12$ give the "actual" temperature-probability curve (see Fig. 1) and the values of T corresponding to $\sigma_1/\sigma_2 = 1{\cdot}15$ give the "mean" curve based on the actual values of $\overline{T}$ and σ_1 and the "mean" value of 1·15 for σ_1/σ_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[1] 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[2,3] 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"[4] still seems to be true, namely that pressure waves in

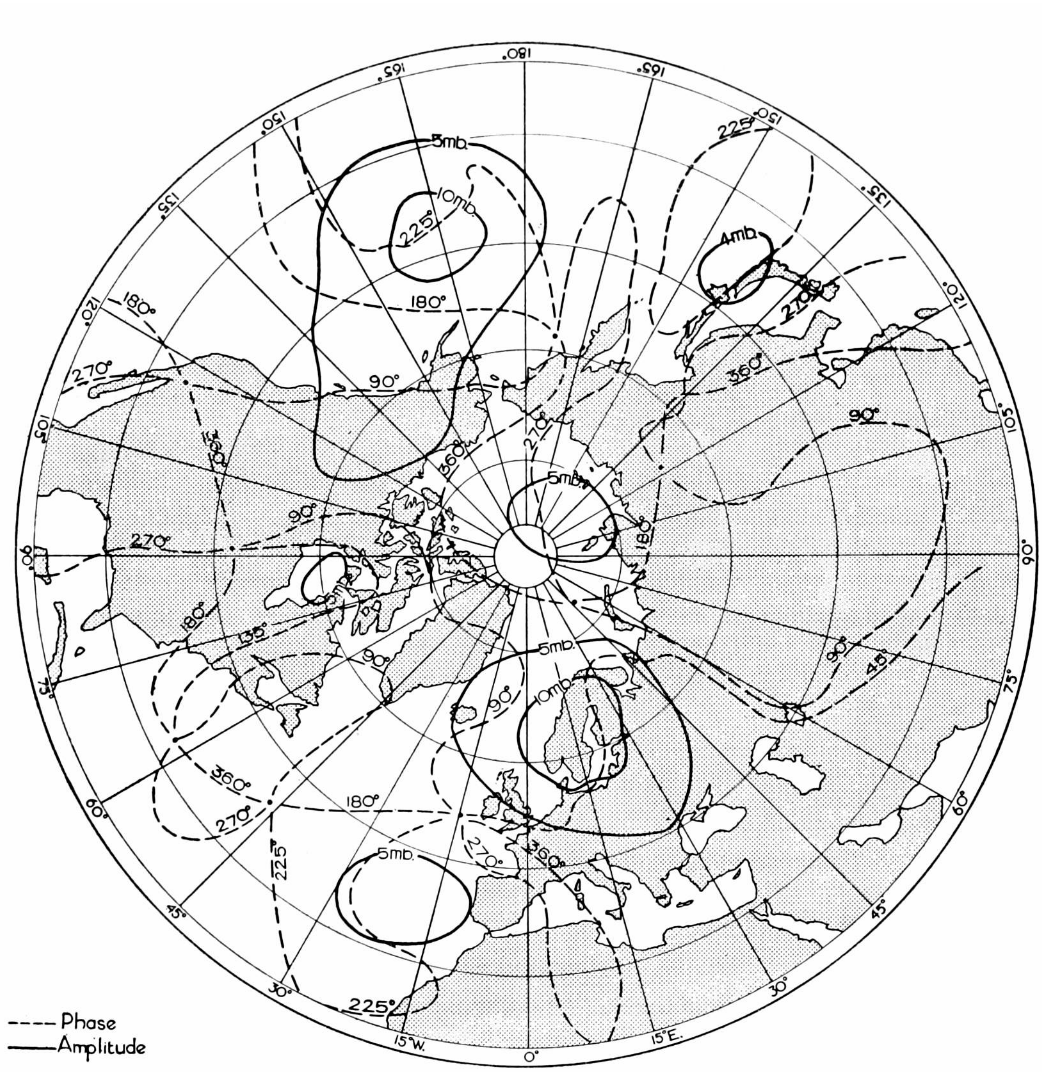


FIG. I—PHASE AND AMPLITUDE OF THE 36-DAY PRESSURE WAVE, OCTOBER 1–DECEMBER 12, 1932

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[5], 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[6] 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[7] and it was found that an approximate 72-day periodicity in pressure also existed then in Europe, exhibiting itself as a repetition

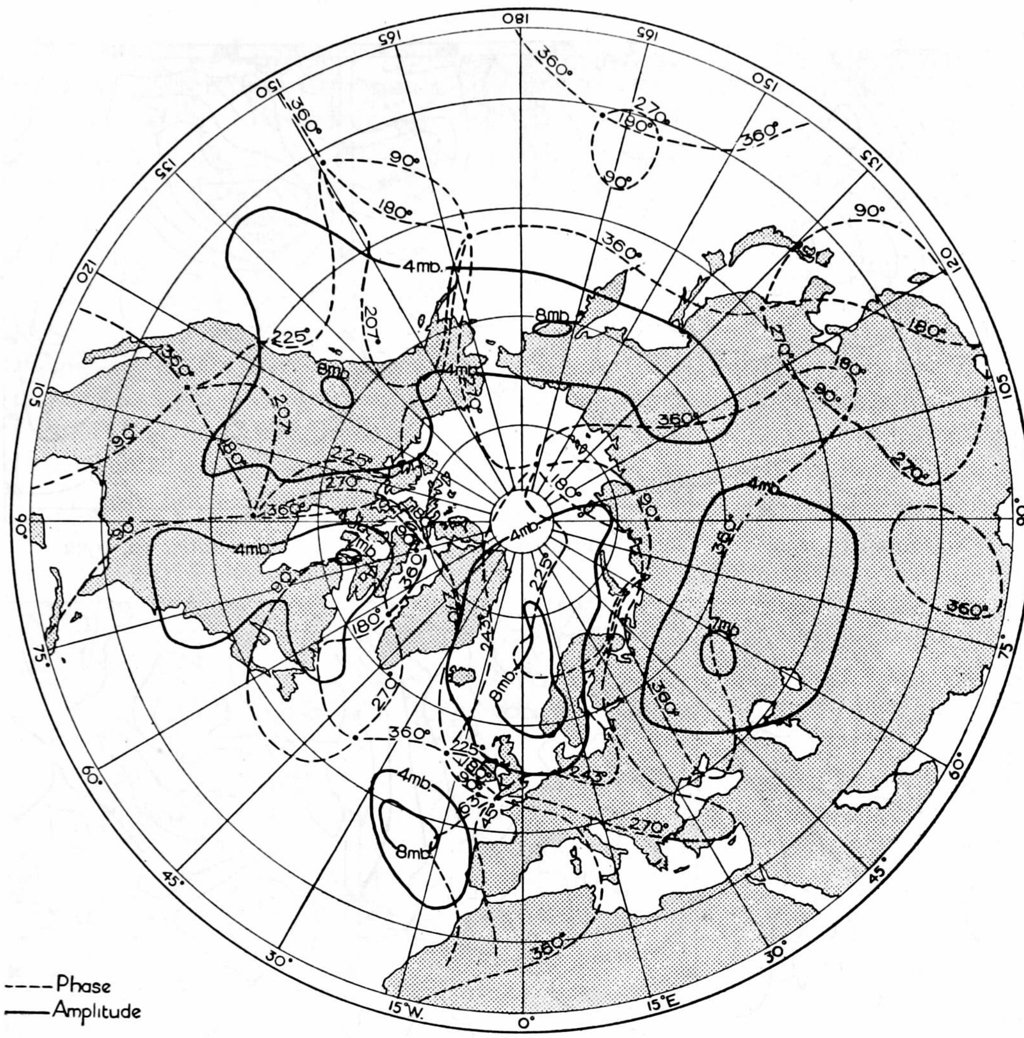
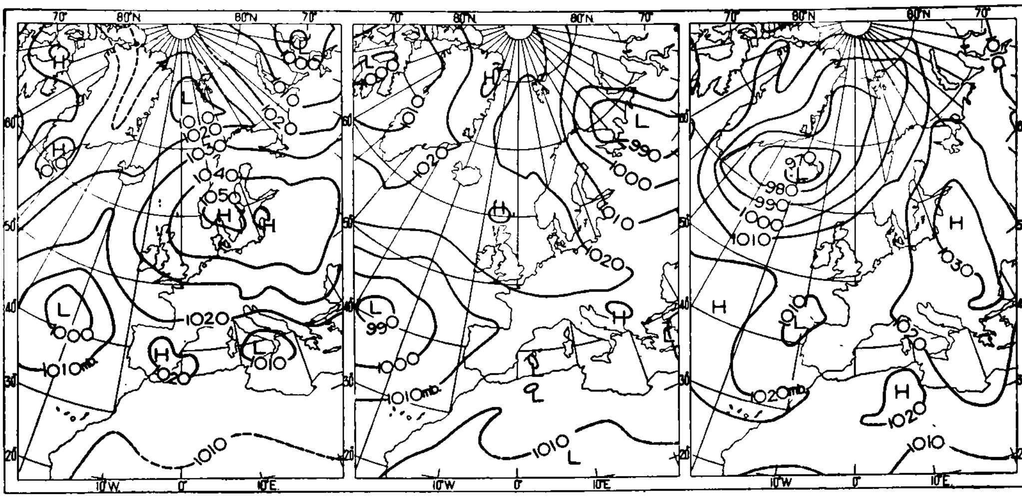


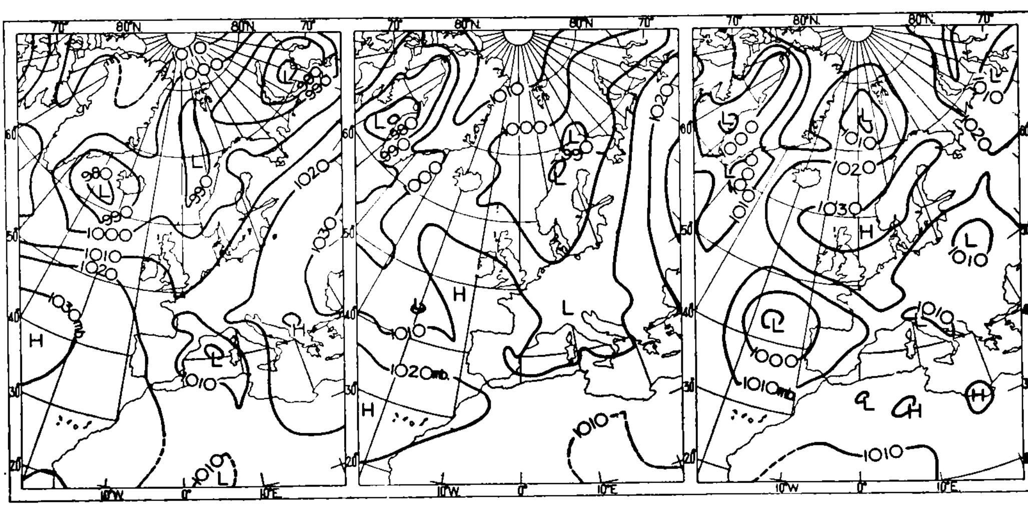
FIG. 2—PHASE AND AMPLITUDE OF THE 24-DAY PRESSURE WAVE, OCTOBER 7–DECEMBER 18, 1932

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

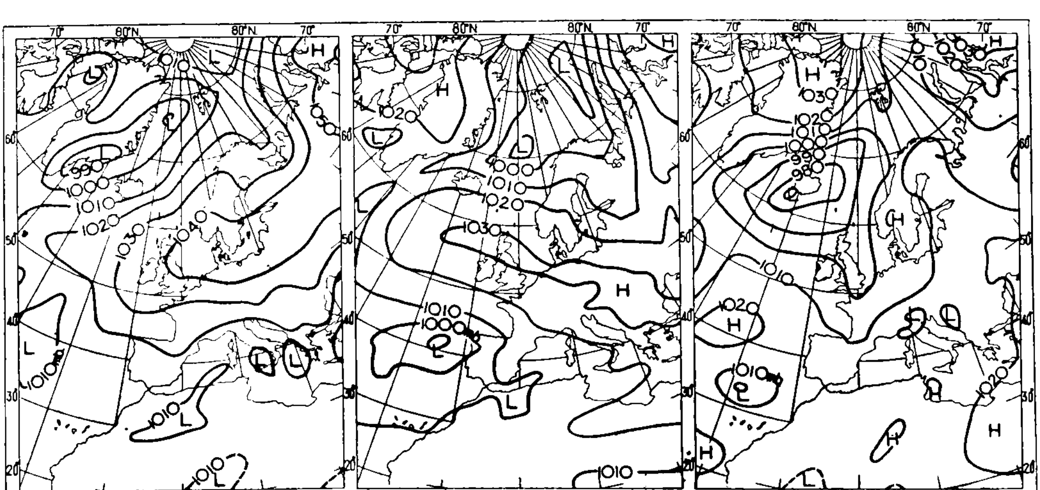
Symmetry points are found with the aid of an index of symmetry which was devised by K. Stumpff[8] to express in numerical form the degree of similarity in size and shape between a pressure graph and its reversed image. Symmetry points are indicated by values of the index near zero and unity. This criterion 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.[9,10] 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[11] 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, θ is the phase angle for any date, ϕ 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°C. to −85°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 (C_2HCl_3; freezing point −86·4°C.) for the lower temperatures. Two water baths are thermostatically maintained by 4-KW. heaters at approximately +48°C. and +27°C. Five trichlorethylene baths are maintained at approximately +4°C., −18°C., −40°C., −62°C. and −85°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 ¼ 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°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°C. and so on. A second vessel and head can now be placed in the +48°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.

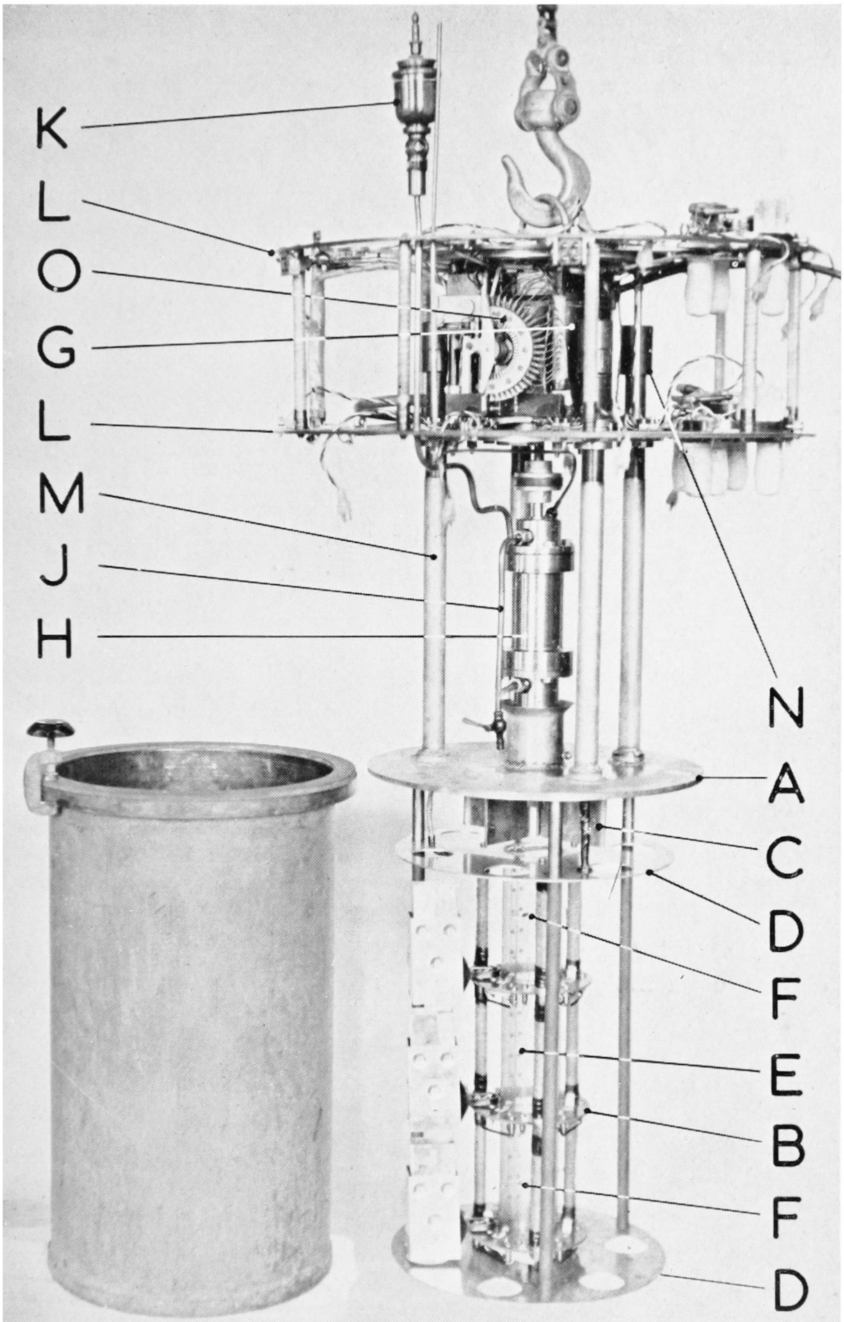
The sublimation point of carbon dioxide is $-78\cdot5$°C., and it is necessary to be able to calibrate to -85°C. A special low-temperature bath was constructed using petrol for the liquid and liquid nitrogen as the cooling agent. A 2-cm. spiral tube in the bath surrounds the chamber with the temperature 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°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°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 $+15$°C. and a shorter calibration at -60°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 $0\cdot2$°C. Temperatures during calibration are recorded to $0\cdot1$°C. Starting from the $+48$°C. bath the first batch of 18 thermometer units is completely calibrated to -85°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.

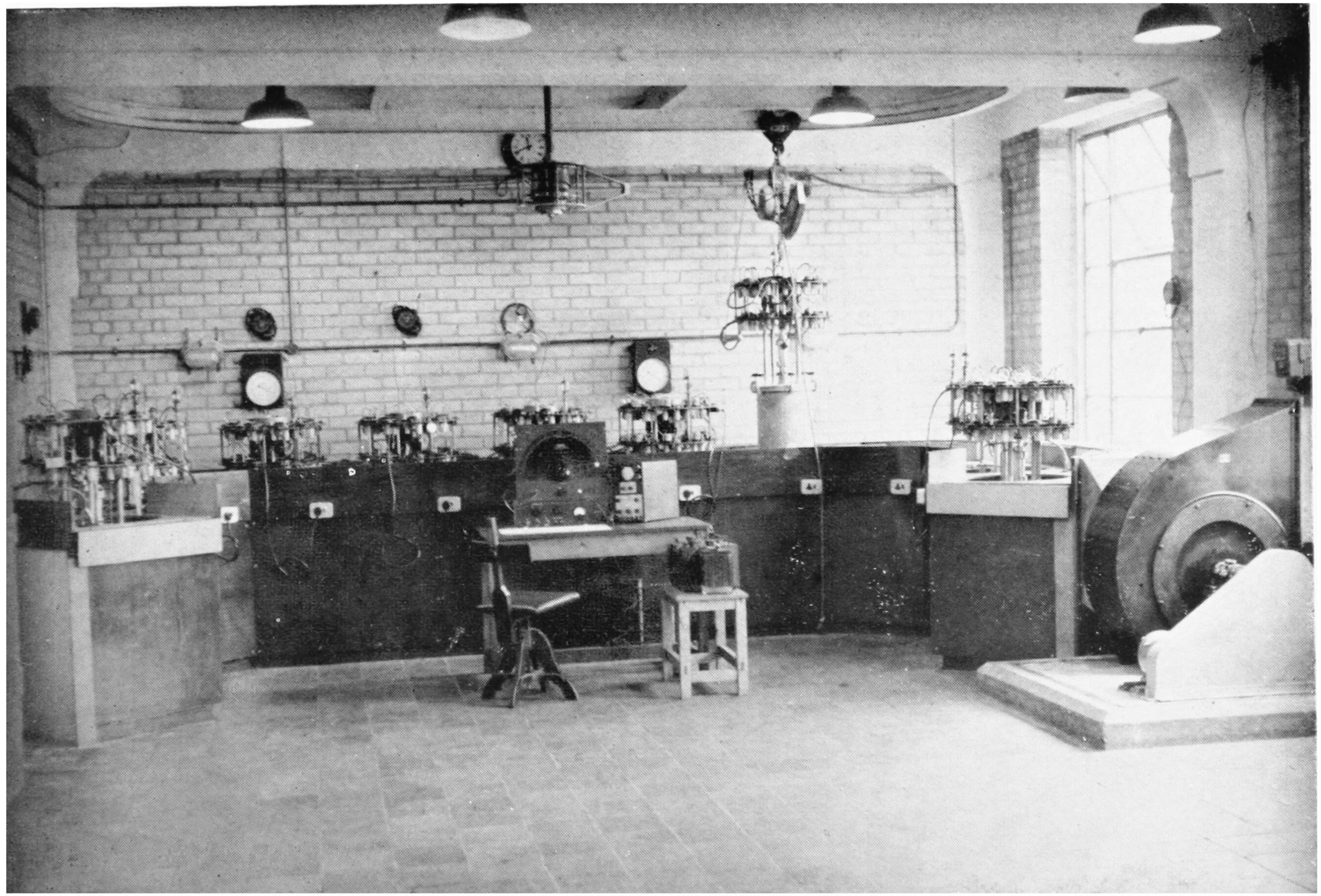
[*To face p. 16*



RADIO-SONDE TEMPERATURE CALIBRATION HEAD

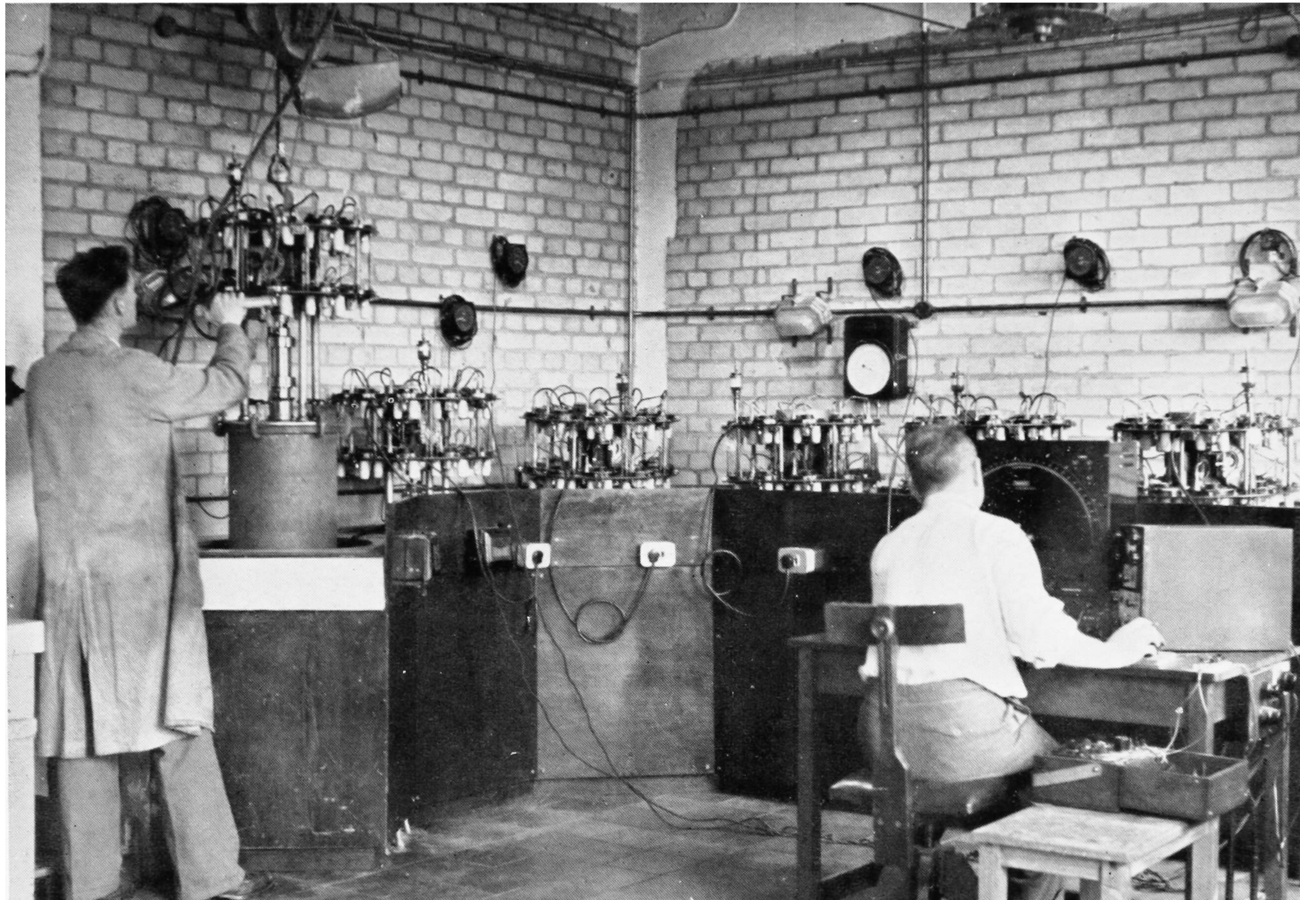
The apparatus on the right of the photograph is known as the head and is fitted into the copper vessel on the left which is then inserted in a calibration bath (see p. 14).

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



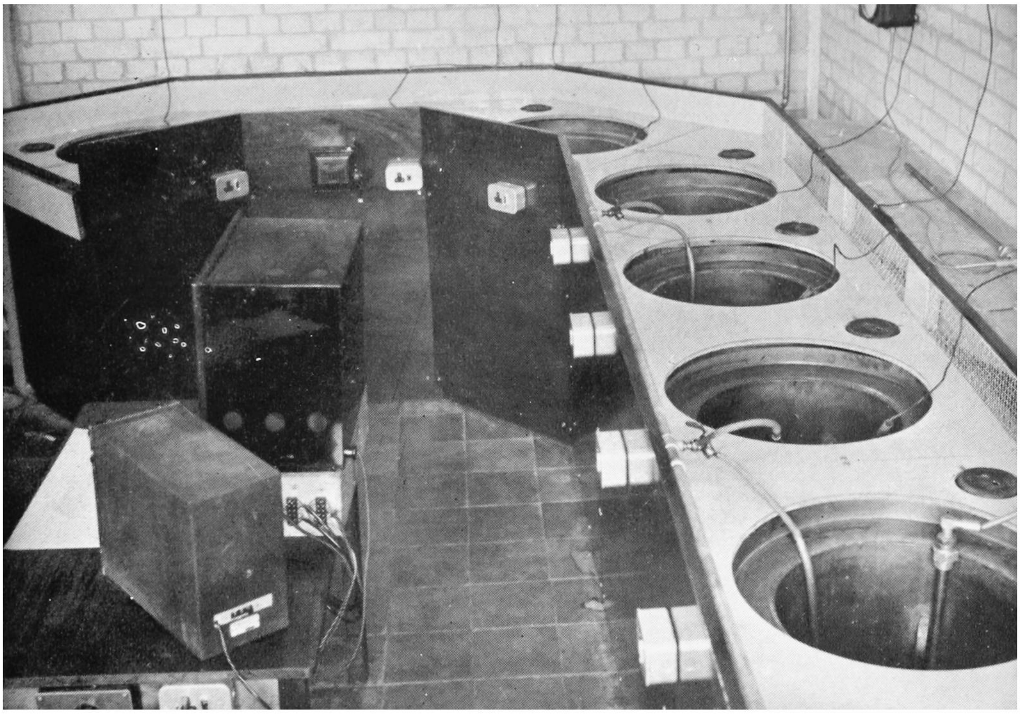
GENERAL VIEW OF THE RADIO-SONDE TEMPERATURE CALIBRATION PLANT

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



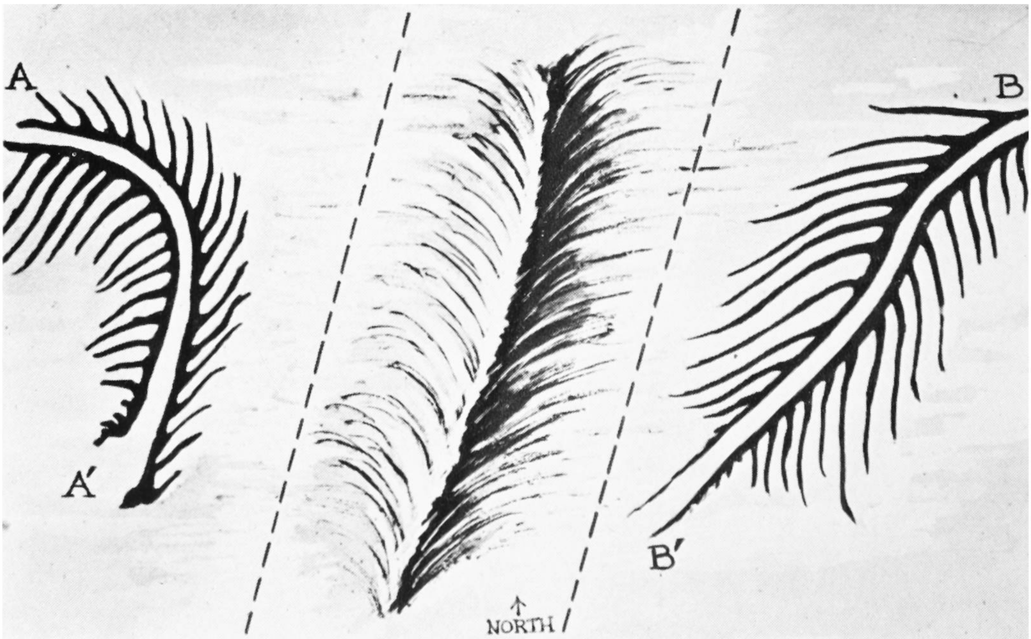
RADIO-SONDE TEMPERATURE CALIBRATION PLANT IN USE

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 uniselector 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[1]. 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[2] 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[3]. 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 anticylonic 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"[4]. For example, they give the mean dates of the summer monsoon in Europe as June 1–21, the latter being partly confirmed by Lamb[5] 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 ⩾ 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°F., in the lower stratosphere 0·64°F. and in the upper stratosphere 0·29°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° azimuth; the horizontal centre line was at an angle of elevation of about 35°. 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

* *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 70–90° (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.

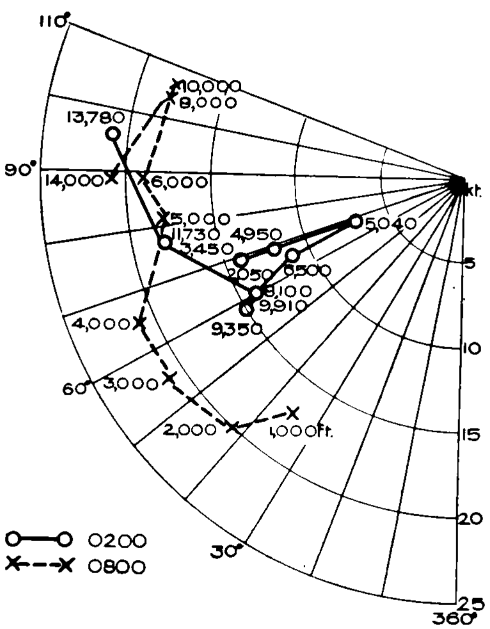

FIG. 1—HODOGRAPH OF UPPER WIND AT CRAWLEY, 0800 G.M.T.

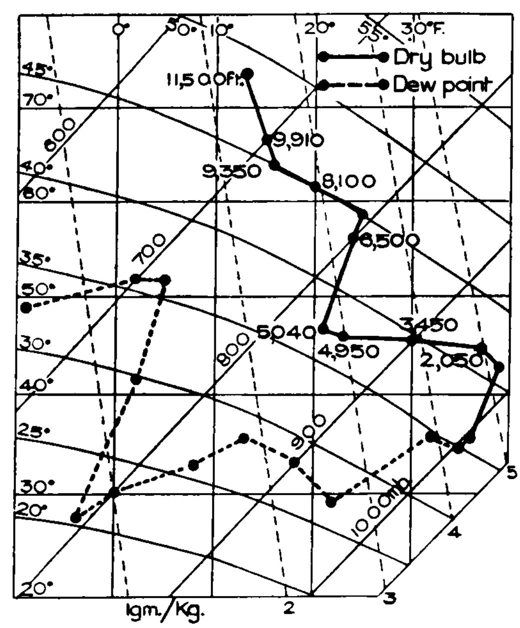

FIG. 2—TEPHIGRAM OF RADIO-SONDE ASCENT AT CRAWLEY, 0800 G.M.T.

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° to 60°) 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. $9\frac{1}{2}$ in. × $6\frac{1}{4}$ in., pp. x + 392, *Illus.*, McGraw-Hill Book Company, Inc., New York, Toronto and London, 1954. Price: 61*s.* 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 chaper 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 Tiree 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	Percentage of average	No. of days difference from average	Percentage 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.
London	Camden Square ...	3·21	136	*Glam.*	Cardiff, Penylan ...	8·80	217
Kent	Dover	4·91	155	*Pemb.*	Tenby	9·39	216
,,	Edenbridge, Falconhurst	5·73	161	*Radnor*	Tyrmynydd	11·87	178
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