M.O. 567 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 82, No. 970, APRIL 1953

GALE OF JANUARY 31, 1953

By C. K. M. DOUGLAS, B.A.

An exceptionally severe NW.–N. gale affected the north and east of the British Isles and most of the North Sea on January 31, 1953. The associated floods caused serious loss of life and immense damage on parts of the east coast, and in Holland, with its larger vulnerable area, the catastrophe was much worse. The storm itself was especially severe in north Scotland, and that was the only part of the British Isles which suffered much inland damage. On the north-east coast of England force 10 was reported. The storm was at least as severe as that of January 15, 1952, and on that occasion the depression moved east-north-east and the worst of the storm was from SW.–W. There is no evidence in our records of any equally severe northerly gale.

The very exceptional nature of the gale in the Orkneys is shown by the anemometer trace at the Electrical Research Association station at Costa Hill, reproduced in Fig. 1 (facing p. 112). It shows a mean speed of about 90 m.p.h. for an hour, and gusts up to 125 m.p.h. The trace is considered reliable. The Dines anemometer at the same station with its head 80 ft. above the ground went out of action at 0910 after gusting to over 110 m.p.h.

The record from Costa Hill was obtained from an electric cup generator anemometer on a 30-ft. high mast driving a recording milliammeter. The instrument has been calibrated in a wind tunnel to a speed of 150 m.p.h. Costa Hill is situated at the extreme north point of Orkney, 59°09′N. 3°12′W., and the anemometer installation is on the summit 500 ft. above M.S.L. The ground slopes gradually to a cliff nearly 500 ft. high overlooking the sea ½ mile to the north of the summit. There are also at the site a Dines pressure tube anemometer and 4 cup contact anemometers fitted at 3 levels to a 120-ft. mast, but these unfortunately ceased recording for various reasons at an early stage of the gale. The cup contact anemometers registered the following mean winds between 0800 and 0840:

at 110 ft.	at 80 ft.	at 80 ft.	at 50 ft.
84 m.p.h.	85·5 m.p.h.	99 m.p.h.	101 m.p.h.

The installation was set up and is operated by the Electrical Research Association, to whom thanks for lending records and permission to publish are due, as part of the Association's investigation into the generation of electricity by wind power on a commercial scale.

The meteorological office at Grimsetter airport, Orkney, 84 ft. above M.S.L., reported winds not much less than those at the very exposed Costa Hill. The mean wind at Grimsetter was over 60 kt. from 0918 to 1200, and at 1018 was 68 kt. with gusts to the limit of the anemometer at 93 kt.

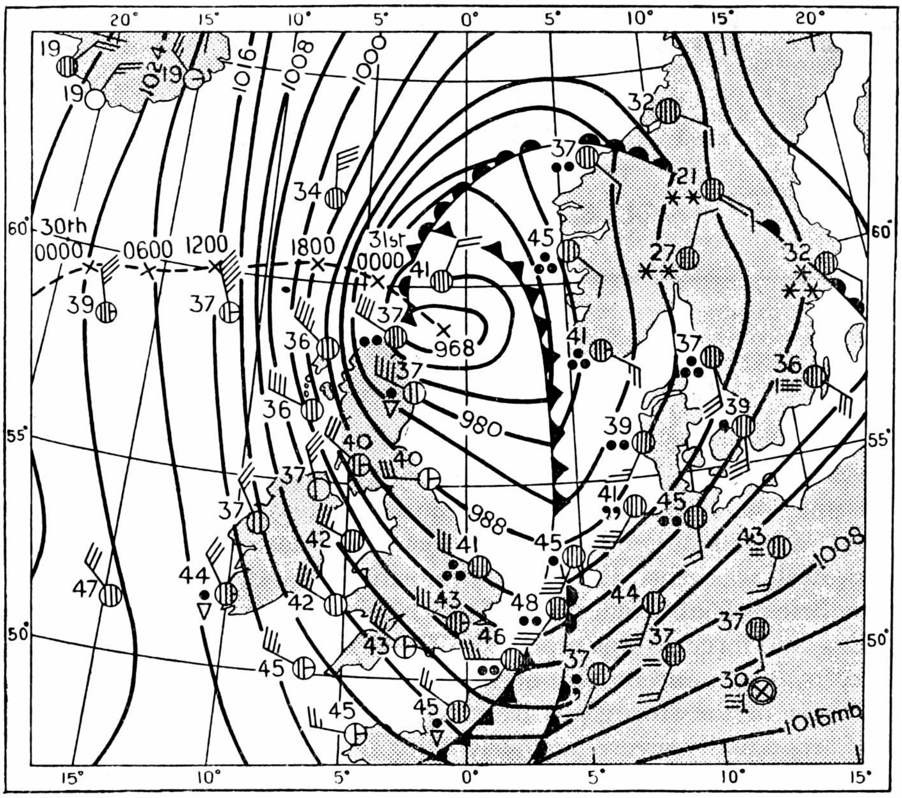


FIG. 2—SYNOPTIC CHART, 0600 G.M.T., JANUARY 31, 1953

The depression formed on January 29 as a warm-front wave, breaking away from a quasi-stationary depression just north of the Azores. A closed centre only appeared at about 1200 on the 29th, at 54½°N. 27°W., with central pressure 1003 mb. It moved north-east and then east-north-east on the track shown in Fig. 2. At 1800 on the 30th, when its central pressure had dropped to 979 mb., it still had an open warm sector with south-west–north-east isobars in it. There was a force 9 northerly wind to the west of it, with a steep and increasing gradient between the depression and an advancing and intensifying anticyclone. By midnight a small central region was occluded and the depression had already turned east-south-east. The lowest pressure recorded was just below 970 mb. in the Orkneys at 0500, but it probably fell some millibars lower over the North Sea at noon. When it reached Denmark at 1800 it was beginning to fill up.

Though the depression assumed the general character of an intense travelling vortex, the maximum winds and gradients occurred behind the trough, and some distortion of the isobars can be seen on both the 0600 and 1200 charts (Figs. 2 and 3). This was related to the cutting in of colder air, and with a movement of the associated fronts against the component of geostrophic wind across them. These fronts consisted of the occlusion and part of what had

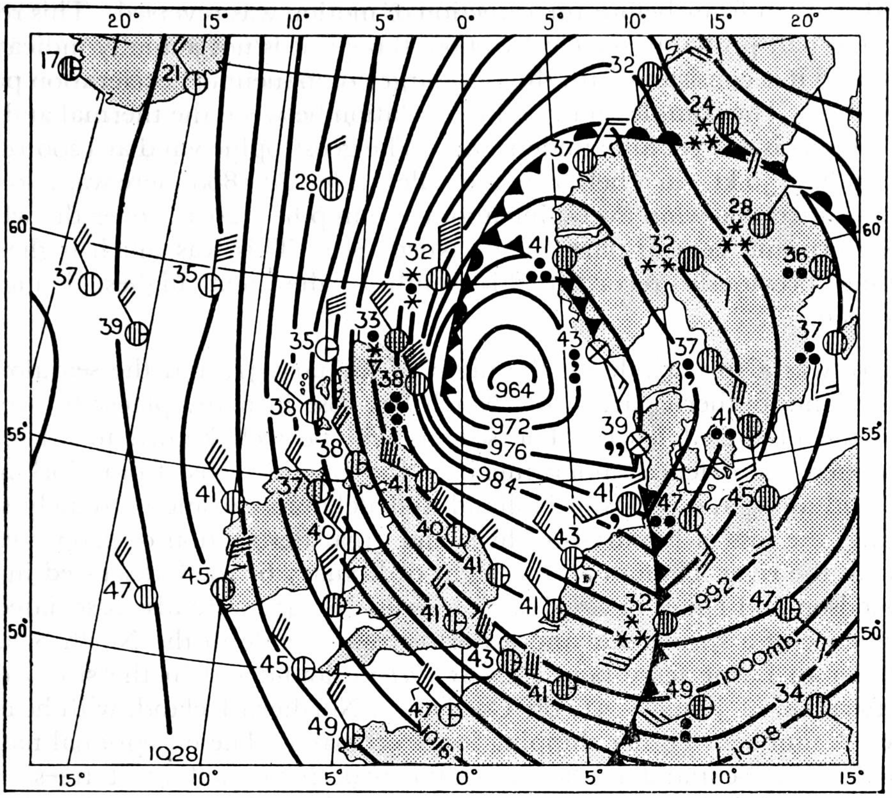


FIG. 3—SYNOPTIC CHART, 1200 G.M.T., JANUARY 31, 1953

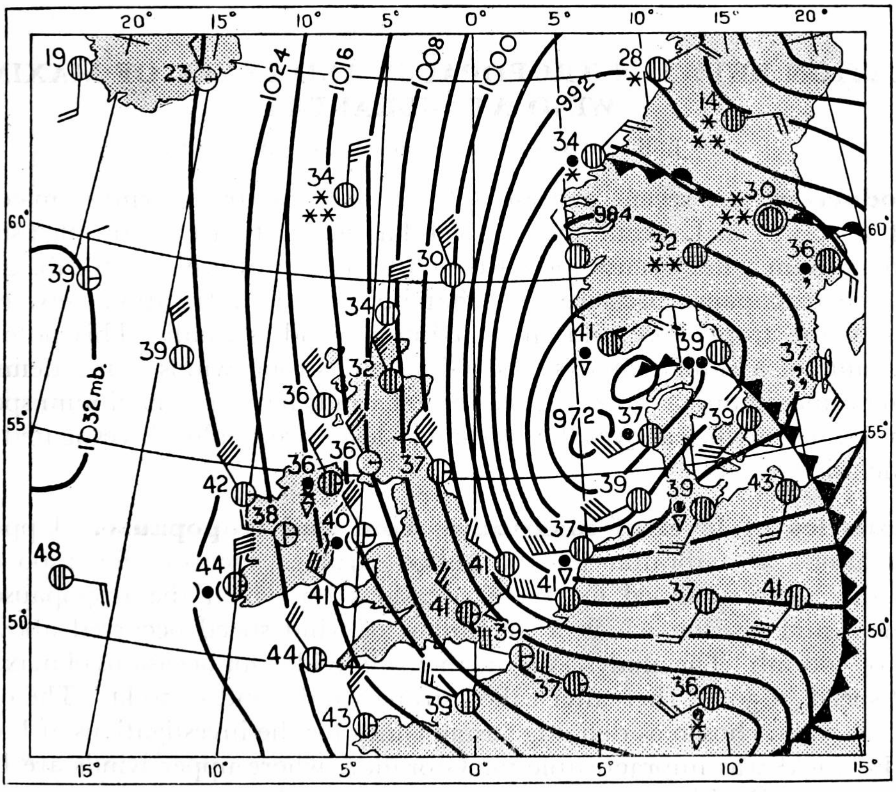


FIG. 4—SYNOPTIC CHART, 1800 G.M.T., JANUARY 31, 1953

been the warm front before the direction of motion was reversed. This reversal of motion had probably started by 0600, though it is not actually indicated on Fig. 2, and it is consistent with the very large component of acceleration parallel to the front. The complex mutual inter-relation between the thermal and dynamical factors is not yet fully understood. The geostrophic wind at 1200 reached 175 m.p.h. (150 kt.) in a belt over 100 miles wide. At 1800 there was a long belt with a geostrophic wind averaging about 140 m.p.h. (120 kt.) over the whole of the western and central parts of the North Sea. This was much higher than anything previously recorded this century; the next highest being only 100 m.p.h.

There was a spring tide on the night of January 31, and the sea along the coasts of the southern part of the North Sea rose in many places to over 6 ft. above the predicted levels. The sea, as will be well known to all readers, overtopped the defences along much of the English coast from Yorkshire to Kent and along the coasts of Holland and Belgium causing extremely serious flooding, the loss of hundreds of lives and great destruction of property. The floods in the river Thames on the night of January 6, 1928, discussed in detail by Doodson and Dines in *Geophysical Memoirs* No. 47, were also associated with coincidence of a spring tide and a north-westerly gale in the North Sea. The Stranraer to Larne ferry boat *Princess Victoria* foundered in the storm during the afternoon of January 31, off Co. Down, Northern Ireland, with heavy loss of life. A number of other shipping losses occurred. The exceptional nature of the gale over Scotland is shown by the widespread felling of trees. Many owners had all their timber blown down and the total quantity laid is believed to be many times the annual felling quota.

RELATION BETWEEN TROPOPAUSE AND LEVEL OF MAXIMUM WIND AT GIBRALTAR

By J. K. BANNON, B.A. and M. P. JACKSON

Introduction.—A recent analysis[1] of occasions of strong winds (maximum wind $\geqslant$ 70 kt.) at Larkhill and Lerwick has shown that over the British Isles the maximum wind occurs most frequently at a pressure 20–40 mb. greater than the tropopause pressure, but that in general the relation between the levels of the tropopause and the maximum wind is small. This note gives the results of a similar analysis for Gibraltar, strong winds being defined as having a maximum $\geqslant$ 50 kt. Occasions of winds having a maximum speed of $<$ 50 kt. occurring above the 500-mb. level were also investigated with inconclusive results.

Statistics of level of maximum wind and tropopause.—Upper air observations at Gibraltar for the period 1948–51 inclusive for 1500 G.M.T. each day were analysed for those occasions on which the tropopause was reached, and also on which a maximum of wind speed occurred above the level of 500 mb. The analysis was further subdivided for occasions of maximum wind speed $\geqslant$ 50 kt. (hereafter called strong winds) and $<$ 50 kt. The critical speed of 70 kt. chosen as defining strong winds for the investigations at Larkhill and Lerwick[1] was impracticable for Gibraltar, where upper winds are lighter than over the British Isles.

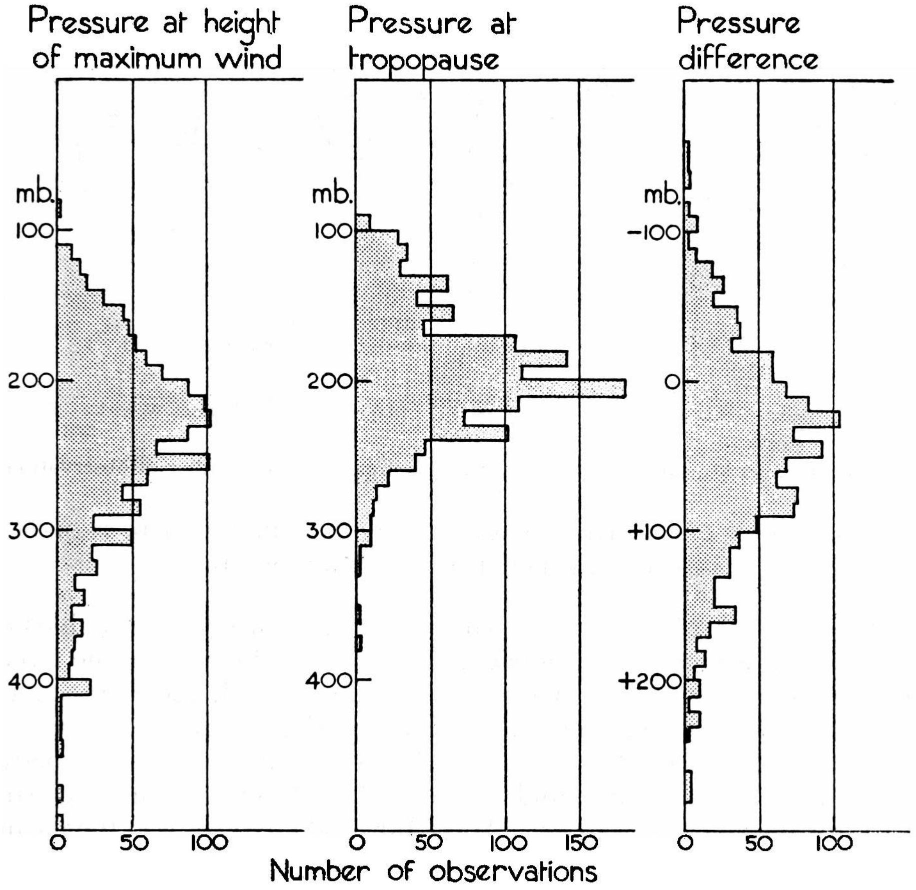
Frequencies for 10-mb. intervals of pressure were then obtained for occasions of both strong and light winds for:—

(*a*) pressure at the level of maximum wind

(*b*) pressure at the tropopause

(*c*) the difference between (*a*) and (*b*).

These are shown for occasions of strong winds in Fig. 1. Similar histograms for light winds are not given here; in all three the frequency distributions were much "flatter" than for strong winds, especially in (*c*).



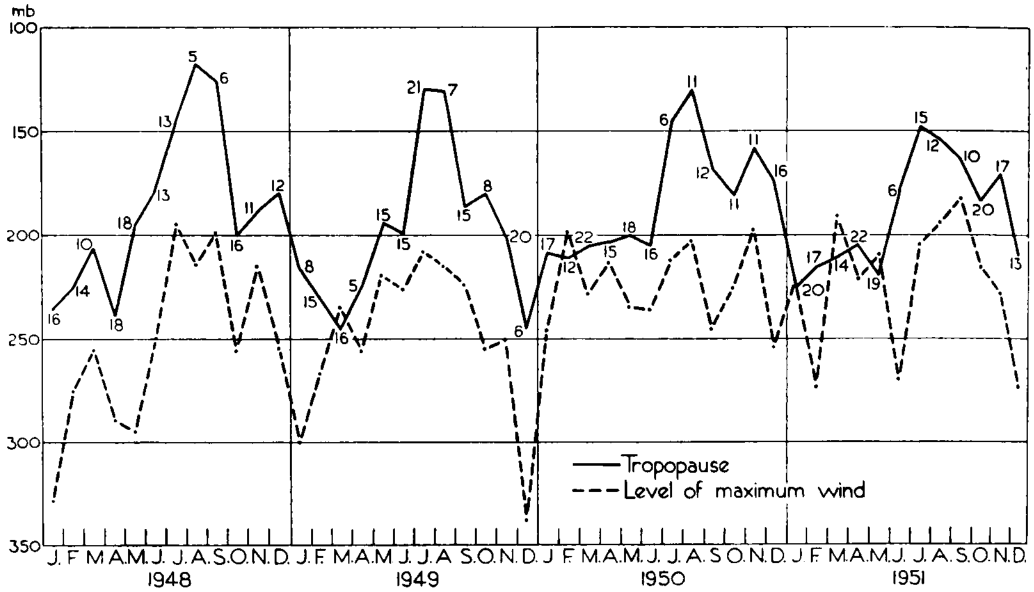
Mean (mb.)	238	194	45
Standard deviation (mb.)	67	44	69

Correlation coefficient between pressure at maximum wind level and at tropopause 0·15
Maximum wind ⩾ 50 kt., Gibraltar 1948–51

FIG. 1—FREQUENCY DISTRIBUTIONS OF PRESSURE AT THE LEVEL OF MAXIMUM WIND AND AT THE TROPOPAUSE AND THEIR PRESSURE DIFFERENCE

Fig. 2 shows mean monthly values of tropopause pressure and pressure at the level of maximum wind for each month of the period 1948–51 for occasions of strong winds. The number of observations available for each month is given. A similar diagram for light winds showed little relation between the two curves and is not reproduced here.

Discussion.—It is seen that for strong winds there is even less relation between the levels of the tropopause and the maximum wind at Gibraltar than there is over the British Isles[1]. Fig. 2 shows that, as at Larkhill and Lerwick, there is some similarity between the month-to-month variation of the monthly mean pressures of these levels, but Fig. 1 and the correlation coefficient quoted there of 0·15 between the levels shows that the relationship is, in general, slight. Compare similar correlations of 0·43 for Larkhill and 0·18 for Lerwick.



Maximum wind ⩾ 50 kt., Gibraltar 1948–51; the figures give the number of observations for each month

FIG. 2—COMPARISON OF MONTHLY MEANS OF THE PRESSURE AT THE TROPOPAUSE AND AT THE LEVEL OF MAXIMUM WIND

In summer at Gibraltar the tropopause is high, often being as high as over the tropics. In winter the tropopause is not much higher on the average than over southern England. It is not surprising to find, therefore, that the relation between tropopause and maximum wind level is much greater in winter than in summer. Table I gives the correlation coefficients between the pressures of the tropopause and at the level of the maximum wind (strong winds) for the four months, January, April, July and October, and the means of these pressures. It is seen that the relation between the two levels is similar at Gibraltar in January to that over southern England[1]; in July there is no relation.

TABLE I—STATISTICS OF TROPOPAUSE PRESSURE AND PRESSURE AT THE LEVEL OF MAXIMUM WIND AT GIBRALTAR

Maximum wind ⩾ 50 kt. occurring above the 500-mb. level

	January	April	July	October
	Number of occasions			
Mean tropopause pressure (mb.)	215	217	163	200
Mean pressure at level of maximum wind (mb.)	267	243	208	235
Correlation between tropopause pressure and pressure at maximum wind	0·43	0·27	−0·03	0·19

REFERENCE

1. AUSTIN, E. E. and BANNON, J. K.; Relation of the height of the maximum wind to the level of the tropopause on occasions of strong wind. *Met. Mag., London*, **81**, 1952, p. 321.

REDUCTION OF AVERAGES OF VAPOUR PRESSURE TO SEA LEVEL

By G. A. TUNNELL, B.Sc.

Introduction.—In preparing world maps of average mean of day atmospheric water-vapour pressure it is necessary to examine its variation with height, because data are drawn from stations at many different levels and variations due to differences in altitude often mask differences in the horizontal field.

It is possible to derive a formula for the variation in the vertical of long-period averages by which the component due to altitude alone can be removed. A satisfactory formula would be one which would remove variations due to height, but would leave horizontal variations caused by the presence of high land, for example the fall in vapour pressure associated with a "rain-shadow area". By means of this formula maps of average vapour pressure reduced to sea level could be constructed.

Sir Napier Shaw[1] gave the following formula used by Kaminsky in the production of the "Climatological atlas of the Russian Empire", which agrees with the Hann formula (discussed below) up to about 1,000 m.

$$e_0 = e\,(1 + 0{\cdot}0004\,h)$$

where e_0 is the vapour pressure at M.S.L. and e the vapour pressure at height h (in metres) above M.S.L.

In the preparation of the "Climatological atlas of the British Isles" neither the Hann nor the Kaminsky formula proved satisfactory. For this reason a new analysis was carried out and is now explained.

Previous work.—The variation of vapour pressure with height was first considered by Lt. Col. Richard Strachey[2] who pointed out in 1861 that, contrary to Dalton's suggestion, water vapour does not exist as a separate atmosphere independent from the rest of the constituents of the air, and that its variation with height indicates it is not even approximately in static equilibrium. To support this, results obtained by Dr. Hooker on the Himalayan Mountains and Mr. Welsh in four balloon ascents were quoted.

J. Hann, using data from Strachey's paper and additional information, suggested[3,4] in 1874 and 1894 that the variation of average vapour pressure with height could be represented by a formula of the form

$$e = e_0 10^{-\gamma h}$$

where γ is, in principle, a function of h; Hann took it to be 1/6,500 which was the average value over the height range he used.

In the latest (1939) edition of the "Hann-Süring, Lehrbuch der Meteorologie"[5], formulae for the free air are distinguished from those for land stations. The formula given for land stations is

$$e = e_0 10^{-h/6300}.$$

This formula is in almost universal use in the reduction of vapour-pressure averages to sea level and is known as the Hann formula; $1/\gamma$ or 6,300 is known as Hann's constant.

The presence of the land surface influences the magnitude of the vapour pressure at mountain stations and formulae for the free air differ from those for land stations. K. L. Bhatia[6] states, in a paper in which aeroplane observations over the Peshawar plain are compared with those at Cherat (4,272 ft.), that vapour pressure at Cherat is, in general, higher than in the free air at the same level. The present paper is concerned exclusively with land stations.

Theory of the present analysis.—Data for British Columbia averaged over July, August and September 1941 were plotted against height. For heights up to over 1,000 m. above sea level the relationship was almost linear. Mean-of-day values showed less scatter about the straight line than averages for individual hours.

Data were then analysed from five areas. Mean-of-day averages for January, April, July and October over as long a period as possible were taken for Argentina[7], Ceylon[8], east Africa[9-11], southern Germany[12] and western Canada[13,14]. These areas were chosen because good data were available, their distribution of vapour pressure was convenient and they have widely differing climates. It was decided to fit the following equation to the data for each area.

$$e = ah + b\lambda + c\phi + d \qquad \ldots\ldots (1)$$

where λ and ϕ are position co-ordinates which may be with respect to any convenient axes in a horizontal plane, and a, b, c and d are constants (regression coefficients) derived from the analysis. Equation (1) may be rewritten

$$e - \bar{e} = a(h - \bar{h}) + b(\lambda - \bar{\lambda}) + c(\phi - \bar{\phi}) \qquad \ldots\ldots (2)$$

where a bar indicates an average value. At the point $\bar{\lambda}$, $\bar{\phi}$

$$e - \bar{e} = a(h - \bar{h}) \qquad \ldots\ldots (3)$$

$$\text{i.e. } e = e_0(1 - \alpha h) \qquad \ldots\ldots (4)$$

where $e_0 = \bar{e} - a\bar{h}$ and $\alpha = -a/(\bar{e} - a\bar{h})$. Equation (4) gives conditions along a vertical line over the point $(\bar{\lambda}, \bar{\phi})$. It is assumed that for long-period averages this relationship holds everywhere, giving a method of finding e_0 when e is known.

Equation (2) contains the first four terms of a Taylor series about the point $(\bar{\lambda}, \bar{\phi}, \bar{h})$ representing the vapour pressure at any point (λ, ϕ, h). By arranging for the isopleths of vapour pressure to be almost linear it is necessary for the remaining terms of the Taylor series to be negligible. The good agreement obtained indicates that this is justified. The value of α is determined at the point $(\bar{\lambda}, \bar{\phi})$ in each area. This linear form of the equation is very convenient; logarithmic formulae or polynomials would involve considerably more computation and the degree of agreement obtained could hardly be improved.

An equation of the form of equation (3) could be obtained from a simple correlation of vapour pressure with height, but the additional terms in equation (2) serve to make a correction for the fact that vapour-pressure values are dependent on their position in a horizontal plane.

Results of the analysis.—The results obtained from the analysis are given in Table I, which indicates that the terms in λ and ϕ have materially improved the fit and that α is very consistent except in western Canada. Here, July alone has a value of α consistent with the remaining areas, and January with 0·00063 has a value 2·5 times the most probable value of α. The reasons for this difference will be considered later.

It will be seen that very consistent values were obtained, and 0·00025 has been taken as the most probable value of α which seems (for long-period, mean-of-day averages) to be a universal constant.

TABLE I—STATISTICAL PARAMETERS AND COEFFICIENTS OBTAINED FROM THE ANALYSIS OF LONG-PERIOD AVERAGES

R is the multiple correlation coefficient of equation (1); r_{eh} is the correlation coefficient of vapour pressure with height.*

	Range of latitude	Range of longitude	Height of highest station		R	r_{eh}	a	α	Type of daily mean	Period
	°	°	m.					$\times 10^{-5}$		yr.
Argentine (43 stations)	28·5	15·4	1,269	January	0·81	−0·45	−0·0043	−22	Mean of hourly values	10
				April	0·97	−0·57	−0·0041	−26		
				July	0·94	−0·68	−0·0024	−25		
				October	0·96	−0·60	−0·0031	−23		
Ceylon (16 stations)	3·7	1·9	1,881	January	0·99	−0·99	−0·0070	−27	Estimated from half maximum plus minimum dry-bulb and wet-bulb temperatures	14–21
				April	0·99	−0·99	−0·0082	−27		
				July	0·98	−0·96	−0·0072	−26		
				October	0·99	−0·99	−0·0073	−26		
East Africa (39 stations)	21·8	6·1	1,386	January	0·94	−0·89	−0·0056	−22	Corrected to mean of 24 hr. from diurnal curve	Variable, mainly >10
				April	0·90	−0·84	−0·0066	−25		
				July	0·89	−0·76	−0·0060	−29		
				October	0·85	−0·77	−0·0068	−29		
Southern Germany (52 stations)	2·4	8·3	1,618	January	0·96	−0·88	−0·0010	−24	Mean of vapour pressure measured at 0700, 1400 and 2100 local time	50
				April	0·93	−0·92	−0·0014	−23		
				July	0·96	−0·95	−0·0018	−23		
				October	0·97	−0·96	−0·0017	−23		
Western Canada (21 stations)	16·5	23·7	1,079	January	0·96	−0·52	−0·0030	−63	Derived from averages of dew points at 0130, 0730, 1330, 1930 E.S.T.	3–8
				April	0·98	−0·43	−0·0024	−33		
				July	0·90	−0·51	−0·0030	−22		
				October	0·98	−0·54	−0·0035	−38		

*The standard error in fit for the simple correlation between e and h is $\sigma_e(1 - r_{eh}^2)^{\frac{1}{2}}$, and for equation (1) is $\sigma_e(1 - R^2)^{\frac{1}{2}}$, where σ_e is the standard deviation of the vapour-pressure averages[15]; $(1 - r_{eh}^2)^{\frac{1}{2}}$ and $(1 - R^2)^{\frac{1}{2}}$ are therefore a measure of the deviation of the observations from respectively a straight line or a plane and indicate the improvement in fit due to the additional terms in equation (1). R is always positive.

The final reduction formula is then

$$e = e_0(1 - 0 \cdot 00025h). \qquad \qquad (5)$$

Formulae for reduction from great heights.—In equation (5) e_0 becomes infinite at 4,000 m. This has led to an investigation of the range of height for which the equation is valid, because there are areas from which the only data available are from stations at great heights. Many are above 4,000 m. but there are no networks of stations sufficient to carry out a statistical analysis; 95 per cent. of the stations used are below 1,300 m. above M.S.L. and equation (5) can be said to hold over this range only. If the true law is of the form

$$e = e_0' \exp(-\beta h), \qquad \qquad (6)$$

which holds according to Hann up to approximately 9 Km., then equation (5) is the result of an analysis of variates of the form

$$e = e_0' \exp(-\beta h) + \Delta, \qquad \qquad (7)$$

where Δ is a random variable and β is a constant for values of h distributed between sea level and 1,300 m.

The following analysis is carried out to find the relationship between e_0 derived from equations (5) and (6) and to find a value of β corresponding to $\alpha = 0 \cdot 00025$ and hence to find the corresponding value of Hann's constant.

The analysis is carried out with the assumption of ideal conditions, i.e. an infinite homogeneous population of stations, no horizontal gradient of vapour pressure, and random errors distributed normally about $e = e_0' \exp(-\beta h)$. The least square condition of best fit for an equation of the form $e = ah + d$ to variates of the form of equation (7) is that

$$\sum_{n=0}^{N} \left[\{e_0' \exp(-\beta h_n) + \Delta_n\} - \{ah_n + d\} \right]^2 \qquad \qquad (8)$$

must be a minimum with respect to a and d under the above ideal conditions, where the suffix n refers to the nth station of a total of N stations.

After partially differentiating expression (8) with respect to a and d, equating to zero, integrating and putting $d = e_0$ and $a = -\alpha e_0$, the following is obtained:

$$\frac{e_0'}{e_0} = \frac{\beta}{\exp(-\beta H) - 1} \left(\alpha \frac{H^2}{2} - H \right), \qquad \qquad (9)$$

where H is the range of height over which the stations are distributed. Equation (9) gives

$$\beta = \frac{1 - \exp(-\beta H) \{ \beta H + 1 \}}{\exp(-\beta H) - 1} \left[\frac{\alpha/2 - 1/H}{1/2 - \alpha H/3} \right]. \qquad \qquad (10)$$

β can be found easily from equation (10) by the method of successive approximations.

If α has the value $0 \cdot 00025$ and $H = 1,300$ m. then $\beta = 0 \cdot 295 \times 10^{-3}$ and $e_0'/e_0 = 1 \cdot 008$. It can be seen that e_0' and e_0 are, to a high degree of approximation, equal. This leads to a number of expressions for e:—

$$\left. \begin{aligned} e &= e_0 \exp(-0 \cdot 000295\, h) \\ e &= e_0\, 10^{-0 \cdot 000128h} \\ e &= e_0\, 10^{-h/7800} \\ e &= e_0 (1 - 0 \cdot 00025\, h) \end{aligned} \right\} \qquad \qquad (11)$$

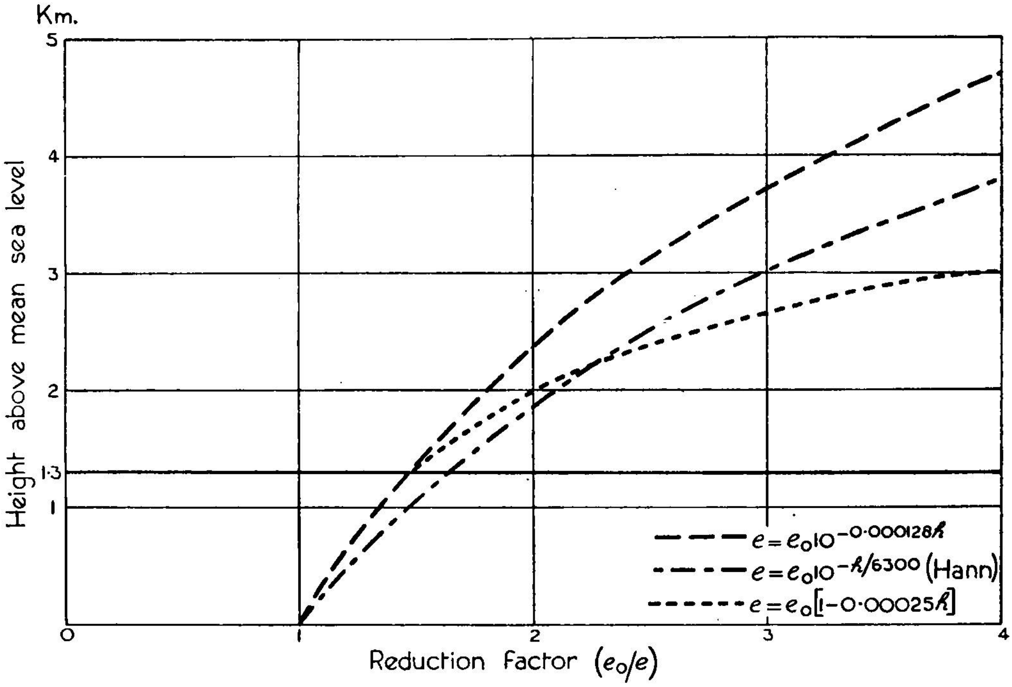


FIG. 1—FACTOR FOR REDUCTION OF VAPOUR PRESSURE TO SEA LEVEL

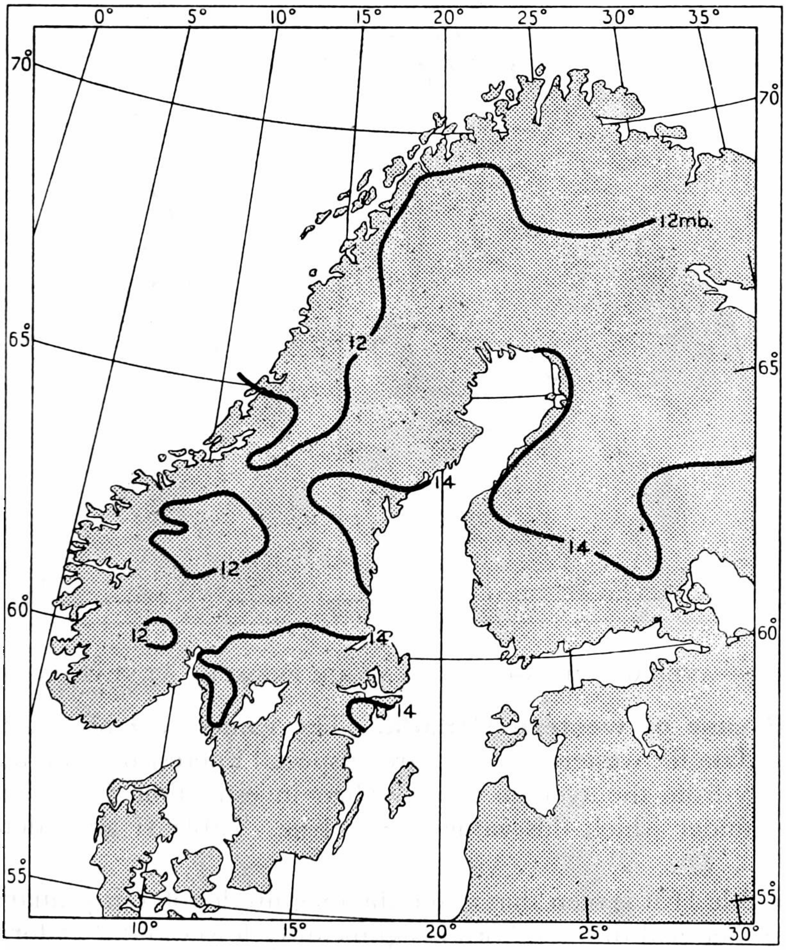


FIG. 2—AVERAGE MEAN-OF-DAY VAPOUR PRESSURE AT M.S.L.

The last of these expressions is accurate for stations less than 1,300 m. above M.S.L.

Fig. 1 gives the variation with height of the reduction factor for reducing vapour pressure to M.S.L. Up to 1,300 m. the linear and logarithmic formulae do not differ greatly, but they diverge fairly rapidly above. This diagram also indicates the relationship between formulae (11) and Hann's formula. Hann's formula gives values of e_0 about 10 per cent. lower than the linear formula at 1,300 m. and under-corrects for height at all levels.

Figs. 2 and 3, giving average mean-of-day vapour pressure for Scandinavia for July at sea level and at station level, demonstrate how the effects due to topography may be removed, leaving true horizontal variations.

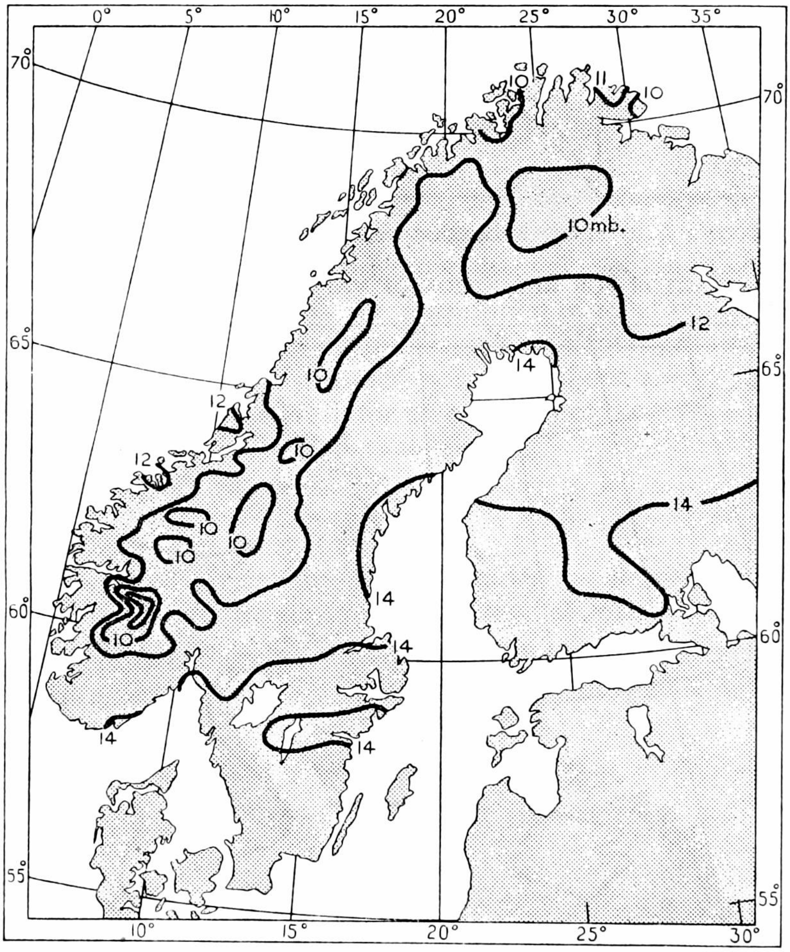


FIG. 3—AVERAGE MEAN-OF-DAY VAPOUR PRESSURE AT STATION LEVEL

Special case of western Canada.—The values of α obtained from the analysis of data for western Canada are of special interest because they diverge considerably from the average value. Their investigation throws light on the conditions under which this value of α is true. Table II gives details of the analysis.

From Table II it is seen that while the magnitudes of a in January and July are almost identical that for April is significantly lower and that for October is higher. The values of α are variable with a maximum in January and a

TABLE II—VALUES FOR WESTERN CANADA

	a	$\bar{h}$	$\bar{e}$	e_0	α
		mb.	mb.	mb.	
January	−0·003029	−1·3592	3·4810	4·8401	0·000626
April	−0·002376	−1·0662	6·0333	7·0996	0·000335
July	−0·003028	−1·3585	12·6286	13·9871	0·000216
October	−0·003492	−1·5666	7·6429	9·2095	0·000379

These values are the results of computation and do not show the accuracy with which they are known.

minimum in July. This indicates that in January and July the rates of fall of vapour pressure with height are identical, but there is a fundamental change in e_0. July represents the normal state consistent with other parts of the world, but in January there is a significant difference.

Let e in January be a linear function of what it would be if the variation in the vertical were normal; then

$$e = L \exp(-\beta h) + M \qquad \ldots\ldots\ldots (12)$$

where L and M are constants.

By similar calculations to those giving e_0'/e_0 and β

$$L = \frac{\frac{1}{12}\alpha''\beta^2 H^3 e_0''}{\frac{1}{2}\beta H\{1+\exp(-\beta H)\} - \{1-\exp(-\beta H)\}}$$

and $$M = e_0''\left[\frac{\frac{1}{12}\alpha''\beta H^2\{\exp(-\beta H)-1\}}{\frac{1}{2}\beta H\{1+\exp(-\beta H)\}-\{1-\exp(-\beta H)\}}+\left(1-\frac{\alpha'' H}{2}\right)\right]$$

where α'' and e_0'' are values of α and e_0 corresponding to a situation in which equation (12) describes the variation of vapour pressure in the vertical. Putting $\alpha'' = 0{\cdot}00063$, $\beta = 0{\cdot}295 \times 10^{-3}$ and $H = 1{,}100$ m. (the limit of altitude of stations analysed) then

$$\left.\begin{aligned} L &= 2{\cdot}46\, e_0'' \\ M &= -\,1{\cdot}44\, e_0'' \end{aligned}\right\} \qquad \ldots\ldots\ldots (13)$$

By equations (6) and (12), a remains unchanged.

Therefore $\alpha'' e_0'' = \alpha e_0$

$$e_0'' = 0{\cdot}40\, e_0. \qquad \ldots\ldots\ldots (14)$$

From equations (12), (13) and (14) we have

$$e = 0{\cdot}984\, e_0 \exp(-\beta H) - 0{\cdot}58 e_0,$$

i.e. to a sufficient degree of approximation

$$e = e_0\,[\exp(-\,0{\cdot}000295h) - 0{\cdot}6]. \qquad \ldots\ldots\ldots (15)$$

Equation (15) is consistent with the two linear equations

$$e = e_0\,(1 - 0{\cdot}00025h) \text{ and}$$

$$e = e_0''\,(1 - 0{\cdot}00063h)$$

i.e. $e_0\,(1 - 0{\cdot}00025h) - 0{\cdot}6\, e_0 = e_0''\,(1 - 0{\cdot}00063h)$.

The explanation now suggested for these differences is as follows. During the summer there is, over western Canada, a freely mixing atmosphere during which the law $e = e_0 \exp(-\beta h)$ holds for long-period averages of vapour pressure. During winter the intense radiation cooling causes a deep inversion in the lower layers which suppresses free vertical mixing; however, above the inversion free mixing continues.

The law followed in winter is of the form

$$e = e_0 [\exp(-\beta h) - \delta]$$

where $e_0\delta$ is the reduction in vapour pressure due to the inversion.

Vapour pressure at sea level at the position $(\bar{\lambda}, \bar{\phi})$ in the area being considered is $e_0(1 - 0{\cdot}6)$ or $0{\cdot}4e_0$, i.e. it is 0·4 times the normal vapour pressure at sea level.

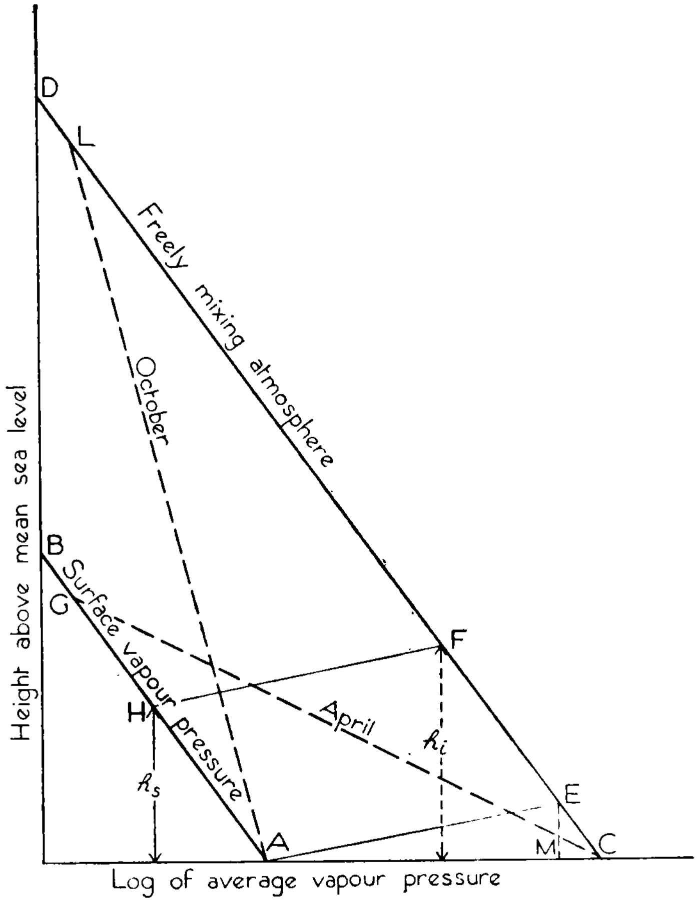


FIG. 4—GENERALIZED DIAGRAM OF VARIATION OF AVERAGE VAPOUR PRESSURE WITH HEIGHT OVER WESTERN CANADA

In Fig. 4, in which the logarithm of average atmospheric vapour pressure is plotted against height above sea level the line AB represents the variations in the vertical of vapour pressure at screen level, AED represents the distribution in the vertical above a sea-level station while HFD represents it above a station h_s m. above M.S.L. (AB is not strictly a straight line). There is a layer with an increase in vapour pressure with height $(h_i - h_s)$ m. thick (dependent on height of station above M.S.L.). The line CD represents a freely mixing atmosphere without the inversion and the point C represents e_0 the sea-level vapour pressure in a freely mixing atmosphere. ME represents the height of the top of the inversion above a sea-level station.

Fig. 5 gives data for Norman Wells[16], one of the northerly stations used in the analysis. The averages used for this diagram are for a short period and for a place well north of the central position for which the above equations hold. However the diagram is sufficient to show the mechanism described above and in Fig. 4. It will be seen that the point E in the diagram corresponds to the top of the temperature inversion. This is true for all stations for which data are available: Fort Smith, Fort Nelson and Norman Wells.

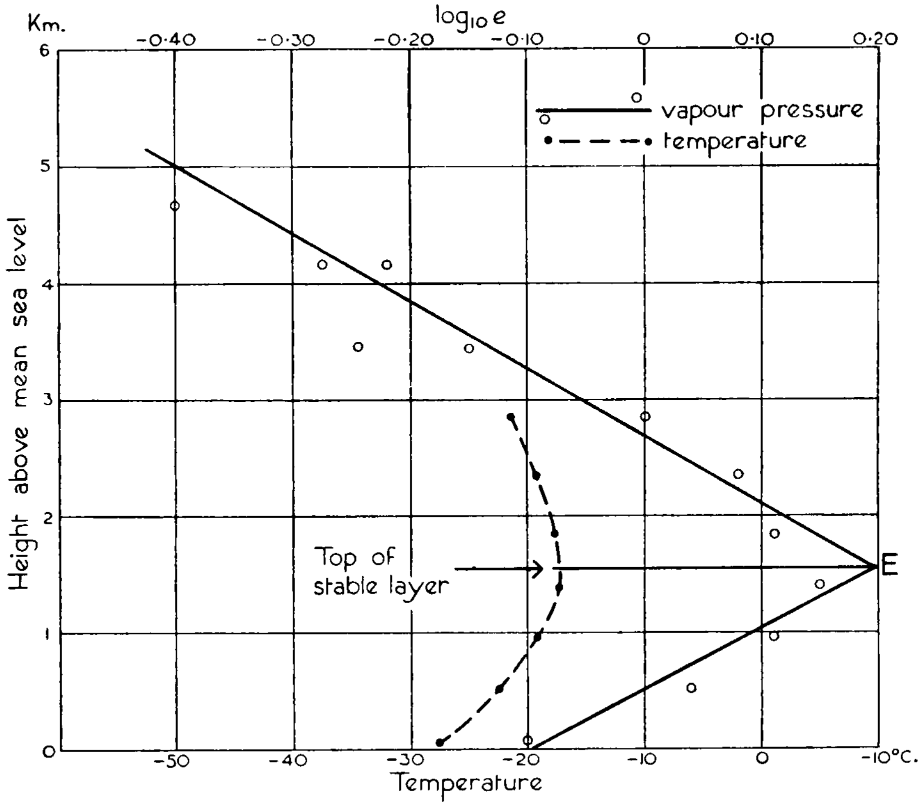


FIG. 5—VARIATION OF VAPOUR PRESSURE AND AIR TEMPERATURE AVERAGES WITH HEIGHT OVER NORMAN WELLS

From Table II and Fig. 4 we see that for April *a* is of smaller magnitude and for October of larger magnitude than the values for January and July. The explanation of this is that October is a transitional month, and the inversion layer AE has formed at lower stations but not at higher ones and the curve runs approximately from A towards the line CD, for example, AL. In April the inversions AE have wholly or partially broken down at the lower stations and the curve of vapour pressure with height runs from some point on CD towards the line AB, for example CG. Thus in the two seasons in which there is a homogeneous structure the variation in the vertical is identical, but in the seasons during which the situation is not homogeneous there are differences. This hypothesis suggests that formulae (11) are true for a freely mixing atmosphere, but when mixing is suppressed by a steep inversion the law breaks down.

Average temperature-height curves for the three stations for which data are available[16] support this theory. For example, in April, at Norman Wells (a low-level station) the only sign of the winter inversion is a slight decrease in the lapse rate at about 1,100 m., but in October the lapse rate has decreased between about 1,500 m. and the surface. There are no data for high-level stations.

Thickness of the inversion.—Some idea can be obtained of the thickness of the inversion from the following considerations.

If the vapour pressure at the top of the inversion is e_i

then $e_i = e_0 \exp(-\beta h_i)$

where h_i is the height of the top of the layer above M.S.L.

If e_s is the vapour pressure at the surface and h_s is the height of the station above sea level

$$e_s = e_0\{\exp(-\beta h_s) - 0{\cdot}6\}.$$

$$\text{Therefore } h_i = -\frac{1}{\beta}\left[\log_e k + \log_e\{\exp(-\beta h_s) - 0{\cdot}6\}\right] - h_s$$

where $k = e_i/e_s$. If average values in January at Norman Wells are taken, where $h_s = 89$ m., $k = 1{\cdot}9$, and $\beta = 0{\cdot}295 \times 10^{-3}$, then $h_i = 1{,}200$ m., which is of the correct order (see Fig. 5). However, this is no more than a rough check.

Conclusions.—(1) The variation in the vertical of the long-period average mean-of-day vapour pressure can be represented very accurately by the following equation:—

$$e = e_0 (1 - 0{\cdot}00025h)$$

where h is less than 1,300 m.

(2) If the true variation of average vapour pressure with height is

$$e = e_0 \exp(-0{\cdot}000295h)$$

the linear equation would be an almost perfect fit up to about 1,300 m. The exponential form may therefore be used as an extrapolation formula to reduce averages from great heights to sea level.

(3) The special case of western Canada shows that the above formulae are true for a freely mixing atmosphere but when free mixing is suppressed by a deep inversion they are not applicable.

(4) It is necessary to note that these relationships apply to averages of daily means only. No simple relationship has been found between diurnal variation of vapour pressure and height.

REFERENCES

1. SHAW, SIR NAPIER; Manual of meteorology. Vol. II: Comparative meteorology. Cambridge, 1928, p. 129.
2. STRACHEY, R.; On the distribution of aqueous vapour in the upper parts of the atmosphere. *Proc. roy. Soc., London*, **11**, 1861, p. 182.
3. HANN, J.; Die Abnahme des Wasserdampfgehaltes der Atmosphäre mit zunehmender Höhe. *Z. Met., Wien*, **9**, 1874, p. 193.
4. HANN, J.; Die Abnahme des Wasserdampfgehaltes mit der Höhe in der Atmosphäre. *Met. Z., Wien*, **11**, 1894, p. 194.
5. SÜRING, R.; Abnahme des Dampfdruckes mit der Höhe. Hann-Süring "Lehrbuch der Meteorologie". Fünfte vollstandig neubearbeitete auflage, Band I, Leipzig, 1939, p. 332.
6. BHATIA, K. L.; A comparison of Cherat surface observations of temperature and humidity at 0800 hrs. L.T. with aeroplane observations over the Peshawar Plain at the same level. *Sci. Notes met. Dep. India, Delhi*, **10**, No. 116, 1942, p. 11.
7. Buenos Aires, Direccion de Meteorologia Geofisica e Hidrologia. *Estadisticas climatologicos, Buenos Aires*, Serie B, No. 1, 1944.
8. Colombo, Department of Meteorology. *Report on the Colombo Observatory for 1947*. Colombo, 1949.

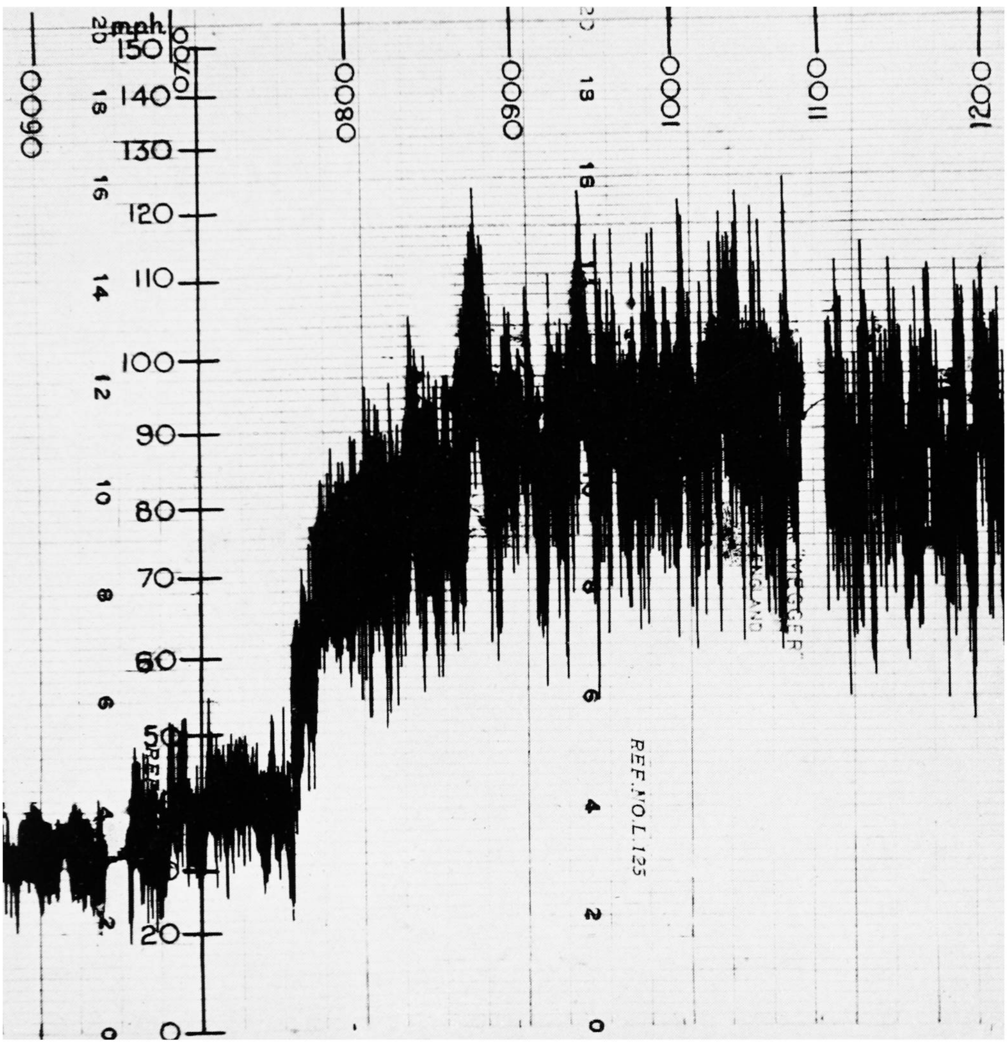
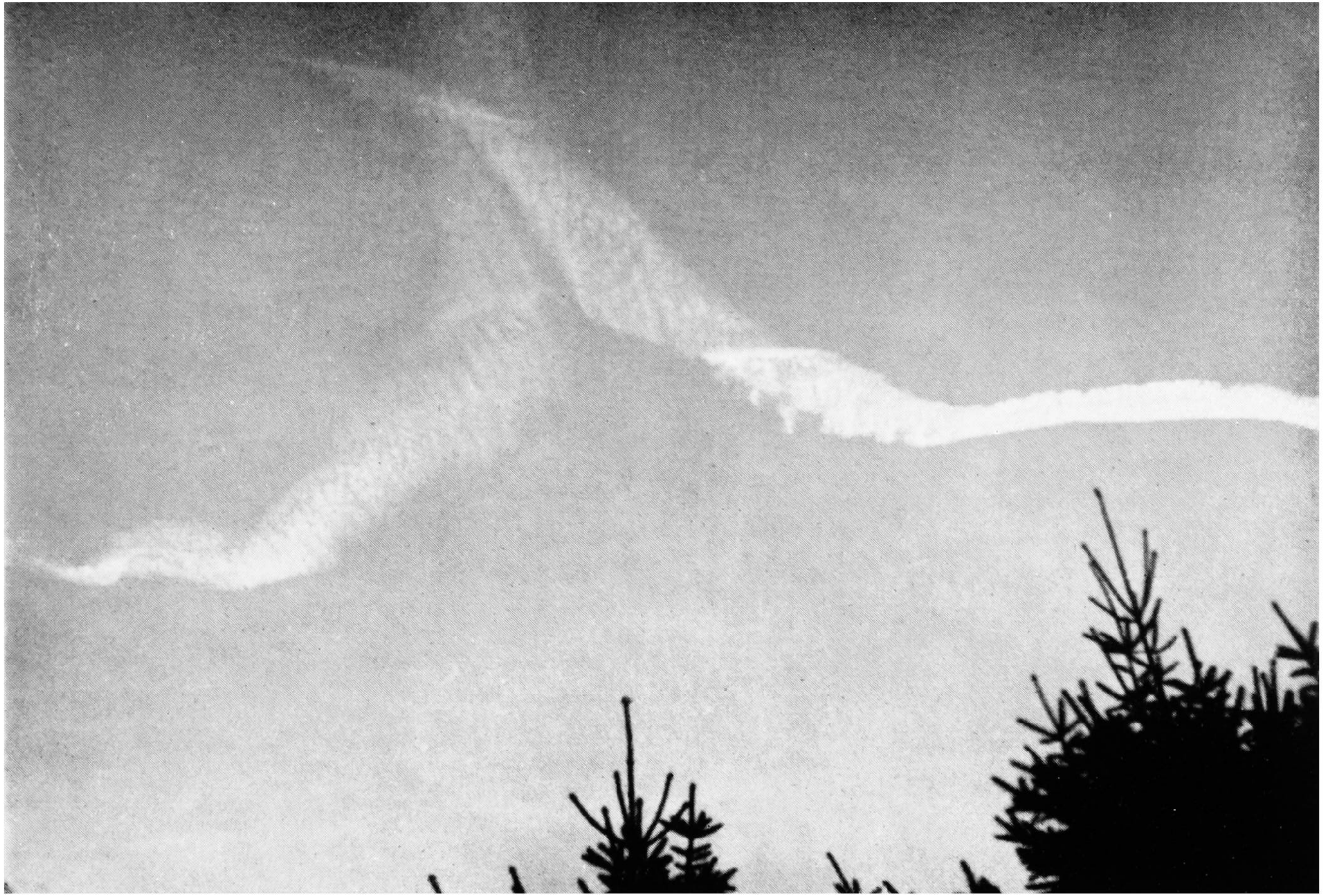


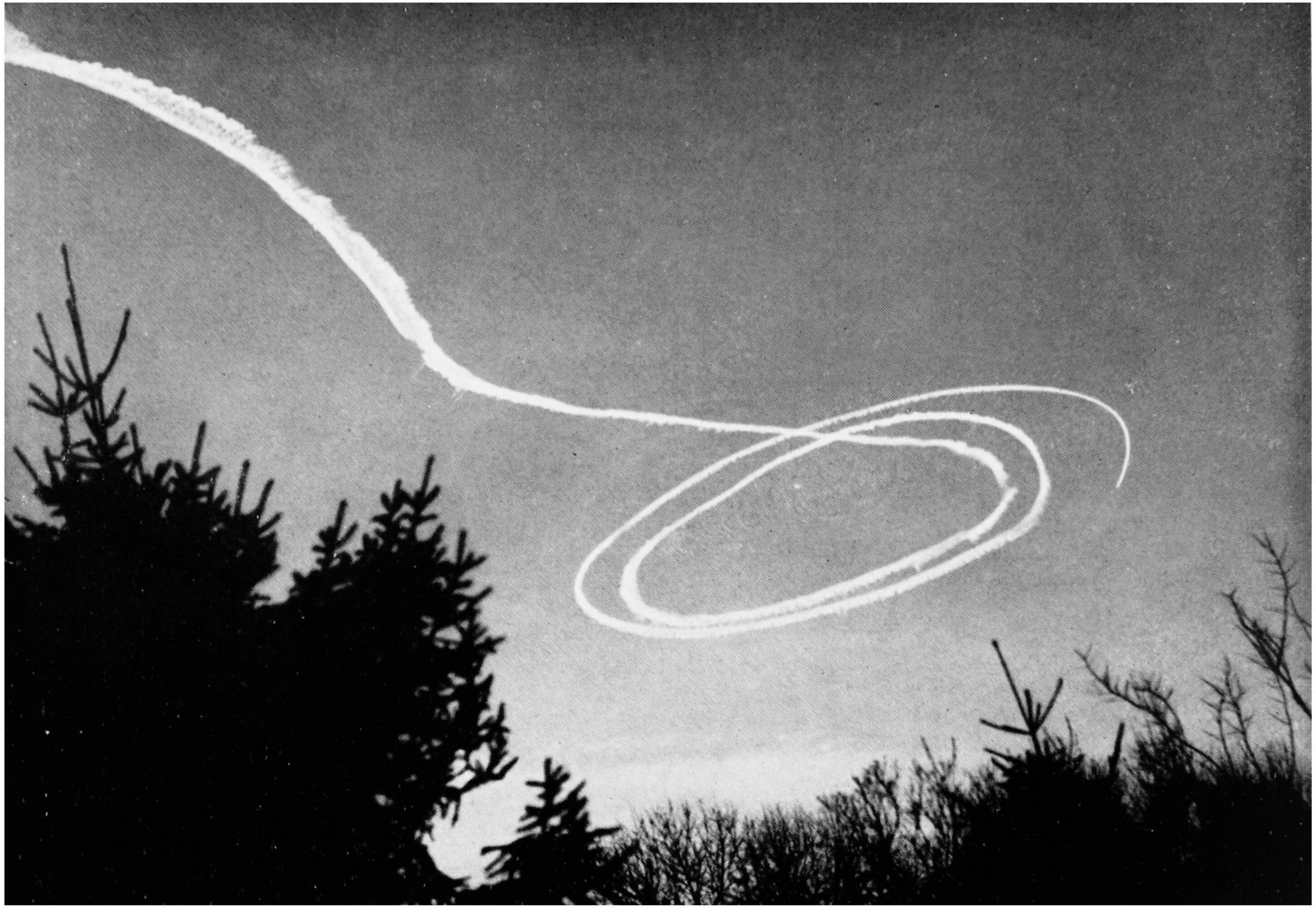
FIG. 1—TRACE FROM THE ELECTRIC CUP GENERATOR ANEMOMETER AT COSTA HILL, ORKNEY

The scale which has been added on the left-hand side is derived from wind-tunnel calibrations and is not linear. On two occasions the clock seems to have "jumped"—at about 0630 and 1100

see p. 97



CONDENSATION TRAILS
Apparent wind shear effect
see p. 125



CONDENSATION TRAILS
Apparent wind shear effect
see p. 125

AFTERNOON VALLEY FOG, 1430 DECEMBER 27, 1952
see p. 125

9. Lourenço Marques, Serviços de Marinha. *Relatório do Observatório Campos Rodrigues em Lourenço Marques*. Ano de 1945. 1947.
10. Nairobi, British East African Meteorological Department. *Summary of meteorological observations in Kenya for 1940–48* (Summaries for 1947 and 1948 have slightly different titles).
11. Nairobi, British East African Meteorological Department. *Summary of meteorological observations for 1946–49. Part II—Tanganyika* (Summary for 1946 has slightly different title).
12. Berlin, Reichsamt für Wetterdienst. Klimakunde des Deutsches Reiches. Band II: Tabellen. Berlin, 1939, p. 235.
13. Toronto, Meteorological Division. Climatic summaries for selected meteorological stations in the Dominion of Canada, Vol. I: Average values of mean and extreme temperature, mean and extreme humidity, sunshine, precipitation. Toronto, 1947, p. 29.
14. BOUGHNER, C. C. and THOMAS, M. K.; Climatic summaries for selected meteorological stations in Canada, Newfoundland and Labrador, Vol. II: Humidity, wind speed and direction. Toronto, 1948, p. 19.
15. WEATHERBURN, C. E.; A first course in mathematical statistics. Cambridge, 1946, p. 242.
16. HENRY, T. J. G. and ARMSTRONG, G. R.; Aerological data for northern Canada. Toronto, 1949.

FORECASTING OUTBREAKS OF POTATO BLIGHT

By L. P. SMITH, B.A.

During the last three years the reporting stations of the Meteorological Office have been helping the Provincial Plant Pathologists of the National Agricultural Advisory Service in England and Wales to solve the problem of forecasting outbreaks of potato blight. An official report on the investigation by the Ministry of Agriculture and Fisheries summarizing the results obtained, has recently been published[1]. Similar work on a smaller scale has previously been done in Scotland.

Blight is a fungus disease which attacks the potato haulms, spreads rapidly under warm moist conditions, and finally kills the plant; late in the season, spores may be washed on to the potatoes themselves, causing subsequent deterioration during storage. The spread of blight may be prevented by spraying, but to obtain maximum benefit the time of spraying is important, and therefore the forecasting of outbreaks is a very essential service.

Previous work on the disease indicated that a period of 48 hr. during which the temperature in a Stevenson screen did not fall below 50°F. and the relative humidity did not fall below 75 per cent. was a good indicator of a blight outbreak some 7–21 days later. For this reason it was suggested by the Agricultural Meteorology Branch of the Meteorological Office that the plant pathologist might make use of the hourly observations taken at official stations. In doing so, it was realized that:—

(i) The criteria assume a constant relationship between screen climate and climate within the crop (or eco-climate)—an assumption which is by no means valid throughout the life of the crop, or during very wet or very dry spells.

(ii) The reporting stations are not all situated in areas where potatoes are grown.

Nevertheless it was agreed to test the criteria over a period of years to ascertain what degree of help could be obtained by the use of existing observations, and in 1950 arrangements were made to supply "Potato blight warnings" to plant pathologists, and for the latter to carry out widespread surveys of the potato crops to determine the dates of outbreaks and progress of the disease.

The results of the first year were very encouraging. Most of the reports from the stations correctly forecast the outbreak of blight. The disease occurred early in the south and west, and reached epidemic proportions in some areas. The stations which failed to give warnings were situated in non-representative areas where the break-down of the criteria was not unexpected. Some of the northern stations did not give warnings of the later outbreak in their area, but, on the other hand, they did not give any misleading false alarms at earlier stages.

Following this initial success, the investigation was intensified in 1951, broken critical periods or "near misses" being included in the warning system and assessment surveys of the disease increased. 1951 was not a "blight year", the outbreaks in most regions being at least a month later than in 1950, but a very warm moist period in September caused a rapid build-up of the disease which rapidly killed off the haulms before lifting, but was too late to affect yields.

Nearly every station gave warnings during the September period, but during the summer there were several partial failures, and it was obvious that a firm screen-crop climate relationship was not present in a marginal year. Experience furthermore indicated that undue weight could not be placed on a warning, or absence thereof, from a single station, and an "operation room" method, whereby the meteorological warnings and disease reports were considered on country-wide maps and charts, was evolved, necessitating twice-weekly consultations between the Agricultural Meteorology Branch at Harrow and the Plant Pathology Laboratory at Harpenden.

This method was extended in 1952, and charts were prepared showing the current incidence of both warnings and outbreaks. When a flush of warnings occurred copies of the chart were circulated by the Laboratory to all provincial pathologists in the form shown in Fig. 1.

1952 was a blight year in the west, but not elsewhere. Early outbreaks in the west were correctly forecast, and a minor flush of warnings in mid June gave warning of sporadic outbreaks on early crops. The second flush of warnings occurred in early August, and enabled a correct forecast of mid-August blight on main crops to be made and circulated.

Preventive spraying is not usually needed if the blight outbreaks occur after mid August; a later attack cannot adversely affect the yield of the crop to any great extent, although it may impair its keeping qualities. In assessing the value of a station warning, it is therefore necessary to judge its performance in allowing a forecast to be made of an outbreak before mid August; in 1952, three stations gave premature warnings, and three others gave no warnings of a significant outbreak. All the other stations either gave valid warnings, or gave no false alarms.

The conclusions of the three-year investigation were to the effect that, although complete accuracy was impossible, the warnings issued by the meteorological stations, assessed by an operations chart method, gave a very reliable guide for the issue of blight forecasts. A few of the stations used were unsuitable, by reason of their site, and will probably be omitted in future plans. Research is going on with a view to obtaining more precise criteria on which to base the warnings, and on the "follow-up" weather which succeeds a warm moist spell and which determines a slow spread or rapid build-up of the disease.

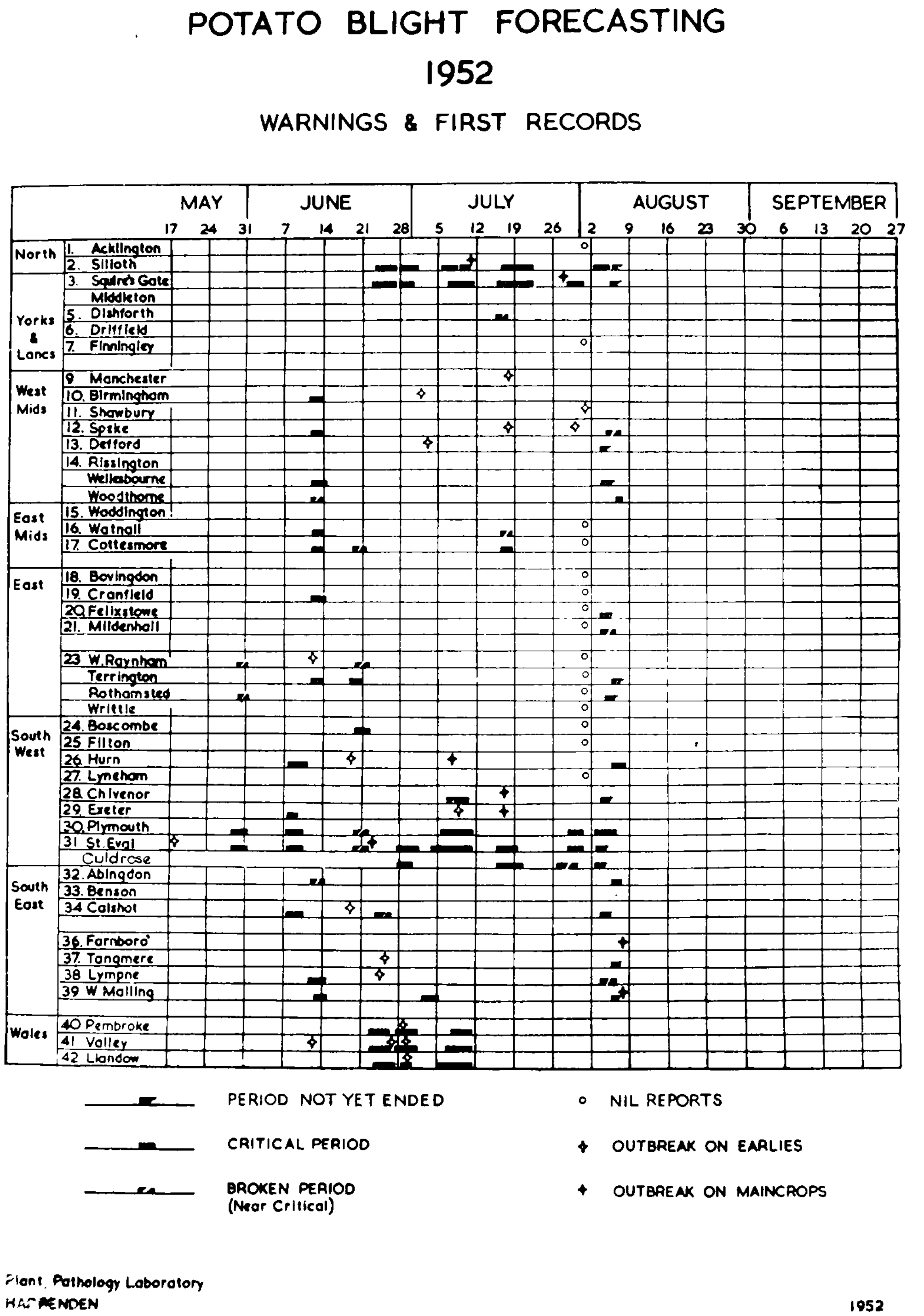


FIG. I—CHART AS CIRCULATED BY THE PLANT PATHOLOGY LABORATORY WHEN A FLUSH OF WARNINGS OCCURRED

The whole investigation is an excellent example of what can be done by close co-operation between scientists to protect our supply of food, and the official report concludes with a note of appreciation and thanks to all the many participators in the scheme.

REFERENCE

1. LARGE, E. C.; Potato blight forecasting investigation in England and Wales, 1950–52. *Plant Path., London*, **2**, 1953, p. 1.

METEOROLOGICAL OFFICE DISCUSSION

Atmospheric circulation at high altitudes in the tropics and subtropics

The discussion on January 19, 1953, held at the Royal Society of Arts was opened by Mr. J. K. Bannon and Mr. N. E. Davis.

Mr. Bannon described recent work in the Upper Air Climatological Branch in summarizing observations of winds at high altitudes in the tropics and subtropics. Up to a few years ago knowledge of such winds was very slight, and was derived from a few pilot-balloon observations and observations of cirrus cloud; this knowledge has been summarized in *Geophysical Memoirs* No. 85, "Upper winds over the world"[1]. During the last two or three years an increasing number of radar or radio wind stations have been in operation in low latitudes, and a start has been made to use the observations from these stations to revise *Geophysical Memoirs* No. 85. Charts for the zone 40°N.–40°S. were shown for four levels between approximately 30,000 and 55,000 ft., namely 300 mb., 200 mb., 150 mb. and 100 mb. for each of the months January, April, July and October. On each chart was plotted the vector mean wind for the month for each station, the great majority of the data so summarized being for 1951. Each vector mean was, in general, computed from 15 or more daily observations. In regions of strong wind observations were often missing as the radar or radio targets were carried out of range before reaching the greater heights. The strong winds occurred for the most part at latitudes greater than 20°, however, and it was possible, therefore, to obtain a good idea of the winds in these regions from temperature data using the geostrophic relation. There were very few observations from the southern hemisphere, and most of the description applied to the northern hemisphere only.

For January the charts showed a strong W. wind belt between 20° and 40°N., the greatest speeds occurring between the levels 200 mb. and 150 mb. There was also a moderate easterly stream (up to 30 kt. in the mean) over equatorial regions, but this stream ceased over the central Pacific. The maximum speeds in the easterlies occurred about the 150-mb. level. The strong westerlies increased eastwards across north Africa. Over Iraq the mean maximum wind was about 100 kt. This stream emerged from Asia near the south of Japan (30°N.) where the maximum mean wind was nearly 200 kt., and a branch of this current could be seen near the Hawaiian Islands. Over the Pacific it is likely that there was a northerly branch also, associated with the polar front. The stream was seen again, much intensified, over the United States and the Caribbean Sea; this stream probably divided over the Atlantic Ocean also, the true subtropical branch flowing east to north-west Africa and the other branch, associated with the polar front, north-eastwards towards Iceland and the British Isles. It was not known if the strong subtropical westerly stream was continuous across the Pacific and Atlantic Oceans as observations were lacking; but this seemed likely, at any rate in the mean.

North–South cross-sections of the January mean flow were shown for longitudes 45°E. (Iraq), 80°W. (United States and Caribbean Sea), 140°E. (Japan) and 160°E. (Marshall Islands). These emphasized the differences in zonal flow in different longitudes. At 80°W. the mean flow had two maxima; the more southerly at about 27°N. was the true subtropical stream, and was not, in general, associated with any front. The more northerly was probably associated with the polar front. At 45°E. only one core could be found in the current, about 28°N., and at 140°E. the maximum was very pronounced at about 30°N. though there may have been a secondary maximum near or to the north of 40°N.

In July, the subtropical westerlies were much lighter than in January, and the equatorial easterlies correspondingly stronger. Over North America strong westerlies were well to the north of 40°N., but they could be found along the Mediterranean Sea and then at about 40°N. to Japan with maximum mean speeds about 50 kt. This stream probably passed to the north of the Hawaiian Islands, but it was not known if it was continuous across the Pacific and Atlantic Oceans. The height of this stream was much the same as in January. The corresponding mean stream over Australia was quite strong (maximum speed about 100 kt.) it being the winter season there. This stream probably extended round the southern hemisphere.

The easterly belt was extensive in July and mean speeds exceeded 40 kt. to the south of Asia and over central Africa where the winds were more steady in direction and speed. The easterlies were lighter and more variable in other equatorial regions and the strong steady easterlies appeared to be associated with the Eurasian land mass. As in January, maximum speeds in the easterlies occurred about the 150-mb. level.

A peculiarity of the July flow over the Caribbean Sea and also over the Marshall Islands was a slow westerly stream some 700 miles wide and 20,000 ft. deep, centred between 200 mb. and 150 mb. and embedded in a general easterly current.

The mean flow in April and October appeared in general to be intermediate between that in January and July.

Mr. N. E. Davis discussed statistics providing information on the wind variation at a particular place or height or over a particular route.

The first is the standard vector deviation σ which is defined by $\sigma^2 = [(\mathbf{V}-\bar{\mathbf{V}})^2]$ where the square brackets denote a mean taken over a large number of observations, and $\bar{\mathbf{V}}$ is the mean vector wind. The standard vector deviation is a measure of the variability of wind and consequently a measure of the intensity of disturbances. The standard vector deviation shows a maximum in temperate latitudes (especially near the British Isles) and a minimum near the equator, so that the upper air circulation over the tropics is such that the disturbances in it are less intense than over middle latitudes.

The standard vector deviation may be used as a yardstick for measuring the success of forecasting. If $\mathbf{V}_f$ is the forecast value and $\mathbf{V}$ the true value, then if $[(\mathbf{V}_f - \mathbf{V})^2] < \sigma^2$ the forecast is better than giving the normal $\bar{\mathbf{V}}$ for the season. In temperate latitudes where σ is large $[(\mathbf{V}_f - \mathbf{V})^2]$ is normally considerably less than σ^2, but in the tropics where σ is 20 kt. or less worthwhile forecasts of upper wind may be more difficult to achieve.

The standard vector deviation though it describes how intense disturbances are does not give any information as to how rapidly they occur. This is given by a second statistic r_t the correlation of wind with time, defined by

$$r_t = \frac{[(\mathbf{V}_t - \bar{\mathbf{V}}) \cdot (\mathbf{V} - \bar{\mathbf{V}})]}{\sigma^2}$$

where $\mathbf{V}_t$ is the wind t hours after the observation of $\mathbf{V}$ for the same place and height. Values of r_t calculated by Mr. Durst for various places show that it depends only on t, and is independent of height and place except that the values are probably slightly lower in the tropics. The equation of r_t is of the form $e^{-\lambda t}$ where λ depends on what might be termed the eddy spectrum of atmospheric disturbances. The value of r_t falls to $\frac{1}{2}$ for t slightly greater than 24 hr.

A third statistic is the correlation of wind with distance defined by

$$r_l = \frac{[(\mathbf{V}_1 - \overline{\mathbf{V}}_1) \cdot (\mathbf{V}_2 - \overline{\mathbf{V}}_2)]}{\sigma_1 \sigma_2}$$

where $\mathbf{V}_1$ and $\mathbf{V}_2$ are simultaneous observations of wind at the same height for two places distant l apart, and σ_1 and σ_2 are the corresponding standard vector deviations. Values of r_l, calculated by Mr. Durst from a number of pairs of places, show that the correlation of wind with distance and consequently the scale of disturbances is less in the tropics than in temperate latitudes. The form of r_l is very similar to that for r_t. In fact, if (for temperate latitudes) the scales of r_t and r_l are such that $t = 6l/100$ then the curves coincide. This is a curious result and must mean that the average speed of upper air disturbances (at least over Europe) is 14–15 kt., which is in broad agreement with figures given by Namias and Clapp[2] and Flöhn[3]. In the tropics the average speed is less since r_l is smaller.

Thus disturbances in the upper air in tropical regions are smaller and less intense than in temperate latitudes and move more slowly. Hence their form will be more rapidly changed by vertical motion, so that the conventional methods of forecasting by estimating the advection of the disturbances and making allowance for vertical motion are less likely to give a good forecast than in temperate latitudes.

Suppose however we have an observation of wind at a point, then it can be modified by means of the equation $\mathbf{V}_t = r_t \mathbf{V} + (1 - r_t)\overline{\mathbf{V}}$ to give an estimate of the wind at some future time t which will be more accurate than giving either the actual observation unmodified or the normal. For the standard error in using the equation is $\sigma \sqrt{(1 - r_t^2)}$ which is less than σ; while the standard error in using the actual observation $\mathbf{V}$ for the wind t hours later is $\sigma\sqrt{\{2(1 - r_t)\}}$ which is greater than $\sigma\sqrt{(1 - r_t^2)}$. In fact for $r_t < \frac{1}{2}$, $\sigma\sqrt{\{2(1 - r_t)\}}$ becomes greater than σ so that giving a latest actual observation more than 24 hr. old is worse than giving the normal for the season.

A similar equation can be set up for the average wind over a route. In this case since an adverse wind at one point is to some extent counteracted by a more favourable wind at another, the standard error in modifying the wind over a route is considerably less than the error for the wind at a point, and indeed for temperate latitudes is comparable with that achieved in standard methods of forecasting. In the tropics, since the standard deviation of wind is less than in temperate regions, the method would attain an accuracy sufficient for all normal route flying. Unfortunately it is impossible in the tropics to determine the average wind on any particular occasion within 5 kt., unless radar wind stations are situated at least every 500 miles.

First reports from Comet and Canberra aircraft which have flown at high levels in tropical regions indicate that cumulonimbus can and does reach up to the tropopause level which is over 50,000 ft., while the amount of cirrus and cirrostratus is much greater than previously realized. These clouds are produced by the vertical motion resulting from the convergence of air at low levels. If the reason for this convergence on a particular occasion could be found or even if it could be measured a great stride would have been made in tropical meteorology. Since convergence can only be determined from accurate measurements of wind this problem is the same as the one described before.

As a possible means of making some progress in tropical meteorology Mr. Durst has suggested that a Tropical Year should be organized in which a concentration of surface and upper air stations would be set up in a limited area to study the motion of the air in the tropics and determine the cause of weather disturbances in the tropics.

The Director, in opening the general discussion, referred to Mr. Davis's remarks regarding a Tropical Year, analogous with the former Polar Years, and said that the International Council of Scientific Unions was proposing to arrange a Geophysical Year in 1957–58, when efforts would be made to obtain special observations from all over the world. The Meteorological Office would press for special consideration to be given to tropical problems, and he hoped that before this date the Meteorological Office would be able to formulate specific problems for investigation in this international project. The Director also asked if the peculiar westerly belts embedded in the easterlies over the Caribbean and south-west Pacific in July were real, or if they could have arisen from the method of analysis. Mr. Bannon replied that as far as could be ascertained these mean westerlies were real, though their physical significance was obscure.

Dr. Robinson inquired how many pairs of observations were used to compute r_l and if much interpolation was required; Mr. Davis replied that little interpolation was necessary as data were used from several pairs of stations at various distances apart.

Mr. Wallington suggested that the regression equation for a wind forecast might be extended by a third term which would take account of a conventional forecast.

The Director then intervened to point out that the statistical technique for forecasting winds had not yet been approved for general use; it was still under test.

Mr. Gilchrist, in showing cross-sections along 80°W. for two days of January 1951 when there was a well defined maximum of wind velocity in the sub-tropics, pointed out differences between this maximum and the polar jet stream, namely, it occurred at about 200 mb. with a very pronounced vertical shear immediately under it, was not associated with a frontal system, and was not related to the tropopause in the usual way. By means of diagrams showing the 200-mb. winds at Miami and Bahrein in January and at Aden and Albrook Field (Panama Canal) in July, he drew attention to the fact that the subtropical flow across Arabia and southern Asia in both summer and winter was much steadier than in other parts of the world.

Mr. Jenkinson described a simple technique for deriving charts of isotachs and stream-lines from charts of temperature at fixed pressure levels using the geostrophic winds from the surface isobars added vectorially to the thermal winds from successive layers of the atmosphere. An example was shown of mean isotachs for January for the Middle East at the 200-mb. level computed by this method; the maximum wind was shown as 120 kt. between Bahrein and Habbaniya. Mr. Jenkinson also drew attention to the advantages of using the cosine of the latitude as horizontal co-ordinate when computing geostrophic zonal winds in low latitudes (James[4]); he claimed that qualitatively, if not quantitatively, correct results could be obtained by this method even over the equator, and as an example quoted a calculated mean easterly component of 50 kt. at 100 mb. over Singapore for July.

Mr. Hay described the main features of the air flow at high levels over Singapore and Hongkong based on two years' observations at both places. In the upper troposphere at Singapore easterlies prevailed all the year, reaching a maximum (mean vector wind) near the 50,000-ft. level in the monsoon periods (December–February, June–August) when 60 kt. was exceeded in many ascents. Typical ascents for these months showed a gradual increase of wind becoming more rapid with height up to near 50,000 ft., then an abrupt change to light westerlies. Decisive evidence for appreciable horizontal thermal gradients over Singapore was not yet available above 30,000 ft. However, the extreme differences noted between ascents at this level in a single year amounted to 16°F. Over Hongkong the wind régime was very similar to that over Bahrein; at the highest levels (100 mb.) easterlies prevailed from May to October, but at 300 mb. their duration was a month less with some interruptions by westerlies which lasted a few days. The easterlies were weaker than at Singapore (maximum mean vector winds 30–40 kt.). Typical ascents at Hongkong in summer showed a gradual increase of easterlies up to 60 mb., but the narrow belt of strong easterlies and the return to westerlies above, so common at Singapore, were not observed.

Prof. Sheppard said he thought the work described by Mr. Bannon was valuable and defended the use of climatic mean values to describe the general circulation of the atmosphere. He then offered an explanation of some of the peculiarities noted in the mean flow. First, he referred to the meridional flow towards the equator at low altitudes, the currents upwards over the equator and the return flow away from the equator in the upper troposphere; the principle of conservation of angular momentum then explained the strong W. winds in the upper troposphere in the subtropics, though friction reduced the speeds considerably. Next, he postulated that by irregularities in the distribution of land and sea and seasonal changes in insolation, the zone of up-currents is displaced to one side of the equator. The equatorward flow in the upper troposphere from the top of this up-current will then result in an easterly current, angular momentum being at least partly conserved. This would explain the strong constant easterlies to the south of Asia during the northern summer.

Mr. Gold said he was surprised that there were no observations shown on the charts for Australia. Mr. Bannon replied that several radar or radio wind stations were now in operation in the Australian area, and that it was understood that many more would be set up in the coming year. Mr. Gold wondered if the range of latitude over which there was a flow toward the equator in the upper troposphere, as postulated by Prof. Sheppard, was sufficient to generate the strong equatorial easterlies at high altitudes in July. Regarding the cross-section shown by Mr. Gilchrist for a particular day in January he pointed out that the discontinuity in lapse rate marked on the figure as a continuation of the polar tropopause surface sloped downwards towards the south, indicating wind increasing with height above it, with the conventional distribution of temperature.

Mr. Dewar showed diagrams of the mean vector winds at various levels up to 100 mb. for each month of the year at Aden, Bahrein and Habbaniya, emphasizing the change-over to easterlies at the first two stations in the summer.

Mr. Dight doubted whether the strong subtropical westerlies in the upper troposphere increased steadily across Asia in winter as Mr. Bannon had implied. He thought the great mountain mass of the Himalayas must have some effect on the flow. Mr. Bannon replied that Chaudhury[5] and Yeh[6] had noted the influence of the Himalayas, and that these mountains undoubtedly must have an important effect on the flow; he had purposely simplified the picture for demonstration purposes.

REFERENCES

1. BROOKS, C. P., DURST, C. S., CARRUTHERS, N., DEWAR, D. and SAWYER, J. S.; Upper winds over the world. *Geophys. Mem., London,* **10**, No. 85, 1950.
2. NAMIAS, J. and CLAPP, P. F.; Studies of the motion and development of long waves in the westerlies. *J. Met., Lancaster Pa.,* **1**, 1944, p. 57.
3. FLÖHN, H.; Probleme der großräumigen Synoptik. *Ber. dtsch. Wetterdienstes, U.S. Zone,* No. 35, 1952, p. 12.
4. JAMES, R. W.; A February cross-section along the Greenwich meridian. *Met. Mag., London,* **80**, 1951, p. 341.
5. CHAUDHURY, A. M.; On the vertical distribution of wind and temperature over Indo-Pakistan along the meridian 76°E. in winter. *Tellus, Stockholm,* **2**, 1950, p. 56.
6. YEH, T-C.; The circulation of the high troposphere over China in the winter of 1945–46. *Tellus, Stockholm,* **2**, 1950, p. 173.

METEOROLOGICAL RESEARCH COMMITTEE

The twenty-third meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held on November 20, 1952.

The Committee considered the problem of long-range forecasting and reviewed the methods put forward at different times.

The Committee also considered a paper by Dr. Sutcliffe[1] on the formation of new anticyclones, one by Dr. Goldie[2] on the storm of January 14–15, 1952, as a moving vortex, and two by Mr. Sawyer[3,4] on rainfall in the British Isles, the first dealing with rainfall resulting from depressions which passed eastwards between Scotland and the Faeroes, the second dealing with rainfall of depressions which moved eastward between the Bristol Channel and the Scottish Border.

ABSTRACTS

1. SUTCLIFFE, R. C., The formation of new anticyclones. *Met. Res. Pap., London,* No. 755, S.C. II/120, 1952.

In Atlantic and western Europe 42 new anticyclones were classified by 500-mb. contour and 1000–500-mb. thickness into 4 types—simple sinusoidal oscillation with and without pre-existing high to the south, anticyclonic wave disruption and complex types. Examples are illustrated and discussed. The upper air patterns however lead to development of ridges from pre-existing high-pressure centres much more often than to closed new highs, and this problem is discussed.

2. GOLDIE, A. H. R., The storm of January 14–15, 1952, as a moving vortex. *Met. Res. Pap., London*, No. 758, S.C. II/122, 1952.

Calculations are given of the vortical intensity and kinetic energy of this depression in comparison with others of a similar type, i.e. solid rotation to a maximum speed V_m at R from centre, and $V \cdot r$ = const. to a further distance S. Kinetic energy per unit thickness, $\pi\rho R^2 V_m^2 \, [\frac{1}{4} + \log_e(S/R)]$ is greatest in midwinter when it is 4–7 times that of a West Indian cyclone. Reduction of mean speed of jet stream by 10 kt. would provide the energy, and some support for this is found in profiles of upper winds on January 14–15 with distance from isobaric centre, but convection from surface layers is also necessary.

3. SAWYER, J. S., Rainfall in the British Isles resulting from depressions which pass eastward between Scotland and the Faeroes. *Met. Res. Pap., London*, No. 748, S.C. II/116, 1952.

Rainfall charts were drawn for 61 frontal depressions, and expressed as averages, standard deviations and medians, and charts are drawn for types classified by fronts crossing the British Isles. Rainfall was investigated in relation to various parameters and a few significant correlations found, but none of these are likely to improve on forecasts based on synoptic experience.

4. SAWYER, J. S., Rainfall of depressions which moved eastward across the British Isles between the Bristol Channel and the Scottish Border. *Met. Res. Pap., London*, No. 762, S.C. II/124, 1952.

Average rainfall and standard deviation of 45 depressions are charted for British Isles, with profile across track and frequency distributions. Amount was correlated with various parameters, giving a regression equation R (mm.) $= 15{\cdot}9 - 0{\cdot}18V - 0{\cdot}23(p - 1000) - 0{\cdot}092(\theta - 90)$, V = speed of depression in knots, p = central pressure of depression, θ = orientation of track in degrees from north; total correlation 0·60.

LETTER TO THE EDITOR

Barograph records of deep depressions

The barograph trace from Reykjavik, Fig. 1, for January 18, 1944, shows an unusually deep depression of the type described by Mr. C. K. M. Douglas in the *Meteorological Magazine* of April 1952. The depression, Fig. 2, which moved from the north-west Atlantic Ocean to the Arctic Ocean along the Denmark Strait was well occluded with the warm sector to the west of the British Isles. From the steepness of the gradients prevailing at the time, the fairly small curvature of the isobars and the barograph reading of approximately 943 mb. at Reykjavik, the central pressure of the low (down to the 930's at least) appears to have been comparable with extreme values for the Denmark-Strait area.

The trace is typical of the passage of a deep Atlantic depression and is V shaped rather than cusp-like, as with the trace of a more rapidly moving tornado or the smaller but more intense hurricane illustrated in the *Meteorological Magazine* of July 1952.

The symmetry of the trace illustrated here is commonly found in air-mass depressions, either of the tropical or polar type, and is unlike the steep fall followed by a steeper rise associated with the young frontal cyclones of temperate latitudes, of which the storm over north Scotland described by Mr. Douglas in

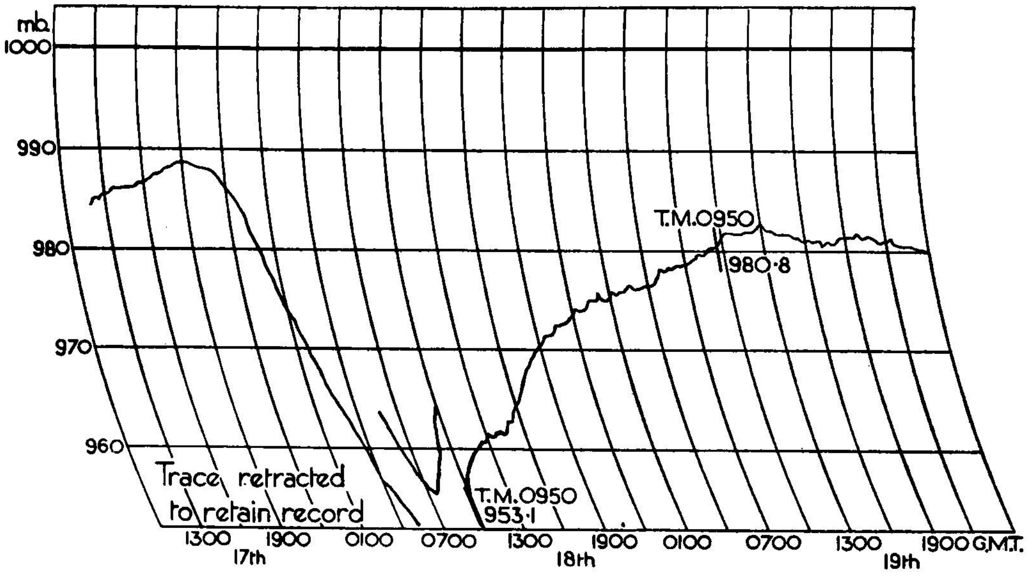


FIG. 1—BAROGRAPH TRACE FROM R.A.F. METEOROLOGICAL OFFICE, REYKJAVIK, JANUARY 18, 1944

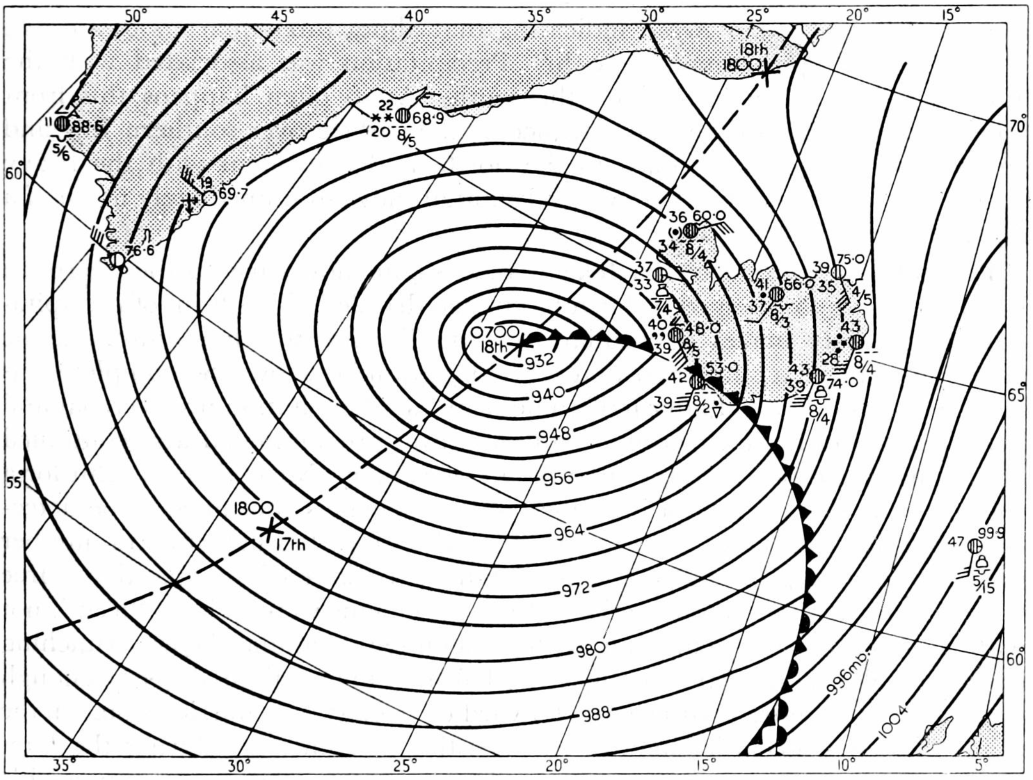


FIG. 2—SYNOPTIC CHART, 0700 G.M.T., JANUARY 18, 1944

the April 1952 issue of the *Meteorological Magazine* is an example. The latter type of low, when well occluded, is more likely to give a symmetrical trace of the type shown here, and when associated with a great deceleration of movement would of course give the reverse trace of a fall followed by a gradual rise.

E. N. LAWRENCE

July 29, 1952

NOTES AND NEWS

An unusually prolonged fall of "frozen drizzle"

The rather familiar expression "raining cats and dogs" may savour of exaggeration, and it is less of an exaggeration to say that it was "raining ice" during the afternoon and evening of Saturday, November 29, 1952, when "frozen drizzle" was observed near London over the remarkably protracted period of some 10 hr.

"Frozen drizzle" at the conclusion of a winter cold spell in the southern half of England is, in my experience, less rare than is commonly supposed. But it is normally a very transient phenomenon and often requires for its detection a favourably located, expectant observer. Invariably in the past I have detected it with the first drops of precipitation preceding a period of general rain. I would emphasize that I refer throughout this note to spherical droplets of clear ice, easily identifiable as such. The most protracted fall previously observed, of perhaps a dozen observations over the years, was one of about five minutes' duration as I was walking across the old Waterloo Bridge late one evening. It must be extremely unusual for the phenomenon to persist over a period of about 10 hr.

The observations were made at Ickenham, near Uxbridge, Middlesex—the extreme western edge of suburban London. The late afternoon of Saturday November 29 and the early hours of Sunday were extremely wet in the London area, the *Daily Weather Report* indicating that about three-quarters of an inch of rain fell in approximately 10 hr. Precipitation was associated with the approach of a warm front from the south. As so often happens this front failed to make any substantial advance at the surface over southern England against the very cold air mass to the north, and coincident with the heavy rain in southern England there was substantial snowfall immediately north of a line from Bristol to London.

Precipitation commenced at Ickenham as slight snow early in the afternoon but at about 1630 changed its form to "frozen drizzle". This form of precipitation in quantity makes a peculiar "swishing" noise which is unmistakable although somewhat similar to that made by granular snow. So complete was the freezing process that after half an hour in the precipitation my overcoat and hat remained quite dry. From about 1700 rain predominated and continued at varying intensities until the small hours of Sunday, November 30. But for a very considerable portion of the time the frozen pellets continued to be detectable, and intermittently as the rain waned the ice pellets increased in number until the "swishing" sound was easily audible. In spite of the quantity of free water falling at times, large sections of the pavements were quickly "iced", not with a smooth glassy icing but with a definitely granular layer, crunching underfoot almost like spilled sugar, and from time to time slippery enough to provide the children with slides of a yard or two, as they hurried home in the rain—there was no earlier snow or ice persisting. Admittedly during the later evening the frozen precipitation was almost entirely absent for appreciable periods and it was therefore with considerable surprise that I awakened at 0220 to the characteristic, eerie, swish-swish-swish. I verified that the precipitation was almost wholly pellets of frozen rain or drizzle. This was probably the final phase of the precipitation.

It is reasonably easy to visualize the thermal state of the lower atmosphere which will permit the phenomenon to occur over a short period. But to attempt to envisage the thermal distribution which will permit such a delicate balance that appreciable frozen droplets will co-exist with raindrops qualifying for an entry in the register as "heavy rain" is an interesting speculation. It is astounding that such a balance could be maintained over such a prolonged period.

F. H. DIGHT

Valley fog

The photograph of valley fog (facing p. 113) was taken by Mr. J. B. Tuke from Eastcombe, Stroud, Gloucestershire at 1430 on December 27, 1952. It shows fog filling the Toadsmoor valley. The valley bottom is at about 400 ft. above M.S.L., the photograph was taken from about 650 ft. and the top of the fog is at about 550 ft. The existence of well defined valley fog at such a late hour with the slopes above the fog in bright sunshine is particularly interesting.

Condensation trails

The photographs of a condensation trail in the centre of this magazine were taken by Mr. J. B. Tuke from Eastcombe, Stroud, Gloucestershire, at 1610 on November 10, 1952. The area of the upper photograph is to the left of that for the lower one, and the direction left to right is south-east to north-west; the whole trail pattern drifted south-eastwards. Interesting features are the twisting of the trail, the comb-like structure and the remarkable "kink" in the photograph on the left-hand page.

Mr. J. K. Bannon has commented as follows: The twisting and comb-like structure of the trail are frequently seen. The slope of the trail after a few minutes depends on several factors including turbulence, distribution of humidity and nuclei, fall-out of particles and distortion by wind shear. The large "kink" in the upper photograph appears to be mainly in a horizontal plane, and was probably produced by a shallow layer of SW. wind. The Larkhill upper wind observation made at 1500 shows a wind of 83 kt. at 450 mb. and 67 kt. at 200 mb. from NW. with little variation of direction with height and little vertical shear. There was a strong NW. jet stream with axis off the Norfolk coast at the time, so horizontal shear may have been large though observations are insufficient to prove it. If there was a large horizontal shear dynamic instability may have set up a thin local horizontal eddy producing the "kink".

Radio fadeouts

The following extract from the radio overseer's report of *Weather Explorer*, Voyage 41, emphasizes some of the difficulties which can be produced by radio fadeouts.

"Communications for the first three weeks of the voyage were good, but from the 26th to 30th January (both dates inclusive) serious fadeouts occurred, commencing at about 1800Z and lasting for six to eight hours. During these periods, no contact could be made with any station in the U.K. on 3, 4, 6 or 8 mc/s. Observations and upper air data were delayed and were usually relayed via the Azores on 6543 kc/s. Attempts were made to contact G.P.O. radio stations on M/F and H/F, but were not successful, although communication on M/F was good."

The vessel was on duty at the time at station "India" in position 59°N. 19°W., distant about 750 nautical miles from Dunstable. During the same voyage the ship's radar followed a balloon and target to a range of 156,000 yd.

This was the voyage during which the gale (discussed on p. 97) occurred in which the *Princess Victoria* was lost. The Master's report mentions that on January 30 the "wind at 1330 was 320° 25 kt., at 1350 was 50 kt., at 1400 was 72 kt., at 1445 50 kt. and at 1500 was 45 kt."

REVIEW

Plant environment and the grower. By S. A. Searle. 8¾ in. × 5½ in., pp. vi + 50, *Illus.* C. F. Casella & Co. Ltd. in collaboration with A. Gallenkamp & Co. Ltd., London, 1952. Price 5*s.* 0*d.*

Mr. Searle's pamphlet is an account of meteorology and soil physics applied to horticulture both glass-house and outdoor. Particular attention is paid to methods of measuring the elements concerned such as soil water content. The work is intended for horticulturists but makes interesting and instructive reading for meteorologists unfamiliar with the application of their science to horticulture.

G. A. BULL

OBITUARY

Frederick William Crewe.—It is with great regret that we record the death on February 25, 1953, of Mr. F. W. Crewe, Experimental Officer, radio-sonde unit, meteorological office, Larkhill.

Mr. Crewe was appointed to the staff of Lerwick Observatory in 1935 and spent his first four years there. During the early part of the war he served for short periods at several synoptic stations, but he was posted to Larkhill in March 1943 and remained there until his death. He was well known to nearly all the staff in the radio-sonde field and was well liked and highly esteemed by his seniors and juniors alike. The Meteorological Office can ill spare such men.

Mr. Crewe leaves a widow and one son to whom we offer our deepest sympathy in their loss.

WEATHER OF FEBRUARY 1953

Mean pressure was above normal over most of the North Atlantic and west Europe and below normal over most of North America. The greatest excess of pressure was 10 mb. over south-west Ireland where mean pressure reached 1022 mb. The lowest mean pressure 997 mb. occurred just south-east of Greenland where it was 5 mb. below normal; mean pressure was also below normal over the eastern Mediterranean to the extent of 2–4 mb.

Mean temperature was below normal over Europe and above normal over North America; it varied from 7°F. in northern Scandinavia to 30–40°F. in west Europe and 40–50°F. over the Mediterranean, and was generally 2–5° below normal in these regions.

In the British Isles the weather was mainly dry, particularly in south and east Scotland, north-west England and Northern Ireland. It was sunny on the whole in Scotland but, apart from Cornwall, most parts of England and Wales had rather less sunshine than usual. The first half of the month was cold, the cold weather lasting until the 13th in Scotland and Ireland but persisting over the 16th in England and Wales; from the 18th onwards conditions were very mild.

During the opening days a depression over north-west Germany moved away south-east and became less deep. Meanwhile an anticyclone off our western seaboard moved in over the country. Northerly gales occurred locally at first but these died down as the depression moved away. Cold weather prevailed with some wintry showers. On the 3rd and 4th a depression east of the Faeroes moved south-east to the Baltic and the anticyclone receded westward; some slight precipitation occurred. Thereafter northerly winds prevailed, with wintry showers. Sunshine was good on the whole during the first week. On the 8th and 9th a trough of low pressure associated with a depression south of Iceland moved over the British Isles giving widespread snow, and on the 10th a deep depression moved east over our southern districts giving further considerable precipitation in England and Wales. Behind this disturbance a cold north-easterly air stream gave further snow in many districts on the 11th and 12th. On high ground in northern England and Wales, snow lay to a considerable depth blocking many roads. For example at Malham Tarn, Yorkshire (1,297 ft.), snow lay 2–3 ft. deep with drifts up to 10 ft. on the 12th to 14th; at Bwlchgwyn, Denbighshire (1,267 ft.), level snow was 17 in. deep on the 11th, 12th and 13th and the whole meteorological station was buried under huge drifts; at Buxton (1,007 ft.) level snow was 14 in. deep on the 12th with heavy drifts; at Lake Vyrnwy (995 ft.) level snow was 12½ in. deep on the 12th with drifts 5–6 ft. On the 13th a small depression moved south-east from Iceland to the Shetlands and on the 14th turned south-south-west across northern and western England; more snow fell over much of England, but it became milder in Scotland, Ireland and the extreme west of England and Wales. Snow was lying over quite a large area from about the 8th until the 16th and at some places until the 17th or 18th. A ridge of high pressure moved south-east over the British Isles on the 15th and 16th giving early morning frost, hard locally in England and Wales (minimum temperature 18°F. at Cranfield on the 15th and 19°F. at Cranfield and 20°F. at Mildenhall on the 16th), but milder weather persisted in the north and west. Subsequently pressure was high to the south and low to the north of the British Isles, and a very mild south-westerly to westerly type of weather was established; considerable rainfall occurred at some places in the north-west, particularly on the 22nd and 24th but measurements were small in the south. Gales were recorded at times in the extreme north-west and north. On the 26th the ridge of high pressure over France spread north and by the 27th anticyclonic conditions prevailed over the whole country; sunshine records were good in many places during this period but they were variable, partly due to the incidence of fog. Day temperature exceeded 55°F. at numerous places between the 21st and 28th; it reached or slightly exceeded 60°F. at a few, for example, at Ross-on-Wye on the 26th, at Tangmere, London Airport and Bristol on the 27th, and at Dyce on the 28th. The minimum, 50°F., at Dyce on the morning of the 26th was notably high for February in that locality.

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 ...	62	13	+0·1	81	−3	97
Scotland	61	14	+1·7	70	−1	109
Northern Ireland ...	59	20	+1·6	47	−2	96

RAINFALL OF FEBRUARY 1953

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·48	89	*Glam.*	Cardiff, Penylan ...	1·96	67
Kent	Dover	2·36	123	*Pemb.*	Tenby	3·09	107
,,	Edenbridge, Falconhurst	1·35	61	*Radnor*	Tyrmynydd	2·85	54
Sussex	Compton, Compton Ho.	2·03	77	*Mont.*	Lake Vyrnwy	3·87	85
,,	Worthing, Beach Ho. Pk.	1·06	54	*Mer.*	Blaenau Festiniog ...	8·26	101
Hants.	Ventnor Park	1·09	50	,,	Aberdovey	2·78	93
,,	Southampton (East Pk.)	1·42	62	*Carn.*	Llandudno	1·85	95
,,	Sherborne St. John ...	1·74	80	*Angl.*	Llanerchymedd ...	2·67	105
Herts.	Royston, Therfield Rec.	1·62	105	*I. Man*	Douglas, Borough Cem.	2·18	68
Bucks.	Slough, Upton... ...	1·58	93	*Wigtown*	Newton Stewart ...	1·33	35
Oxford	Oxford, Radcliffe ...	1·58	96	*Dumf.*	Dumfries, Crichton R.I.	0·97	30
N'hants.	Wellingboro' Swanspool	1·54	96	,,	Eskdalemuir Obsy. ...	2·04	41
Essex	Shoeburyness	1·20	98	*Roxb.*	Crailing...	1·05	57
,,	Dovercourt	0·99	78	*Peebles*	Stobo Castle	1·21	44
Suffolk	Lowestoft Sec. School...	1·36	97	*Berwick*	Marchmont House ...	1·31	63
,,	Bury St. Ed., Westley H.	1·06	71	*E. Loth.*	North Berwick Res. ...	0·75	48
Norfolk	Sandringham Ho. Gdns.	1·93	117	*Midl'n.*	Edinburgh, Blackf'd. H.	0·72	43
Wilts.	Aldbourne	1·61	75	*Lanark*	Hamilton W. W., T'nhill	1·16	40
Dorset	Creech Grange... ...	2·07	72	*Ayr*	Colmonell, Knockdolian	1·49	39
,,	Beaminster, East St. ...	2·05	68	,,	Glen Afton, Ayr San. ...	1·92	44
Devon	Teignmouth, Den Gdns.	1·64	62	*Renfrew.*	Greenock, Prospect Hill	3·36	63
,,	Cullompton	3·01	108	*Bute*	Rothesay, Ardencraig...	2·61	65
,,	Ilfracombe	2·69	97	*Argyll*	Morven (Drimnin) ...	4·48	85
,,	Okehampton	2·25	51	,,	Poltalloch	2·91	61
Cornwall	Bude, School House ...	1·65	66	,,	Inveraray Castle ...	6·43	95
,,	Penzance, Morrab Gdns.	1·89	57	,,	Islay, Eallabus... ...	2·82	67
,,	St. Austell	2·01	52	,,	Tiree	3·26	95
,,	Scilly, Tresco Abbey ...	1·70	61	*Kinross*	Loch Leven Sluice ...	1·36	48
Glos.	Cirencester	1·56	69	*Fife*	Leuchars Airfield ...	0·66	38
Salop	Church Stretton ...	2·14	92	*Perth*	Loch Dhu	4·21	57
,,	Shrewsbury, Monkmore	1·49	95	,,	Crieff, Strathearn Hyd.	0·94	27
Worcs.	Malvern, Free Library...	1·35	75	,,	Pitlochry, Fincastle ...	1·04	35
Warwick	Birmingham, Edgbaston	1·23	73	*Angus*	Montrose, Sunnyside ...	0·89	48
Leics.	Thornton Reservoir ...	1·62	97	*Aberd.*	Braemar	1·37	48
Lincs.	Boston, Skirbeck ...	1·65	113	,,	Dyce, Craibstone ...	1·26	55
,,	Skegness, Marine Gdns.	1·80	118	,,	New Deer School House	1·78	84
Notts.	Mansfield, Carr Bank...	1·52	79	*Moray*	Gordon Castle	1·80	94
Derby	Buxton, Terrace Slopes	2·19	58	*Nairn*	Nairn, Achareidh ...	1·42	88
Ches.	Bidston Observatory ...	0·98	58	*Inverness*	Loch Ness, Garthbeg ...	2·99	87
,,	Manchester, Ringway...	1·17	62	,,	Glenquoich	10·80	104
Lancs.	Stonyhurst College ...	1·80	54	,,	Fort William, Teviot ...	7·85	105
,,	Squires Gate	0·78	37	,,	Skye, Broadford ...	6·30	98
Yorks.	Wakefield, Clarence Pk.	1·53	90	,,	Skye, Duntulm ...	4·15	90
,,	Hull, Pearson Park ...	1·95	117	*R. & C.*	Tain, Mayfield... ...	1·89	83
,,	Felixkirk, Mt. St. John...	1·65	98	,,	Inverbroom, Glackour...	4·52	89
,,	York Museum	1·65	109	,,	Achnashellach	7·68	112
,,	Scarborough	1·82	108	*Suth.*	Lochinver, Bank Ho. ...	3·81	95
,,	Middlesbrough... ...	1·71	132	*Caith.*	Wick Airfield	1·56	69
,,	Baldersdale, Hury Res.	1·49	51	*Shetland*	Lerwick Observatory ...	4·04	128
Norl'd.	Newcastle, Leazes Pk....	1·73	113	*Ferm.*	Crom Castle	1·04	35
,,	Bellingham, High Green	2·05	81	*Armagh*	Armagh Observatory ...	1·43	64
,,	Lilburn Tower Gdns. ...	1·69	85	*Down*	Seaforde	1·04	34
Cumb.	Geltsdale	1·06	41	*Antrim*	Aldergrove Airfield ...	1·00	41
,,	Keswick, High Hill ...	1·96	40	,,	Ballymena, Harryville...	1·65	51
,,	Ravenglass, The Grove	1·49	49	*L'derry*	Garvagh, Moneydig ...	1·63	52
Mon.	Abergavenny, Larchfield	1·64	51	,,	Londonderry, Creggan	1·53	48
Glam.	Ystalyfera, Wern House	4·85	94	*Tyrone*	Omagh, Edenfel ...	1·59	53

Printed in Great Britain under the authority of Her Majesty's Stationery Office
By Geo. Gibbons Ltd., Leicester

Wt-33. K16.