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RAINFALL ANALYSIS AT WOODTHORPE, NOTTINGHAMSHIRE

By A. B. TINN

An analysis of the rainfall observations made at Woodthorpe, Notts. for the 21 years, 1936 to 1956, has been made. This was done to find the average frequency of rain days within stated limits and the actual amount of rain falling within those limits.

Table I shows the average frequency of days with measureable rain and Table II gives the average amount of rainfall expressed as percentages of the monthly average for the period. The slight discrepancies in the total of days with 1.0 in. or more for the year and the total for the individual months is due to fractional monthly differences, and this also applies to the year's total rain days.

TABLE I.—MEAN NUMBER OF DAYS WITH RAIN WITHIN SPECIFIED AMOUNTS

	Rainfall in inches						Total
	1.00 or more	0.99 to 0.75	0.74 to 0.50	0.49 to 0.25	0.24 to 0.10	0.09 to 0.01	
				<i>days</i>			
Jan.	0.1	0.2	0.8	2.6	4.8	10.3	18.8
Feb.	<0.1	0.1	0.5	2.0	3.4	9.6	15.7
March	<0.1	0.1	0.4	1.8	2.9	8.0	13.3
April	nil	0.1	0.4	1.6	3.0	7.9	13.0
May	0.1	0.1	0.6	2.2	3.1	6.9	13.0
June	<0.1	0.3	0.5	1.6	3.7	6.9	13.1
July	0.2	0.5	0.4	1.7	4.0	7.5	14.3
Aug.	0.3	0.4	1.0	2.2	3.2	7.3	14.4
Sept.	<0.1	0.2	0.3	1.5	3.3	8.1	13.5
Oct.	0.2	0.3	0.6	1.6	3.1	9.0	14.8
Nov.	0.1	0.3	0.7	2.7	4.3	9.8	17.9
Dec.	0.1	0.1	0.3	1.9	3.9	12.1	18.4
Year	1.2	2.7	6.4	23.4	42.7	103.0	179.4

Daily amounts of 0.5 in. or over occur on an average on about 10 days in a year while days with less than 0.1 in. account for more than half the total rain days. In the 20 years 1936 to 1955, on an average, the 10 wettest days in a year accounted for 28.2 per cent of the annual fall, the 30 wettest days 55.9 per cent and the wettest 70 days 82.6 per cent.

The following percentages of the year's rainfall occurred in the number of days shown:

25 per cent of the year's fall in 9 days, 50 per cent in 26 days and 75 per cent in 55 days.

During the period under review the averages showed the driest month as April with 1·62 in. The wettest months were August and November with 2·84 in. and 2·83 in. April was the only month of the year without a day of 1·00 in or more in the 21 years, the maximum fall being 0·91 in. on April 6 1949.

TABLE II.—MEAN AMOUNT OF RAIN CONTRIBUTED BY DAILY AMOUNTS WITHIN SPECIFIED AMOUNTS, EXPRESSED AS A PERCENTAGE OF TOTAL FOR THE MONTH

	Rainfall in inches					
	1·00 or more	0·99 to 0·75	0·74 to 0·50	0·49 to 0·25	0·24 to 0·10	0·09 to 0·01
			<i>per cent</i>			
Jan.	3·6	7·2	16·7	32·6	27·2	12·7
Feb.	3·5	4·5	14·0	33·5	28·0	16·5
Mar.	3·5	7·5	12·7	34·7	25·4	16·2
Apr.	nil	2·5	14·8	35·2	29·0	18·5
May	6·3	1·9	17·5	38·3	24·3	11·7
June	4·3	13·9	13·9	29·2	26·2	12·5
July	7·0	19·4	11·2	24·4	26·4	11·6
Aug.	14·1	12·3	19·7	26·0	18·0	9·9
Sept.	2·9	9·2	11·0	31·2	28·9	16·8
Oct.	12·2	10·4	17·4	25·7	21·7	12·6
Nov.	3·9	9·5	14·8	35·3	24·5	12·0
Dec.	5·9	2·0	8·4	32·2	31·2	20·3
Year	6·0	9·0	14·6	31·3	25·4	13·7

THE WEATHER OF 1958 IN THE BRITISH ISLES

By R. E. BOOTH

Weather in the British Isles during the first two months of 1958 was changeable but predominantly mild although during a severely cold spell in January temperature locally fell below 0°F. and snow, which isolated many rural areas, lay over a foot deep in the Midlands during the later part of February. March was very cold with severe night frosts; temperature fell to -9°F. at Logie-Coldstone, Aberdeenshire, on the 14th, this being the lowest March temperature recorded in the British Isles for more than 100 years. The cold weather continued during the first half of April giving the coldest Easter on record but subsequently temperature rose rapidly and reached 80°F. at a number of places during the first week of May. The warm weather was short-lived, however, as sleet showers were reported in northern England later in the month.

The unsettled weather of May continued throughout the summer which was generally wet and cold except in northern Scotland. Apart from June 1903, it was the wettest June at Kew Observatory since 1856. July and August were both notable for exceptionally heavy thunderstorms; during one of these storms nearly 1½ inches of rain fell in an hour at Golder's Green, north London, on 22 August.

The wet weather of the late spring and summer continued into the autumn, but September was milder than usual. A tornado moved north-east across much of Sussex on the 5th accompanied by torrential rain and hail which did considerable damage; in places the hailstones were larger than tennis balls. Both October and November were wet to start with but became dry during the latter part of each month; many places in south-east England and East Anglia

had two weeks without measurable rain in November. Fog was particularly persistent during the last week of November and the first week of December, but weather during the remainder of the year was generally changeable with rain at times and some sleet or snow in the north.

THE TATTERING RATE OF FLAGS AS AN INDEX OF EXPOSURE TO WIND

By D. THOMAS, M.A.

Recent work by J. W. L. Zehetmayr¹ and R. Lines² of the Forestry Commission Research Branch has suggested that by studying the extent to which specially prepared flags tatter, a general comparative evaluation may be made of the exposure to which trees upon different sites are subject. The technique is one which has obvious applications in many fields, and not least in that of assessing the need for the provision of artificial shelter in agricultural areas in this country. Its greatest advantage lies in the cheapness and convenience with which either intensive or extensive contemporaneous studies into wind behaviour may be carried out. The purpose of this communication is to describe the procedure adopted in exposing such flags to wind blast in Cardiganshire, and also to show the nature of the consequent tattering in order that valid judgements may be made of the significance of the results obtained by the method.

Equipment and experimental procedure.—Each flag was firmly sewn to a metal rod, five-sixteenths of an inch in diameter, as shown in Figure 1. The rod was held in position by two screw-eyes, which allowed it to rotate freely, and rested upon a plastic base. These were supported on a wooden stake so that the centre of the flag was four feet above ground level. It was necessary that the rod should rotate with the wind in order that the length of flag which was exposed to the wind was always at a maximum. The wrapping of the flag about the rod reduces considerably the effective length of the flag which is flying free, and this, as will be shown later, has a marked effect upon the rate of tattering. In wind speeds below about seven miles per hour it was found that the drag exerted by the flag was insufficient to overcome the friction caused by the screw-eyes and plastic base, and to swivel the rod into the wind. A light metal fin was thus added at the upper end of the rod, meeting it in the same vertical plane as the flag itself. All metal parts were coated with aluminium paint as a protection against rusting.

Of the fabrics tested, two ounce Madapollam (D.T.D. 343), the cloth used by the Forestry Commission, was found most suitable for flag material. It tatters evenly and at a measurable speed, and does not rend even in extremely high winds. It also gives a record of wind conditions by which comparatively minor differences in exposure over small areas may be recognized. The cloth to be used was washed several times to obviate subsequent shrinkage and then cut along drawn threads so that the free flying area of the flag was exactly 9×14 inches. Cutting along the threads ensured that the flag edge was always standard in character.

Given normal wind conditions, the rate of flag tattering is far more pronounced in the first few days of exposure than subsequently. The times of recording of tattering were thus standardized and always taken on the third day following the beginning of a run, on the seventh day, and then weekly. The

extent of the tattering was recorded by pricking through with a needle the outline of the unfrayed part of the flag onto graph paper. The residual area was then measured by planimeter. Throughout its life, each flag was always recorded on the same piece of graph paper thus giving an immediate visual impression of the rate of tattering. To enable successive measurements to be transferred accurately, guide lines were ruled on each flag before it was exposed. This also ensured that any warping of the fabric which had occurred could be corrected before recording took place.

The calibration of flag tattering.—Figure 2 shows a typical curve produced by plotting cumulatively the mean reduction, in square inches, of the areas of three similarly sited flags exposed over the same period against run of wind in miles, measured by a standard cup counter anemometer also at four feet above ground level. Using a logarithmic scale for the wind axis, the relationship is clearly shown to be linear and therefore exponential. Successive replications have verified that for conditions in which actual wind speeds do not approach 25 miles per hour this curve may be taken as representative. Thus the regression equation of the reduction in flag area (x) on the logarithm of run of wind (y) may be shown to be:

$$x = 1.715y - 0.449 \quad \dots \quad \dots \quad \dots \quad (1)$$

The standard error of the estimate in this case is 0.191. That is, we should expect actual values of x to lie within 0.382 (2×0.191) of the estimated values given by the regression equation for 95 per cent of the measurements made.

The precise nature of the tattering which assumes this form is clearly related to the amount of lash experienced by the free end of the flag. The extent of this movement is in turn conditioned not only by the length of the flag but also by its shape. Thus, with the rectangular flags used, far greater wear takes place at the corners than along the straight edges, resulting eventually in a characteristically curved profile. The gradual reduction in the free corners of the flag consequently contributes towards the exponential curve produced under the conditions outlined above. The wetting of the flag as a result of precipitation, on the other hand, seems to have no appreciable effect upon the rate at which tattering takes place and, provided short period records only are taken, cannot influence results by aiding the weathering and disintegration of the fabric. Over longer periods the character of the fabric becomes changed as a result of the combined effects of rain, sunshine and continuous flapping and thus it has seemed advisable in practice to limit the periods of exposure of individual flags to five or six weeks.

When actual wind speeds exceed approximately 25 miles per hour the tattering rate does not conform with the above relationship. At this speed there appears to be a threshold, beyond which the extent of tattering is greatly increased. Winds of more than 25 miles per hour thus give rise to a "step" in the curve as illustrated in Figure 3, where the mean reduction in the areas of three similarly sited flags is again shown. In this case the lower part of the curve obviously represents conditions in which wind speed did not exceed the threshold, and has a regression equation:

$$x = 1.460y + 0.431 \quad \dots \quad \dots \quad \dots \quad (2)$$

The difference between the slope of this section of the curve, given by the regression coefficient, and that of the curve shown in Equation (1) may be attributed to the fact that the former is fitted through two points only, and is thus liable to error. Nevertheless, the incidence of strong winds over 25 miles per hour is well shown by the step-back of the straight line trend. Following this break the return to less severe wind conditions is indicated by the upper part of the curve which has the regression equation:

$$x = 1.687y + 1.430 \quad \dots \quad \dots \quad \dots \quad (3)$$

Here again the slope of the line is very similar to that shown in Equation (1). The intensity of the severe wind may be estimated from the difference between the constants in Equation (2) and Equation (3), which indicates the amount to which the straight line has been off-set.

The occurrence of a threshold at 25 miles per hour is essentially a function of the interaction of wind with the particular fabric used. Other types of material, although conforming with the exponential relationship in moderate winds, would not necessarily experience an increased tattering rate at the same wind speed level as Madapollam.

The error involved in the technique.—So far, in the production of representative curves, mean values taken from batteries of three flags have been used. In the experimental assessment of exposure, however, it is neither practical nor desirable that three flags should be similarly sited at every point where records are to be made. It is thus necessary to have an estimate of the error involved in the use of one flag only at each site.

Of the flags which have been allowed to tatter under wind conditions measured by a cup counter anemometer, three batteries of three flags each have given straight line relationships unaffected by winds of over 25 miles per hour. Using the records of the individual flags, the slope of each line can be calculated and expressed as a regression coefficient. This allows eight degrees of freedom, and the standard deviation of the regression coefficients may then be shown to be 0.0901. That is, we might reasonably expect 95 per cent of the regression coefficients of single flags to fall within 0.1802 of the mean value, 1.621. The regression coefficient limits of 1.4408 and 1.8012 have been inserted on Figure 2 in broken lines. Putting this another way, assuming that the units on both axes of the graph were on the same scale, then we might expect 19 out of 20 regression lines to have slopes between $34^{\circ} 46'$ and $29^{\circ} 2'$ (that is, the angles of which the limiting regression coefficients are cotangents).

Conclusion.—Whilst the estimation of exposure by means of flags can never approach the reliability of anemometric surveys, its accuracy can be defined within reasonably narrow limits and its use supported upon a number of counts. In addition to the cheapness with which studies into the relative severity of wind blast may be carried out, it is possible to detect the incidence of the more fierce winds, which in many fields of study, especially agricultural, is of utmost importance. Particularly is this so in areas which are marginally subject to strong winds or which have a considerable range of exposure conditions. In such situations, comparative analyses by the use of flags are most likely to give reliable and significant results. It is hoped later to illustrate the application of the technique to specific farm units of the type described.

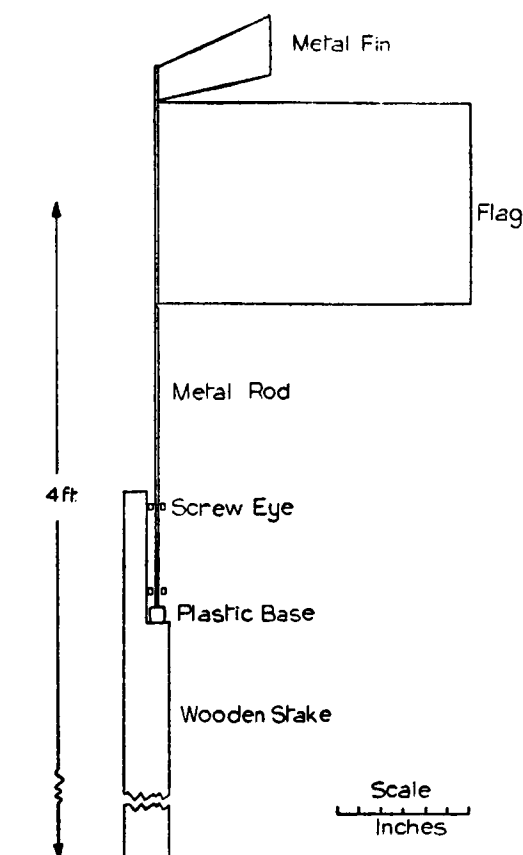


FIGURE 1—THE FLAG MOUNTING
(See also photograph facing p. 90)

Acknowledgement.—The above work formed part of the Livestock Shelter Research Programme being carried out at the University College of Wales, Aberystwyth, under the direction of Professor J. E. Nichols. Grateful acknowledgement is made for the advice received from Mr. R. Lines of the Forestry Commission in the initial stages of this work.

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THE RATE OF ASCENT OF FREE BALLOONS

By R. FROST, B.A.

(Written in 1943)

The rate of ascent of pilot balloons is usually calculated on the assumption that the resistance of the air to a balloon moving through it may be represented by a simple expression of the form

$$R = a\rho r^2 V^2, \quad \dots \dots (1)$$

where R is the resistance, ρ is the density of the air, r is the radius of the balloon, V is the velocity of the balloon relative to the air, and a is a constant.

This law is inexact and the rates of ascent calculated from it differ considerably from those actually observed.

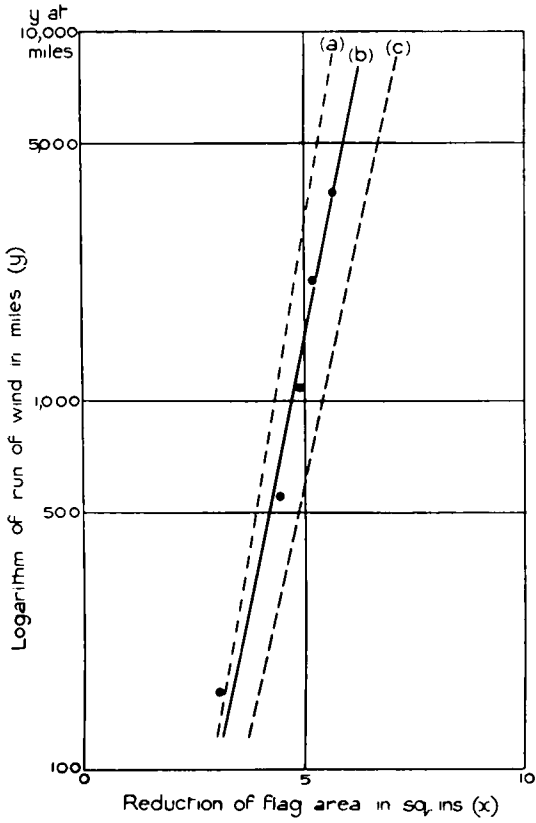


FIGURE 2.
(when actual wind velocity did not exceed
25 m.p.h. (approx.).)

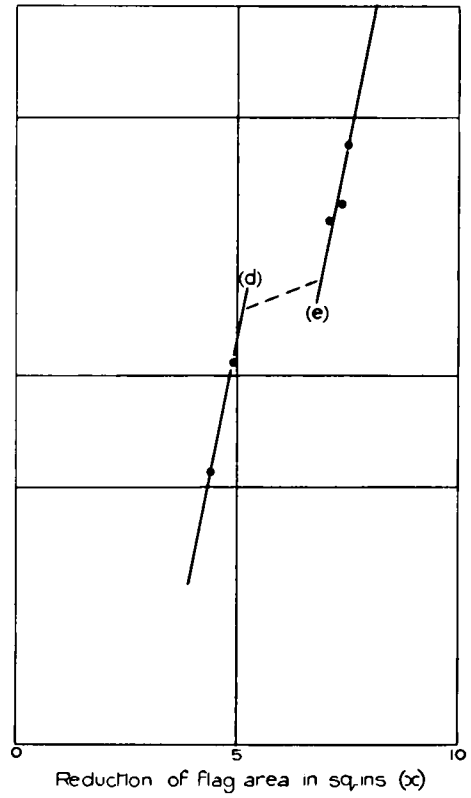


FIGURE 3.
(when actual wind velocity exceeded 25 m.p.h.
(approx.).)

THE RELATIONSHIP BETWEEN FLAG TATTERING AND RUN OF WIND

$$\begin{aligned}
 (a) \ x &= 1.4408y & (b) \ x &= 1.715y - 0.449 & (c) \ x &= 1.8012y \\
 (d) \ x &= 1.460y + 0.431 & (e) \ x &= 1.687y + 1.430
 \end{aligned}$$

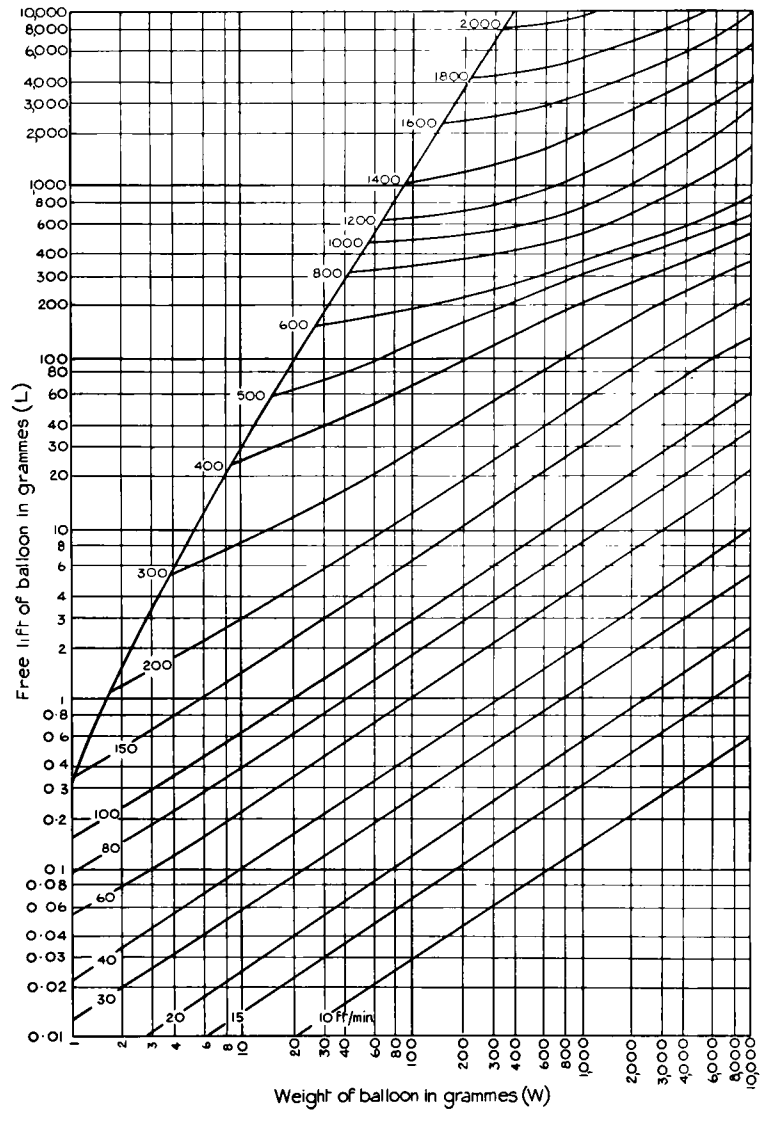


FIGURE 1—RELATION BETWEEN THE WEIGHT, THE FREE LIFT AND THE VERTICAL VELOCITY OF FREE BALLOONS

The line terminating the isopleths of velocity on the left hand side of the diagram is calculated on the assumption that the maximum stretched diameter of the balloon is $4\frac{1}{2}$ times the unstretched diameter.

The resistance to a balloon of approximately spherical shape moving through a fluid can be shown by the principle of dynamical similarity to be

$$R = \frac{1}{2} \rho V^2 \pi r^2 f\left(\frac{\nu}{2Vr}\right), \quad \dots \dots \dots (2)$$

where r is the radius of the cross-section of the balloon perpendicular to the direction of motion and where $f(\nu/2Vr)$ is known as the drag coefficient. If the drag coefficient is plotted for different values of the Reynolds number, $2Vr/\nu$, the resulting curve is known as the drag curve. (ν is the kinematic viscosity of air.)

The drag curve shows no marked discontinuities. The drag coefficient increases slowly from a minimum at a Reynolds number of 5×10^3 to a maximum at a Reynolds number of approximately 10^5 and then falls suddenly. The critical range over which the drag coefficient experiences a sudden fall depends upon the degree of turbulence already existing in the free-air stream. If the air stream is very turbulent the sudden fall occurs earlier (that is, for lower values of the Reynolds number) and vice versa. In all cases, however, the critical region occurs between Reynolds numbers having values lying between 8×10^4 and 4×10^5 approximately. Beyond the critical region the drag coefficient is small and rises very slowly.

The sudden fall is due to the fact that at low Reynolds numbers the flow in the boundary layer is laminar up to the point of separation with a large region of violent eddying behind the sphere. At higher values of the Reynolds number the flow in the boundary layer becomes turbulent and the point of separation is delayed, with a consequent reduction in the size of the eddying wake in the rear. Observations of spheres dropped from aircraft in relatively quiet conditions show that the ratio of the drag coefficient immediately before and after the critical range is 2.6.

It is rather unfortunate that a large number of balloons used in meteorological work have Reynolds numbers which lie within the critical region and it is not altogether surprising that various investigators have found considerable difficulty in obtaining a simple formula which would be valid for balloons of different sizes and velocities.

No attempt is made here to derive such a formula, but from general theoretical considerations and the utilization of pilot-balloon data, curves are constructed which enable the rate of ascent of a pilot balloon to be calculated from a knowledge of the weight and the free lift of the balloon.

When the balloon reaches a steady rate of ascent (which it does a few seconds after the start) the resistance of the air must be equal to the free lift, L , and hence we have

$$R = L = \frac{1}{2} \rho V^2 \pi r^2 f\left(\frac{\nu}{2Vr}\right),$$

$$\text{that is, } L \propto \left(\frac{2Vr}{\nu}\right)^2 f\left(\frac{\nu}{2Vr}\right),$$

$$\text{that is, } L \propto \phi\left(\frac{2Vr}{\nu}\right). \quad \dots \dots \dots (3)$$

For a detailed explanation of this see *Modern developments in fluid dynamics*.¹

The principle of flotation gives a second relation, namely,

$$L + W = \frac{4}{3} \pi r^3 \rho (1 - k), \quad \dots \dots \dots (4)$$

where k is the ratio of the density of hydrogen to air at the same pressure. Equation (4) is strictly true for a spherical balloon. If, however, the balloon is not spherical $\frac{4}{3} \pi$ would be replaced by a slightly different constant. Hence from (3) and (4) we have

$$\phi \left\{ \frac{V(L+W)^{\frac{1}{3}}}{C} \right\} = \frac{L}{B},$$

where B and C are invariants (the variation of density with height is neglected in this),

$$\text{or } V = \frac{f_1(L)}{(L+W)^{\frac{1}{3}}}. \quad \dots \dots \dots (5)$$

The usual formula used to evaluate V is

$$V = \frac{qL^{\frac{1}{3}}}{(L+W)^{\frac{1}{3}}}$$

$$\text{and hence } q = \frac{f_1(L)}{L^{\frac{1}{3}}}, \quad \dots \dots \dots (5.1)$$

that is, q is a function of L only.

Hesselberg, Birkland and Dines found that for Reynolds numbers less than 10^5 , q was a constant ($= 276$) so that $f_1(L) \propto L^{\frac{1}{3}}$.

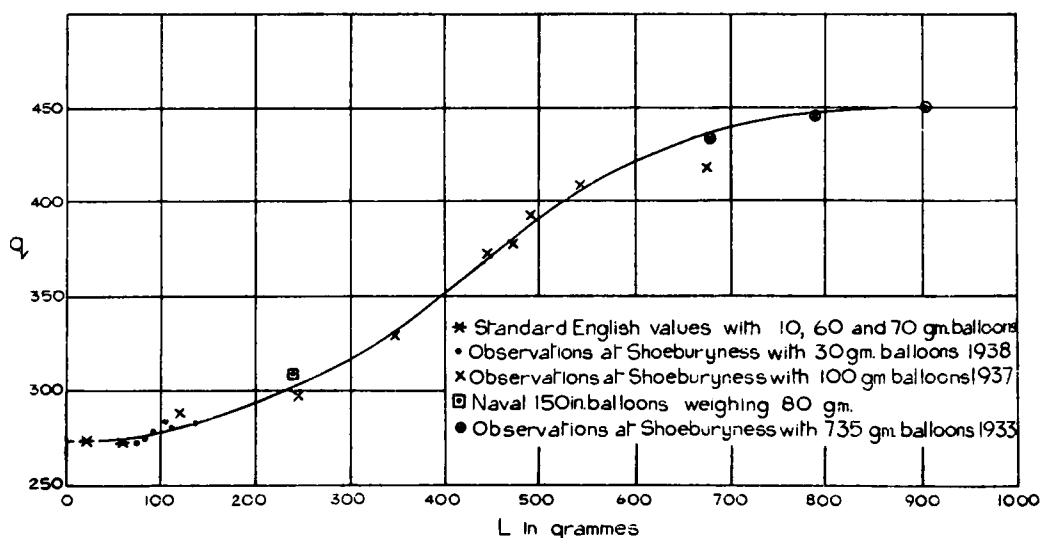


FIGURE 2—VARIATION OF q WITH L , THE FREE LIFT OF THE BALLOONS
The values of q are corrected for density variations.

Values of q for varying values of L are plotted in Figure 2, and it can be seen that with increasing values of L (that is, with increasing values of the Reynolds number) q appears to become independent of L again and to approach a limiting value of 450.

If now we consider the drag curve for spheres dropped from aircraft it can be seen that before and after the critical range the resistance can be written as

$$R = a_1 \rho r_1^2 V_1^2 \text{ and } R = a_2 \rho r_2^2 V_2^2.$$

Hence q_2/q_1 should vary as $(a_1/a_2)^{\frac{1}{2}}$, that is, as $(2.6)^{\frac{1}{2}}$.

$$\begin{aligned}\text{That is, } q &= 276 (2.6)^{\frac{1}{2}} \\ &= 445,\end{aligned}$$

which is in excellent agreement.

The rates of ascent in the attached curves (Figure 1) are calculated from the formula

$$V = \frac{q L^{\frac{1}{2}}}{(L+W)^{\frac{1}{2}}},$$

where q is a function of L and whose values are taken from Figure 2.

The values of q for the Shoeburyness ascents in 1933² were calculated using the mean rates of ascent over the first 10,000 feet. In obtaining the formula, (5.1), the variation of density with height was neglected and hence a slight correction must be made to these values of q in order that they may be strictly comparable with values of q calculated from rates of ascent measured at the surface. For balloons such as these which lie outside the critical region it can easily be seen that the formula for the rate of ascent which takes into account the variation of density with height is

$$V = q \left(\frac{\rho_0}{\rho} \right)^{\frac{1}{2}} \cdot \frac{L^{\frac{1}{2}}}{(L+W)^{\frac{1}{2}}}, \quad \dots \dots (6)$$

where ρ_0 is the density at the ground and ρ is the density at the height at which V is measured. The values of q obtained in the Shoeburyness ascents have been corrected in accordance with (6).

Whilst for a balloon of any given weight it is theoretically possible to find a definite free lift to give any required rate of ascent, this is impossible in practice. The physical properties of the rubber set an upper limit to the free lift which may be given to a rubber balloon. L. H. G. Dines³ found that a good quality rubber balloon would on the average expand to $4\frac{1}{2}$ times its unstretched diameter before bursting. Thus if the unstretched diameter of a balloon of weight W is $2r$, then the maximum free lift L which can be given to the balloon is given by

$$L + W = \frac{4}{3} \pi r^3 (4\frac{1}{2})^3 \rho (1-k) \quad \dots \dots (7)$$

$$= 0.43 r^3. \quad \dots \dots (7.1)$$

If now t is the thickness of the rubber and σ the specific gravity of the rubber we have as a second relation

$$W = 4 \pi r^2 \sigma t. \quad \dots \dots (8)$$

The average thickness of a good rubber balloon is 0.4 millimetres, and the specific gravity of the rubber is 0.93.

$$\text{Therefore } W = 0.48 r^2. \quad \dots \dots (8.1)$$

The elimination of r between these two expressions gives the upper value of L for a balloon of any given W and is

$$L = 1.3 W^{\frac{2}{3}} - W. \quad \dots \dots (9)$$

The isopleths of velocity on the L, W diagram (Figure 1) are accordingly terminated at the curve given by (9).

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METEOROLOGICAL OFFICE DISCUSSION

Forecasting cirrus

The discussion was held on Monday, 17 November, 1958 at the Royal Society of Arts.

Dr. R. J. Murgatroyd, who was the first opening speaker said that in his opinion the main factors in the preparation of forecasts of any meteorological element at present are probably:

- (i) The available observations before and at the time of the preparation of the forecast.

This includes observations of the element itself and also of others used in the forecast procedure, for example, wind, temperature and humidity.

- (ii) The forecaster's experience as regards the usual behaviour and general climatology of that element.

- (iii) His knowledge of the physical and dynamical factors associated with its development.

In particular, for cloud formation, questions of condensation, humidity of the atmosphere and cooling by vertical motion or other means are of primary importance.

For high cloud forecasting the situation is not satisfactory on any of these counts although it has improved considerably in recent years. Each was then discussed in turn, (i) and (ii) briefly and (iii) in some greater detail.

Observations of high cloud.—If a comprehensive set of synoptic observations were always available it might be possible to achieve some forecasting success simply by plotting and tracking the observed cloud masses. Unfortunately this is not always possible as the great majority of observations have to be made at the surface. Thus, when fog or thick lower clouds intervene, the upper cloud will not be visible. Moreover, even when it is fine but hazy, the upper cloud may only be seen when the sun is at a low altitude. Under these conditions high-flying aircraft often report high cloud which is not observed from the surface. It has also been demonstrated in a statistical study that, at night, the amount of high cloud reported varies with the phase of the moon. Even at full moon, however, the observations are less than those made in the daytime and the continuity of observations from night to day is poor, that is, the percentage of high cloud reported increases very rapidly around dawn. Although we may be able to put forward reasons why the frequency of some forms of cirrus, for example, anvil or orographic cirrus, should have a true diurnal variation, the weight of evidence is that this is not so for all high cloud and that the observations are greatly dependent on the way in which the illumination varies.

It is believed therefore that while surface observations of considerable high cloud present should be accepted, those of small amounts of the upper cloud should be treated with reserve.

Some improvement in the frequency of observation of both medium and high clouds would be possible if radar operating on lower wavelengths than the usual 3 and 10-centimetre equipment and looking vertically upwards were available. Equipment used in America on 0.86 and 1.25-centimetre wavelengths has been tested against visual observation for this purpose and shown considerable promise. It requires rather large ice crystals, however, to produce reflections and hence results may not be obtained when cloud is very thin. Moreover, the system may also fail when the clouds below are precipitating and thus attenuating or even totally absorbing the radio beam.

Aircraft observations are usually reliable but not made as a routine. Practically all the information obtained for research purposes, however, is based on studies using aircraft, and work of this type has now been carried out in several countries including the United States of America, Canada, France, Germany and the United Kingdom.

The climatology of high clouds.—Ice-crystal clouds are found at all latitudes. In polar regions in winter they exist near the surface as well as at greater altitudes; in tropical regions they may be widespread in the intertropical convergence zone and also near cumulonimbus anvils up to heights of 50,000 feet or more. It was found from double theodolite observations in 1896, the International Cloud Year, and more recently aircraft observations have confirmed that, on the average, high cloud bases rise from about 24,000 feet at 80°N. to 40,000 feet at the equator. The base of high clouds thus tends to have a similar type of latitudinal variation to the height of the tropopause.

Dr. Murgatroyd then gave statistics obtained from the Meteorological Research Flight's investigations over this country.¹ These aircraft observations have shown that the mean tops extend to within a few thousand feet of a high tropopause (greater than 35,000 feet) and almost reach up to a low tropopause (less than 35,000 feet). The corresponding thickness of the high cloud layer is most frequently between 3,000 and 5,000 feet. Stratification is common. There may be considerable departures from these average conditions but they are useful figures to have

in mind when no other information is available. The most frequent temperature ranges may also be assessed from the same data. Cloud base temperatures usually vary between $-10^{\circ}\text{C}.$ and $-60^{\circ}\text{C}.$ with a mean about $-40^{\circ}\text{C}.$ and cloud top temperatures from $-40^{\circ}\text{C}.$ to $-70^{\circ}\text{C}.$ with a mean of about $-50^{\circ}\text{C}.$ The flight results also suggested that high cloud is present over a given area in southern England for almost 50 per cent of the time and for only about 25 per cent are large areas completely free of low cloud. No significant variations with season were noted and occurrences must be related always to the given synoptic situation.

It should be noted that we must distinguish broadly between two types of high cloud:

(a) Clouds formed by some convection mechanism, for example, from cumulonimbus or instability in shallow layers—commonly called “convective cirrus” in the literature.

(b) Clouds formed by slow widespread ascent.

It had not been possible to separate them in the climatological studies but it is necessary to consider their possible formation mechanisms separately for forecasting purposes.

Physical and dynamical factors

Physical features.—It is now widely believed that formation of ice cloud normally takes place only when the atmosphere is saturated with respect to water, that is, the change from vapour to solid must take place via the liquid phase. Once formed the ice crystals will persist until the atmosphere is no longer saturated with respect to ice. At 300 millibars with temperatures between $-30^{\circ}\text{C}.$ and $-40^{\circ}\text{C}.$ the temperature difference between water and ice saturation conditions is about $3^{\circ}\text{C}.$ (which corresponds to 1500 feet or more in height). This has several important consequences. Rising air which is becoming more saturated will have a region of ice saturation below that of water saturation and it follows that crystals once formed can fall some considerable distance before they evaporate. A typical fall speed of a cirrus crystal has been estimated to be three centimetres per second and therefore it could fall for three hours or so before starting to evaporate. In the strong winds of the upper troposphere high cloud might therefore be displaced several hundred miles from its formation region before dissipating. It follows that a direct connexion with the dynamical conditions for formation, that is, high humidity and vertical upward motion is not always necessary for cloud to exist. This imposes a limit on the usefulness of a forecast system based entirely on dynamic considerations and emphasizes the desirability of obtaining better cloud observations.

A good deal is known about the physical constitution of high clouds through the aircraft observations of Weickmann² and others. The crystals vary in shape and size according to the saturation conditions in their formation as determined by the temperature and speed of updraught. In convection cirrus they have a typical hollow structure but in cirrostratus they have a more solid form usually with hexagonal faces. They are commonly several hundred microns across, a size sufficient to produce radar reflections in the one-centimetre wavelength range. Their concentration is usually in the order of one per cubic centimetre and the water content of middle latitude cirrostratus is probably about 0.1 gramme per cubic metre. The ice-crystal content of cirrus densus in the neighbourhood of cumulonimbus clouds is of course very much higher and it may reach several grammes per cubic metre. Aircraft icing in high clouds is unusual but there have been several reports in the literature. Turbulence appears to have no special connexion with temperate latitude high clouds although it is to be expected near cumulonimbus clouds. Visibility in cirrus is usually quite good and is rarely less than half a mile, except in or near the tops of cumulonimbus clouds.

Dynamical considerations.—The dynamical aspects to be considered must be based on the humidity at the level concerned and the vertical displacement of the air regarded as a result of the vertical motion field in the same layer of the atmosphere. Since the high cloud is usually at about 30,000 feet, we should not generally expect simply to use surface weather charts but should concentrate our interest on the 400–300-millibar or 300–200-millibar layers to obtain direct information. Increasing cirrus cloud has of course long been known as the fore-runner of a warm front or occlusion and in fact there is a high probability of cirrus in this situation. It is obvious, however, that cirrus occurs in other synoptic conditions, for example, anticyclones and ridges which indicate no connexion with surface features, and also that many fronts have no cirrus directly associated with them and do not extend to these levels. Another situation in which surface observations are useful is that of widespread instability including deep troughs and cold pools where the spreading of cumulonimbus tops can produce widespread convective type cirrus. This mode of formation is of first importance in tropical regions but in this country more often results in patchy high cloud often at lower altitudes than other types.

The study of upper air temperature and wind soundings on the tephigram at present only gives a limited amount of information. It is useful of course in helping to predict instability leading to cumulonimbus formation. The subsequent production of layers of cirrus densus may often be associated with the level at which a slackening of the lapse rate can be detected. Moreover, if there are thin layers in the upper troposphere with lapse rates greater than the wet adiabatic, convective cirrus may be anticipated. The tops of high cloud will in general be determined by the level of stabilization of the lapse rate either at or just below the tropopause. Up to the present, however, no generally accepted relationship has been established between the variation of temperature and wind with height on the tephigram and the base of high cloud produced by

widespread ascent. It appears that the latter can only be detected by a study of a network of upper air soundings by means of contours, thickness lines etc., and this is discussed further below.

Upper air soundings at present are not capable of giving measurements of humidity at cirrus levels since the element of the radio-sonde is not sufficiently sensitive to respond to the small amounts of water which can be contained by air at the low temperature there. Readings can be obtained in aircraft rather laboriously using frost-point hygrometers and the Meteorological Research Flight, using this instrument, has shown that saturation is approached near cirrus and increases as an aircraft flies upwind towards a cirrus area. On the other hand, in certain air masses, mainly with northerly and easterly winds the air is very dry at cirrus levels and a very considerable vertical motion would be necessary before cloud could possibly form. Hence it seems likely that if the standard of routine upper air measurements of humidity could be considerably improved an important step would have been taken towards an improvement in high cloud forecasting. Meanwhile it has been found by James³ that, since there is some correlation between humidity at cirrus levels and that at the greatest height of measurement, dew-point depressions of less than 10°C. at the 500, 450 and 400-millibar levels or above are a useful pointer to the presence of cirrus at higher levels.

Although in the future the field of vertical motion at various levels may be produced by electronic computing methods, the requirement up to the present has been for the development of methods which can be used directly by outstations without a great deal of labour or alternatively for methods which can readily be handled at a large office and then rapidly disseminated within the normal communication system. There are several upper air situations which are known to be often associated with high cloud or alternatively clear skies and these are briefly described below.

(i) *Jet streams*.—It has been found from British flight results that there is a marked asymmetry in the distribution of high and medium cloud across the axes of jet streams, considerably more high cloud being observed on the high pressure side than on the low pressure side. The greatest ratio of cirrus to no cirrus observations occurs up to 300 miles from the jet axis on the high pressure side. Humidity readings on the same flights indicated higher values on the high pressure side. These observations have been considered to suggest that on the whole there is general ascent in this region and descent on the low pressure side. American investigations have indicated, however, that the frequency of high clouds have two maxima of 30 per cent, one at about 300 miles to the north of the core and about 5,000 feet below the polar tropopause, the other at about 350 miles south of the core at about the same altitude, that is, at 15,000 feet or so below the equatorial tropopause. At and below the core the frequency was only about 15 per cent. Cloud was infrequent anywhere above the level of maximum wind (which coincides with or is slightly above the polar tropopause but is about 5,000 feet below the equatorial tropopause). Both sets of results agree that the cloud types on the low pressure side tend to be more convective in character and those on the high pressure side of a frontal or layer type. The former may therefore often be associated with instability in the cold air. It appears that forecasters can apply this kind of general picture of high cloud types around a jet stream with some confidence. If the jet is associated with active fronts it is likely that there will be more cloud present than if it passes nearly over surface highs when there may sometimes be little or no cirrus at all.

(ii) *Indications on contour charts of regions of vertical ascent*.—It has been shown that the advection of warm air (similar to conditions ahead of a warm front) indicated by the positions of the 300-millibar surface isotherms on the 300-millibar contour chart is frequently a pointer to vertical motion at this level and leads to cloud formation. Alternatively, the relation of the 500–300-millibar or 400–300-millibar thickness lines with respect to the 300-millibar contours or the veering of wind with height at these levels may be used as an indication of warm or cold air advection, the latter often being associated with conditions of no cloud. Frequently, however, these criteria are difficult to apply when the contours and thickness lines tend to be parallel or the wind veers small.

Another useful suggestion is that upward motion and hence cloud formation may be associated with the advection of cyclonic vorticity in the upper troposphere. It is not difficult for large forecast offices to produce vorticity charts at 300 millibars and disseminate the results but it is probably beyond the capabilities of outstation offices. Fortunately regions of positive vorticity advection usually have a characteristic position on the 300-millibar chart—the area from the forward edge of a trough to the centre of the preceding ridge. A statistical test by James³ of the use of this region as an indicator of high cloud showed considerable success. The same region of the 300-millibar chart was also found by Gayikian (Stone⁴) to be that most likely to be associated with high cloud particularly on the high pressure side of the jet stream. Based on his experience with the use of this pattern he proposed several rules for its use in forecasting the cloud density and movement. A decrease in the amplitude of the pattern or an increase in its wavelength on the whole tend to decrease the high cloud coverage and vice versa.

It has also been found in this country that high cloud is most likely with upper winds between south-west and north-west and absent with easterly directions. To some extent this

may be a reflection of the patterns discussed above, although the occurrence of convective cirrus in unstable situations will be an exception.

Dr. Murgatroyd concluded by saying that the above account of proposed methods of forecasting high cloud is not comprehensive and further information could be obtained from the references quoted below. Other systems have been tried using objective techniques but none of them have been sufficiently successful to warrant general adoption. At present it is recommended that the methods described above and listed by James³ should be exploited as far as possible. For forecasting convective cirrus the tephigram and surface charts should be examined for signs of instability to great heights and instability in shallow layers in the upper troposphere. For forecasting layer clouds consideration should be given to possible high humidities in the upper troposphere, wind direction, warm advection, the position of the jet stream and the position of ridges and troughs on the 300-millibar contour chart. In all cases, of course, reported observations should be used fully and full weight given to the possibility that high cloud might be present but not observed. The heights of bases and tops at present will most often have to be related to the tropopause height in terms of the climatological statistics.

As regards future progress Dr. Murgatroyd suggested that the following may be the most important lines of investigation. Several of them are being actively worked on within the Research Directorate of the Meteorological Office for other reasons as well as high cloud studies.

- (i) The more extensive collection and dissemination of aircraft reports of high cloud.
- (ii) Trials of radar cloud height detection equipment of about one centimetre wavelength both for high and medium cloud observations including the cloud structure of fronts.
- (iii) Continued attempts to produce a radio-sonde humidity element which would work reliably at temperatures down to at least -70°C .
- (iv) Use of an electronic computer to calculate and make available fields of vertical motion at different levels.
- (v) It may also be useful to consider whether any further information could be obtained by more dynamical studies, particularly one relating to the trajectories at these levels of air with high humidity.

Mr. J. Harding, the second opening speaker, said that whereas Dr. Murgatroyd had dealt mainly with the results and plans of research, he on the other hand would talk about outstation experiences and problems. The problem was discussed from the viewpoint of (i) aircrews engaged on photographic reconnaissance (ii) aircrews in other branches of aviation and (iii) forecasters, with special reference to those at Wyton.

Photographic reconnaissance.—Photographic reconnaissance aircraft have many duties assigned to them. Much of the work involves photography of the ground using vertically mounted cameras. Obvious tasks are surveying in time of peace and photographing military targets in wartime. The flying height of an aircraft engaged in taking a series of photographs of the ground is all-important. For any given camera, the greater the height the greater the coverage achieved by each print, an important factor in terms of hard cash. But this increased coverage means prints of smaller scale and poorer definition. However, high-level photography can be improved by using cameras of large focal length, which give smaller coverage but better definition. Cameras with focal lengths of up to 48 inches are now available. High-level flying for photographic work by jet aircraft is also desirable in terms of aircraft endurance and, in time of war, in the interests of safety.

Needless to say, cloud and haze are the bugbears of photographic reconnaissance. In addition to the obvious effects of haze on the quality of the prints, haze can seriously hamper the work of the navigator. High-level photography necessitates a considerable run up to the target, and the oblique visibility, which is often worse than the vertical visibility, can hamper the work or even prevent the target from being located and photographed.

The effects of cloud and, to a lesser extent, haze, can be lessened by flying at relatively low levels. For example, in the presence of cirrus only, photography can be effected at, say, approximately 16,000 feet (a standard photographic level) or even at 33,000 feet on occasions, whilst in the presence of medium cloud and in the absence of low cloud, certain tasks can be accomplished successfully with low-level photography. Successful planning of a day's photographic reconnaissance depends upon accurate forecasting of clouds at all levels. In other words, there is an operational requirement for forecasts of the occurrence or, preferably, the non-occurrence of cirrus clouds.

Before leaving the field of photographic reconnaissance we might ask ourselves whether cirrus constitutes a hazard to reconnaissance aircraft. The answer is, generally speaking, in the negative. Much of the flying in temperate latitudes is done above cirrus levels. Flight through the cirrus presents no icing problems, and turbulence therein is probably regarded in much the same light as clear-air turbulence. However, turbulence will be discussed in greater detail later. At this stage Mr. Harding digressed to give details of CINTEL, a photographic printer using electronic methods, illustrating his remarks with slides of cloud photographs prepared by CINTEL and by the usual subjective method.

Military aircraft other than photographic reconnaissance aircraft.—It is hardly necessary to mention that cirrus has operational significance in respect of other military aircraft. As examples we might mention fighter interceptions, visual bombing from high altitudes and refuelling of aircraft at cirrus levels. However, with the advance of scientific techniques the nuisance value of cirrus is likely to diminish. This afternoon's discussion should reveal just how general in the Office is the problem of cirrus forecasting.

It is appropriate at this stage to refer briefly to a hazard presented by cirrus to some military aircraft under certain circumstances and described in an article by Pavely.⁵ Two fighter aircraft flying in formation in extensive cirrus clouds over the English Channel in July 1957 at about 30,000 feet experienced, without visible warning, airframe icing, severe turbulence and damage by hail. The cirrus was anvil cirrus, and the aircraft flew into a cumulonimbus that was feeding into the cirrus layer. Visibility in anvil cirrus is often very low, and pilots have intimated that there is seldom visual warning of the transition from the relatively quiet anvil to the active core of the associated cumulonimbus cloud.

Civil aircraft.—With a few exceptions it is unlikely that civil aviation can have been particularly interested in cirrus forecasting in recent years, though one may call to mind the limited use of jet-stream cirrus in navigation. However, with the recent introduction of jet aircraft on North Atlantic routes, it is understood that the operating companies have expressed interest in forecasts of cirrus clouds. We hope, in the discussion that follows, that our colleagues who are associated with civil aviation will tell us the full implications of this interest. Most forecasts of cirrus, for example, are unlikely to improve the operators' chances of steering their fare-paying passengers around turbulent areas. The possibility of penetrating cumulonimbus tops while flying in extensive anvil cirrus has been referred to, but this hazard can be avoided by the use of navigational weather radar. Forecasting the cumulonimbus cloud is probably much more important than that of the associated anvil cirrus, but it can well be imagined that it may be advantageous to know of and to avoid widespread areas of young anvil cirrus.

Cirrus in the central Pacific.—Mr. Harding went on to remark that it was appropriate to say something of the experiences of Royal Air Force pilots operating in the central Pacific, with particular reference to cirrus clouds. These remarks could be regarded as a curtain-raiser to December's Meteorological Office discussion on Tropical Meteorology.

We understand from pilots and some of the literature that here we are concerned mainly with convection cirrus often originating from cumulonimbus clouds. It is not uncommon for this cirrus to last for long periods after the decay of the parent clouds, and to cover extensive areas. The cloud is commonly found between 40,000 and 50,000 feet and, in general, is more turbulent than anvil cirrus over and around the British Isles. Flight can be very bumpy in it, even some hours after the parent convection cloud has dispersed. Moreover, patches of slight to moderate turbulence are not uncommon in a layer 1,000 feet thick immediately above the cirrus layer. Looking ahead to the time when civil jets operate at these heights in tropical regions, it would seem that areas of widespread cirrus should, whenever possible, be avoided in the interests of passenger comfort. If, as is probably the case, conditions in the cirrus are unsuitable for comfortable flight during the active stage of cloud development in convergence zones and for some hours after the decay of the cumulonimbus clouds, the forecast problem will rest largely with that of forecasting the position and time of development of convergence zone clouds. Heavy airframe icing has also been experienced in the anvils away from the main cumulonimbus cores.

There is another very important feature associated with flight in the tops of large cumulonimbus clouds in the central Pacific, or in the air immediately above the anvil, namely the effect of the associated turbulence on jet engines. The ambient temperatures are very low, and under these conditions engines may suffer a "flame-out" when the smooth flow of air is interrupted by marked turbulence. An aircraft recently suffered a double "flame-out" at a temperature of -75°C . immediately following a particularly marked bump in anvil cirrus over the Pacific.

We cannot leave the tropics without some reference to reports of a thin layer of cirrostratus at levels above those normally favoured by anvil cirrus. Pilots operating in the central Pacific have reported that cirrostratus is commonplace at levels estimated to be around 50,000 feet. This cirrus is seldom reported by ground stations. It is normally visible from a high-flying aircraft when viewed obliquely, and although sometimes "formless" usually exhibits roll characteristics. This cirrus is normally quite distinct from the tops of the convective cirrus. How is this cirrus maintained at these levels? Is it visible evidence of sustained slow upward motion in the high troposphere in equatorial regions?

The wave-like appearance of the cloud is interesting in that it recalls the persistent waviness over a number of days at about 49,000 feet in July 1953 over the British Isles, as evidenced by the appearance of a thin layer of dust. This was reported fully by Jacobs.⁶

The forecasting problem.—We are probably correct in saying that until quite recently forecasts of non-convective cirrus cloud were based largely on frontal models and, where possible, on simple advection processes. Dr. Murgatroyd has referred to recent investigations of the problem in the United States of America, Canada, Germany, France and this country. It is interesting

to note how closely the results, published recently by Alt,⁷ of many observations on cirrus clouds from aircraft based mostly in France, agree with the earlier findings in this country. The various publications contain many statistics and suggestions for helping the forecaster to deal with this cloud. However, when it comes to producing a relatively simple procedure we are particularly indebted to Dr. D. G. James³. James lists thirteen questions which require the answer "yes" or "no". If there are five or more "yeses" the conditions are favourable for the occurrence of four oktas or more cirrus cloud. On any occasion most or all of the questions can be answered readily at any outstation where a reasonable sequence of surface and upper air working charts is maintained. The questions are based on a statistical study of associations between the presence of cirrus cloud and features of the synoptic charts and upper air observations, as discussed by Dr. Murgatroyd this afternoon. The answers are deduced from the latest synoptic charts and upper air observations, and are valid for the time of the charts and observations. The forecasting value arises from the assumption that the answers will be valid for a further period of six to nine hours. This procedure of James is attractive in that it is largely objective. However, this objective approach to the problem is insufficient to meet forecast requirements for photographic reconnaissance. Such forecasts are produced late in the night for daylight hours. Positive or negative answers are given to the thirteen questions of James' technique, using the midnight charts and appropriate upper air soundings. If five or more "yeses" are obtained it is assumed that there were four oktas or more of cirrus cloud around midnight and that, with any luck, the cloud will persist into the morning. However, we are interested in cirrus conditions throughout the daylight hours. The procedure now used is to forecast those features of the synoptic charts and upper air observations for 1200 G.M.T. that are necessary to give positive or negative answers to the thirteen questions and hence to indicate whether or not cirrus is likely later in the day. It is not always possible to give confident answers to all the questions for twelve hours ahead, but it is usually possible to give likely trends and to deduce whether the occurrence of cirrus is becoming more, or less, likely. Needless to say, 1200 G.M.T. is chosen as the time of the forecast to enable an objective check of the accuracy of the forecasts to be made when the midday working charts and upper air ascents are available.

James' technique.³—The first three questions deal with humidity at 500, 450 and 400 millibars. Relatively high humidities in this layer favour the occurrence of cirrus in or above the layer, and James uses a dew-point depression of 10°C. or less as his criterion for cirrus. Dr. Murgatroyd has referred to the shortcomings of routine upper air measurements of humidity and the need for considerable improvement. Alt,⁷ in his paper on work done in France on this problem, strikes a pessimistic note, concluding that current radio-sonde ascents do not allow the determination of the heights of the upper clouds, nor even the verification of their existence. However, experience has shown that this criterion of James is in itself useful in this country. It is not uncommon to find dry air at medium cloud levels and a marked increase of humidity in the 500 to 400-millibar layer: when cirrus is either present or about to occur in the area. Sometimes a fairly accurate estimate of the base of the cirrus can be made, when this is low, but generally speaking the forecasting of the cloud base has to be based on statistics.

We would be interested to hear something during discussion this afternoon on the prospects of accurate measurements of humidity at high levels by radio-sondes. During the second session of the Commission for Synoptic Meteorology at New Delhi early this year high claims were made in committee for the latest techniques used in Sweden, including claims for high sensitivity and accuracy through the tropopause and well into the stratosphere.

James' fourth question deals with the lapse rate in the 500- to 300-millibar layer. He has found that the presence of a layer with a lapse rate greater than the wet adiabatic is closely associated with cirrus cloud, and Dr. Murgatroyd has stated this afternoon that convective cirrus may be anticipated when such lapse rates occur in the upper troposphere. Like the questions on humidity this one on lapse rate can be answered at a glance. However, it does serve to illustrate the interdependence of many of James' criteria. A lapse rate greater than the wet adiabatic is itself no guarantee of cirrus cloud. Widespread cirrus could be forecast with lapse rates in a strengthening southerly flow over France and the British Isles as cold air advances from the west. Thanks to general upward motion clouds may well form in the unstable air. The occurrence of high and medium clouds is commonplace in advance of thundery weather moving north from France in the summer. On the other hand, unstable layers in the upper troposphere in northerly flows may well be cloudless, and remain so.

Questions 5 and 6 deal with the 400-millibar wind and the wind change between 500 and 300 millibars and no further comments are called for.

Question 7 deals with the 1000 to 500-millibar thermal wind. In a study of the association between thermal wind speed in the 1000 to 500-millibar layer and occasions of cirrus and no cirrus James found that the mean thermal wind was higher with cirrus than without it, and concluded that there is a useful association between thermal winds greater than, say, 20 knots and the occurrence of cirrus cloud. This association is hardly surprising in respect of non-convective cirrus clouds, especially when we recall the association of cirrus with well-defined baroclinic zones and jet streams. It should be remembered, however, that convective cirrus associated with cumulonimbus clouds will occur often with light thermal winds.

Questions 8 and 9 deal with ridges and anticyclonic curvature of the 1000 to 500-millibar thickness lines. Cirrus is more likely to occur in the thermal ridges and where the thickness lines have anticyclonic curvature than in the presence of troughs and cyclonic curvature. This relationship between cirrus clouds and thickness patterns was suggested by the association of cirrus clouds with surface fronts.

Question 10 deals with deep cold pools or intense thickness troughs. This is merely a question of expecting anvil cirrus and its products when cumulonimbus is forecast.

Question 11 deals with the 300-millibar contour pattern. The area from the forward edge of the trough to the centre of the preceding ridge is favourable for cirrus. Alt,⁷ in his paper on cirrus and cirriform clouds, goes into more detail in considering the flow at 300 millibars and the associated occurrence of cirrus over north-east France and south-west Germany. He considers six types of flow:—

(i) *A strong westerly or south-westerly flow of relatively warm air of maritime origin.*—Thick wide-spread cirrus is common, with a mean depth of about 8,000 feet and tops often at 30,000–33,000 feet. Needless to say, jet streams are frequent in this situation, and much of the cirrus is associated with these streams. Alt found 71 per cent of jet stream cirrus on the anticyclonic side and 29 per cent on the cyclonic side.

(ii) *Ridge on the edge of a distant south-westerly flow.*—Cirrus is mostly less than four oktas in fairly deep layers. Several broken layers at different levels is a characteristic of this flow pattern.

(iii) *Northerly polar flow.*—Isolated cirrus is a feature of northerly flow, usually less than 5,000 feet deep and at low altitudes, the tops seldom exceeding 24,000–27,000 feet. We can assume that this will normally be convective cirrus.

(iv) *Disturbed westerly flow with a succession of depressions or troughs and ridges.*—The characteristics of the cirrus are very variable, but it is usually less extensive and thick than with established west or south-west flow.

(v) *Warm south-east flow of Mediterranean origin.*—This is not a frequent situation. When the Mediterranean flow is direct, the cirrus is extensive and thick, as with established westerly flows. However, if the flow is more continental, the cirrus is thin and isolated.

(vi) *Unorganized circulation, with flat pressure field.*—Alt was unable to make any useful conclusions, for any accompanying cirrus had very variable characteristics.

Question 12 deals with cirrus cloud in relation to the jet stream, which Dr. Murgatroyd has discussed at some length.

Finally, Question 13 deals with cirrus in relation to warm fronts or occlusions. The area up to 300 miles ahead of a surface warm front or occlusion is particularly favourable for cirrus, and warrants an affirmative answer. The incidence of cirrus is not as high in the neighbourhood of cold fronts as near warm fronts, and cold fronts do not feature in James' technique. No distinction is made in the statistics between kata- and ana-type cold fronts, but we may infer that wide-spread cirrus is unlikely immediately to the rear of kata-cold fronts.

Experience at Wyton has shown that the thirteen questions can be answered in a few minutes. Some weeks after the formal introduction of the technique as a routine at Wyton I asked a forecaster there what he thought of it as a forecasting tool. "Well", was the reply, "when I wade through the thirteen questions and get five or more 'yeses' and look out of the window I see cirrus". Now this is a compliment to the technique and gives us confidence in the presence or absence of cirrus on those mornings when the cirrus levels cannot be observed and aircraft observations are not available. Then the cirrus trend during the morning is usually readily determined by forecasting answers to the questions for 1200 G.M.T. In fact, James has laid down a technique for cirrus forecasts for 24–36 hours ahead, making use of pronouns and prebaratics to answer questions on humidity, warm air advection, the thickness and 300-millibar patterns, the jet stream and warm front or occlusion. In tests carried out at Dunstable the percentage of successful forecasts of cirrus and no cirrus fell from about 87 per cent for the six to nine hour forecasts to about 79 per cent for the 24 to 36 hour forecasts. At Wyton we regard the James technique for cirrus forecasts as being in the same category as, say, the Craddock technique for forecasting fogs, that is to say, it is a forecasting tool that is easy to use and reasonably successful in its results.

Turbulence in cirrus clouds.—Detailed studies of turbulence in cirrus clouds have yet to be made. We know that turbulence is experienced at times in cirrus, just as it is experienced in clear air, sometimes slight, sometimes moderate and sometimes severe. But we do not know whether the probability of turbulence at cirrus levels is greater or less in the clouds than out of them. Nor do we know much about the varying probabilities of turbulence in the different species and varieties of cirrus clouds. Stone⁴ has very little to say on the subject, but suggests that cirrus uncinus and the chaotic (intortus) variety of cirrus indicate turbulence. The recently published French investigations contain some statistics on the occurrence of turbulence in or near cirrus, but the statistics carry little weight in that the presence or absence of turbulence was reported in only a fraction of the cirrus observations. Moreover, no attempt is made to correlate turbulence with the different species of cirrus clouds.

We know that turbulence is experienced in anvil cirrus in temperate latitudes, even outside the more active cumulonimbus cores. From pilots' reports in the central Pacific we can infer that turbulence in anvil cirrus there is often more severe than in temperate latitudes and that turbulence is considerable in the residual spissatus cirrus, hours after the parent cumulonimbus has dispersed. We infer also that patchy slight or moderate turbulence is commonplace just above the anvils of equatorial cumulonimbus clouds.

Can we say anything about turbulence in cirrus associated with jet streams in temperate latitudes? The problem of clear-air turbulence was discussed at the Meteorological Office discussion in October 1958.⁸ It will be recalled that in the study of clear-air turbulence around the jet axis an almost complete absence of marked clear-air turbulence was revealed on the anticyclonic side of the jet and below the level of the jet axis. Now this is the region of the jet stream favoured by frontal and layer types of cirrus. Might we not infer then that turbulence in this cirrus will normally be slight. It has been argued also that the direct circulation set up in an intensifying baroclinic zone, in which the warm air rises and where, in consequence, we might expect developing medium and high clouds, is not favourable for turbulent flow. It would be interesting to know if turbulence is more likely in cirrus which is breaking up or dissolving as the result of indirect circulations where the frontal zone is weakening. Turning to the cyclonic side of the jet, we are more likely to find convective cirrus, and presumably some degree of turbulence is indicated.

Mr. Harding then drew attention to a recent Meteorological Office order calling for reports of severe clear-air turbulence experienced by aircraft, and expressed the view that reports of severe turbulence within cirrus clouds were also worthy of attention. Alt's statistics include an appreciable number of cases of strong turbulence either in or immediately above or below a cirrus layer.

Cirrus in the stratosphere.—James³ points out that for all cases of dense cirrus cloud observed in the stratosphere over the British Isles from 1952 to 1954 there was advection of anticyclonic vorticity at 300 millibars. In other words, the vorticity advection term is not in favour of cirrus in the troposphere. Squadron Leader J. W. Monaghan of the Royal Air Force, to whom we are deeply indebted for many valuable cloud observations, has reported a widespread thin sheet of cirrostratus in the Gloucester area on 3 October 1957. Application of James' technique for forecasting tropospheric cirrus produced only two answers in the affirmative, namely in respect of thermal wind and the position of the jet stream. This is yet another example of cirrus in the stratosphere with advection of anticyclonic vorticity at 300 millibars. Squadron Leader Monaghan has stated that in appearance this cirrostratus sheet was very similar to those commonly observed by him in the central Pacific. The temperature at the cirrus level over England on 3 October 1957 was around -60°C ., somewhat warmer than that of the high cirrostratus in the central Pacific.

Conclusion.—Mr. Harding, in conclusion, stressed forecasters' indebtedness to those who have published statistics and other information on cirrus clouds in recent years. In particular, the James technique is a useful forecasting tool, easy to apply and reasonably satisfactory in its results. There is still much to be learnt about cirrus clouds, but a good beginning has been made towards solving the many problems involved.

Mr. Harding illustrated his remarks with a number of slides of cloud photographs taken by Royal Air Force pilots. He paid tribute to the Officers of No. 58 Squadron for their co-operation in producing many interesting reports on cloud and turbulence, and in obtaining many excellent cloud photographs.

Mr. Evans considered that high cloud forecasting is important to Civil Aviation both for economic reasons and also as regards passenger comfort. Pilots may be able to use high cloud formations near jet streams as indicators of the position of the jet stream axis. The bases and tops of the high cloud layers may also indicate heights of temperature changes to which jet engines are sensitive. More information on the relation of turbulent areas to high cloud is also desirable. Dr. Murgatroyd agreed that areas of maximum wind may be related to cloud features and in particular the top of the high cloud layer is frequently near the height of the wind maximum. The lateral relation between cloud and maximum wind, however, is not so close and probably the operators would be better advised to install navigational equipment such as the Doppler system which would allow the accurate measurement in flight of the wind itself. The top of the high cloud layer is of course frequently a region of lapse rate change particularly when the cloud reaches the tropopause. Mr. Harding had pointed out that the region of high cloud formed by slow ascent was frequently on the high pressure side of the jet stream and the preferred regions of clear-air turbulence on the low pressure side. Turbulence in convective-type cirrus can be vigorous especially near cumulonimbus anvils. He agreed that further work is needed on the occurrence of turbulence in high cloud.

Mr. May asked for further information regarding the occurrence of solar haloes and also wondered whether one of the effects of atomic explosions is to produce many more nuclei at high altitudes and so lead to larger amounts of high cloud. Dr. Murgatroyd thought that the

occurrence or otherwise of solar haloes is related to the crystal type. For instance, the 22-degree halo is thought to be due to refraction by hexagonal crystals and other shapes would not necessarily lead to haloes. As regards the question of nuclei he considered that it is unlikely that there is a substantial lack of nuclei at high levels since supersaturation with respect to water is hardly ever observed there. Hence even if the number of nuclei were greatly increased it would not probably lead to greater amounts of high cloud.

Mr. Bradbury asked if the considerations underlying high cloud forecasting as outlined above were necessarily consistent with the methods given by Dr. James. Was Dr. Murgatroyd suggesting a more subjective approach rather than using that technique objectively? Mr. Harding thought that if possible, rather than use it completely objectively, it would be preferable to consider what type of cirrus might form, for example, convectively or by widespread ascent, but it was agreed that for a hard-pressed forecaster it might only be possible in practice to apply the rules rigidly.

Sir Graham Sutton compared Dr. James' method of forecasting high cloud to that of a well-known system of bidding in bridge and said that presumably, according to the synoptic situation, different factors should have different weights. He was interested in Mr. Harding's remark that some jet aircraft had experienced "flame-outs" at the same time as turbulence in high cloud. What was the relationship between these two occurrences? Mr. Harding said that the important factor concerning "flame-outs" was the very low temperature at which they were experienced. Pilots had the impression that the possibility of "flame-outs" at such temperatures was aggravated by turbulent conditions. The problem was being investigated.

Mr. Hastings was not happy with the statement that the tops of high cloud reach to low tropopause but not to high tropopause. He was also interested in the occurrence of cirrus in the stratosphere when the tropopause height varied. Dr. Murgatroyd said that low tropopause seemed to be associated with rapid discontinuities from the lapse rate in the upper troposphere to the more isothermal conditions of the lower stratosphere. With high tropopause on the other hand there were frequent small "stops" in the lapse rate in the upper troposphere before the stratosphere was definitely reached. High cloud could therefore be limited by these "stops". If the tropopause is regarded as a lid on vertical motion the latter must of course decrease as the tropopause is approached and divergence take place so that in neither case could the vertical motion quite extend right up to the tropopause. Mr. Harding discussed at some length the possibility of cirrus in the stratosphere, pointing out that it could easily be observed there as the tropopause height changed in successive steps and air which was now stratospheric could have recently been of tropospheric origin in this way. There was no *prima facie* reason why cloud should not exist in the stratosphere when vertical motion is present and low humidity there will be the chief limiting factor.

Mr. Clark emphasized the importance of cirrus persistence when the air was near ice saturation and asked about observations of its existence at large distances from the formation area. Mr. Harding thought this was possible in south-westerly situations and in the tropics. In northerly situations with convective cirrus in a subsiding air mass he had not observed this to occur.

Mr. Graystone referred to Mr. Harding's description of high cloud at about 50,000 feet over Christmas Island and said that it sometimes could be observed from the surface around sunrise and sunset.

Mr. Wales-Smith then referred to some further trials of James' technique. He and his colleagues had obtained good results simply by considering the last three parameters (jet stream, upper ridge and warm front) in conjunction with the surface and 200-millibar contour charts. Mr. Harding was surprised at this finding since it had always been recommended that all parameters and not simply a selection should be used in this technique. Presumably those considered referred only to cirrus formed by large-scale ascent and not the convection type.

Dr. Stagg was concerned about the different frequencies of high cloud reports by day and by night and wondered how much was due to observation conditions and how much was a real variation in cloud amount. How did the diurnal variation of lower clouds affect this question? Dr. Murgatroyd thought that the observed variation was almost entirely due to effects of illumination and/or obscuration. He thought that diurnal variation of lower clouds, for example, cumulus, would in general make it easier to observe the upper clouds by night.

Mr. McCaffery described how he, using searchlights, had also observed cirrus cloud to be present at night when it could not be seen from the surface.

Mr. Gold said that in olden times it was thought that an arriving warm front was preceded by a layer of cirrus. How often in advance of a warm front do you get this high cloud and how frequently is it associated with haloes? Dr. Murgatroyd said there were no statistics on these points but he would expect the approaching warm front to be associated with warm air advection on the 300-millibar chart in the cases when high cloud preceded it. In fact he would regard the production of high cloud in this situation simply as a special case of warm air advection at cirrus levels. Since the haloes are usually associated with regular hexagonal crystal forms they would be expected frequently in the case of widespread slow ascent ahead of a warm front.

Mr. Harding remarked that the very close association of cirrus with approaching warm fronts was one of the few features of fronts and pressure systems on which views had remained almost unchanged over the last 20 years or so in his experience.

Dr. Frith questioned whether there was general agreement that condensation at low temperatures always required saturation with respect to water. There have been suggestions from laboratory work that this is not always so. Dr. Murgatroyd said that it was thought that the rate of ascent and the presence of easily activated nuclei were the determining factors. If there is slow ascent and many active nuclei, condensation might take place somewhere between the ice and water saturation temperatures and all the moisture would be used on these nuclei as it becomes available. With more rapid ascent and less active nuclei it was probably always necessary to reach saturation with respect to a water surface.

Dr. Stagg, closing the discussion, considered that there were now available several ideas on this subject that were worth further research and exploration by forecasters. He hoped that James' techniques and any modifications would be used and thoroughly tested as high cloud forecasting was obviously a problem of increasing importance to the Office. Dr. Stagg also asked Mr. Harding to convey the thanks of the Meteorological Office to the Commanding Officer and Officers of No. 58 Squadron for the excellent cloud photographs and other services they had provided.

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REVIEWS

Climate and economic development in the tropics. By Douglas H. K. Lee. 8½ in. × 5½ in. pp. xviii + 182, *illus.*, Harper and Brothers, New York. Oxford University Press, London, 1957. Price 28s.

It should be said at the outset that economic development is the main theme of this book and that discussion of climate enters only sufficiently to convey the necessary background knowledge in a brief early chapter; thereafter it is only referred to incidentally.

The book is published under the auspices of the U.S. Council on Foreign Relations and though appearing under the name of a single author it stems largely from the discussions held by an exploratory group of experts brought together to consider and report on the effects of tropical climates on various economic activities. To quote the Foreword "the author has produced a summary statement of what we know about the effect of tropical climate on agriculture, animal husbandry, human physiology and industry." The main part of the book is devoted to separate chapters under each of these four heads. In each case the premise is that tropical countries are in the main much under-developed largely on account of the disadvantages imposed by the climate. Several statistical tables provide evidence of various aspects or effects of this under-development.

Only a few of the adverse influences of climate can here be mentioned by way of illustration: the increased vulnerability of plants and animals to disease on

account of disease vectors and spores being favoured by warm and humid conditions; the loss of soil fertility due to leaching in areas where rainfall is abundant (fertility which can only be restored to the surface soil by deep-rooted forest trees which shed their leaves); crop failures and animal losses where rainfall is unreliable; and perhaps not least the lethargic habits so easily produced in men's minds and bodies where climate is genial and subsistence to be had for the mere gathering.

But climatic factors are not the only ones causing the under-development of tropical countries; lack of capital, lack of accessible markets, poor transport facilities and tribal customs are some others, and their effects are hard to disentangle. The problems are recognized as complex; nevertheless some remedial measures are suggested in each of the economic fields surveyed.

All this makes most interesting reading but is in no way special to the meteorologist. For him the chapter on climate contains little that is not well known already; it describes the distribution of climate over the earth's surface and a few of the better known climatic classifications. The few illustrative charts are poorly produced and difficult to read.

A. G. FORSDYKE

Exploring the atmosphere's first mile. Proceedings of the Great Plains turbulence field program, 1 August to 8 September 1953, O'Neill, Nebraska. Volume I—Instrumentation and data evaluation. pp. xiv + 376, *illus.* Volume II—Site description and data tabulation. pp. vi + 202, *illus.* Edited by H. H. Lettau and B. Davidson, published on behalf of the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command by the Pergamon Press, London, 1957. Price £7 per set.

The "Great Plains turbulence field program" described in these two volumes was a co-operative effort by 15 United States Government scientific services, universities and scientific institutions to study the micrometeorology of a flat, well exposed site at O'Neill, Nebraska from 1 August to 8 September 1953. By far the most attention was given to the layer from about 0.5-metre depth to 16 metres above the surface but aircraft flights, smoke puff drifts, pilot balloon and radar-wind ascents and radio-sonde measurements were used to extend the investigation to about 2000 metres.

The project arose out of an attempt by H. Lettau of the Geophysics Research Directorate in 1947 to gather sufficient micrometeorological data to make a thorough study of the surface layer. After various universities had been asked to develop special instruments and techniques it was decided that it would be best to assemble all the workers on one site and, after a survey in the summer of 1952, the open prairie O'Neill region was selected. A study of seven years' synoptic charts showed that in the period 1 August to 15 September (the dates were largely governed by the commitments of the universities) southerly airflows predominated and on the average one twenty-four-hour period per week occurred when such airflows were accompanied by fine weather. Clear days and nights were required so that large diurnal changes in the heat budget terms could be studied. It was decided therefore to space the operating agencies along a 500-metre east-west line and to be ready from 1 August 1953 for southerly airflows which would thus have an unobstructed fetch over several miles of the prairie, the last 500 metres of which was mown.

Decisions to start observational periods were made by the editors and it was fortunate that 1953 proved to be a fairly normal year when seven periods occurred (and were forecast) in the six weeks, the average length being 25 hours and the shortest lasting 10 hours (when bad weather set in).

Volume 1 consists of 65 scientific papers grouped into six chapters. In Chapter 1 an introduction by the Editors, giving the aims and general results of the project, is followed by an account of the routine surface observations made, synoptic charts plotted (small reproductions are given in Volume 2) and determination of the surface (up to 16 metres) wind direction. A thorough discussion of techniques for measuring the soil temperature, thermal conductivity, moisture content, density, specific heat and heat flux follows in Chapter 2. The only instrument the reviewer noted as missing is a soil balance whereby moisture changes are recorded continuously. Unexpectedly large horizontal variations in such apparently homogeneous ground were found over short distances, so that the normal calculations of heat balance in the vertical, ignoring horizontal flow, were not valid. Further work is promised on this subject.

Radiation, boundary shear stress, low-level smoke puff drifts and dewfall measurements are considered in Chapter 3. Chapters 4 and 5 describe respectively the slow and fast response instruments fixed on various masts and towers to measure wind and temperature profiles at heights up to 16 metres. The slow response anemometers were all of the cup variety, an interesting type having semicylindrical cups to cut down the response to vertical winds. Fast response to horizontal and vertical wind fluctuations was obtained by using thermo-couples, light bi-vanes and instruments still being developed, such as the electronic wind vane and the rotating pressure tube and sonic anemometers.

Low-level ozone and humidity measurements are followed by an account of the upper air (to 2000 metres) work. The volume ends with three most useful review articles by H. Lettau summarising the main results of the investigation and the many questions unanswered.

Volume 2 contains results obtained in the seven observational periods in the form of two-hourly values of all the quantities measured. This type of presentation had been agreed before the project started. However, most of the instruments used were recording continuously throughout the observation periods and some for much longer than this and thus more data are available to the individual participants; some of this has already been discussed in papers published since the programme ended—papers are quoted up to 1956 and more are promised. The second-to-second fast response and some other data are available on punch cards for interested research workers.

The two volumes thus provide a reasonably up-to-date account of the instruments and techniques in use and being developed for micrometeorological work and will be an invaluable source of information and reference for a long time to come. The Pergamon Press presentation is of the usual high standard with excellent diagrams and photographs but the reproductions of autographic records given in Volume 1 could usefully have been larger. L. JACOBS

Pico-Aerologische Untersuchungen über Temperatur-und Windverhältnisse der bodennahen Schicht bis 10m. Höhe in Lindenberg. By H. Henning. *Abh. Met. Hydrol. Dienst.*

D.D.R. 11 $\frac{3}{4}$ in. \times 8 $\frac{1}{4}$ in., pp. 66, *illus.*, Akademie-Verlag, Berlin, 1957. Price DM 29.50.

This is Number 42 of a series of meteorological (and some hydrological) memoirs published by the Meteorological Service in the Soviet zone of Germany since 1 January 1950. In Number 18 of the series the mean temperature gradient over the layer 1–76 metres in the one year 1950–51 was discussed; these measurements were made at an open site at Lindenberg Observatory.

The present memoir considers the continuous records of wind and temperature from the ground to 10 metres high at a site, presumably in the Lindenberg Observatory grounds although its position is not given, mainly for the year April 1953 to March 1954.

Chapter I gives details of the instruments used; namely, platinum thermometers, cup and hot-wire anemometers (fixed on a mast) all with distance recorders. The temperature values for the measuring heights of 0.01, 0.10, 0.50, 1.0, 2.0, 5.0 and 10.0 metres are examined in Chapter 2 and the wind records (speed only) of cup anemometers at 1.0, 5.0 and 10.0 metres and hot-wire anemometers (from December 1953) at one metre are discussed in the third and last chapter. Earth temperatures were measured continuously, by means of platinum thermometers, at 1, 2 and 10 centimetres depth but apart from the reproduction of three records and a brief discussion thereon they are seldom mentioned.

The results are presented in 41 tables of mean values; there are 8 photographs (half size) of original temperature records (six heights on the same paper), 12 photographs (two-thirds size) of wind speed records of hot-wire anemometers and 8 diagrams illustrating original temperature and cup anemometer records. Discussion is almost entirely qualitative and in a few cases does not agree with the relevant tables and figures; for example, there are two values in Table 13 below the minimum value stated in the text and in Figure 19 where curves of temperature against time for heights from one centimetre to 76 metres high are obtained by mixing the results from two separate sites without indicating the height and sites on the graphs, the stated inversion heights do not entirely agree with those indicated by the diagram. There is thus a wealth of material presented. However, the first essential in micrometeorological work is careful consideration of the exposure of the site. Here, apart from a suggestion that it is in the observatory grounds, one is neither told the position nor given any details of the surroundings. The tiny photograph supplied is not reassuring, showing as it does a stout trellis fence and a wooden screen near the mast with houses and trees not too far in the background.

The author seems to be unaware of the work of Johnson (*Geophys. Mem.* Nos. 46 and 77), Best (*Geophys. Mem.* No. 65) Deacon (*Geophys. Mem.* No. 91) or Sutton (for example, "Micrometeorology", 1953), although he makes one brief reference to Flower's work (via the reference in Geiger's "Climate near the ground") in Egypt. Yet Johnson's diagrams Figure 21 (1929) and Figure 15 (1938) explain the marked temperature oscillations on nights with light wind, which puzzle the present author, as due to wind direction changes, although the author hints at this explanation in one section where he speaks of a local wind setting in from a nearby wood. (Wind direction at the site is not measured and such wind directions as the author quotes are from the main observatory

observations.) The graphs given by Best and Johnson for two- and five-year periods confirm that the occurrence of maximum superadiabatic rates in April 1953 rather than in summer was due to the cloudiness of that summer.

It seems that the recording is continuing beyond the period mentioned and it is to be hoped that if results are discussed over a period of several years, the reader will be given full details of the site, that comparisons will be made with the older work, that the figures and tables, unlike some in the present work, will all be for one site and that an attempt will be made to answer some of the many questions propounded by Sutton ("Micrometeorology", Chapters 6 and 7). The prefix "pico" should be dropped; the one term "micrometeorology" is surely quite adequate.

The few misprints detected were minor ones. It was disconcerting, however, to find nine Type B inversions mentioned on page 39 but only eight on page 57 and to discover that the curves in Figure 18 were wrongly numbered. The measurement heights were not given for several of the plotted curves.

L. JACOBS

Solar-terrestrische Beziehungen in Meteorologie und Biologie. By Hellmut Berg. Probleme der kosmischen Physik. Band XXX. 9 in. \times 6 in., pp. vii + 172, illus., Akademische Verlagsgesellschaft Geest und Portig K.-G., Leipzig. 1957. Price DM 23.

A common opening gambit on the part of the meteorologist is to detail the numerous complicating factors which beset his science and which serve as a general apologia for his relative lack of progress over the past 30 years in the practical business of forecasting the weather. Among such factors he often neglects to enumerate the variability of the sun, not because he is ignorant that there is visual, geomagnetic and ionospheric evidence that the sun is a variable star but because he believes, both by physical reasoning concerning the nature of this variability and by the results of a host of statistical studies, that solar variability plays a minor and perhaps quite insignificant role in the vast complexity of variation with which the meteorologist has to contend.

How different it is with those meteorologists with whose work this book by H. Berg is largely concerned. Their conviction appears to be that solar variability plays so important a part in meteorology that its effects must clearly emerge with appropriate arrangement of relatively few data. As a result we have here, for the most part, a wearisome catalogue of "successful" discoveries of short-period connexions between, on the one hand, variable solar radiations (particle or wave) and, on the other, a variety of meteorological elements and parameters—pressure, temperature, circulation indices, high-level topography etc. Four main methods are employed—correlation, parallel curves, "superposed-epochs", and (in synoptic studies) charted isopleths. Despite all the physical factors that make for weather variation an estimate is rarely made in these studies of the contribution made by such factors to the mean statistical variation of the weather parameters arranged in relation to the selected solar or geomagnetic events. A real connexion is often held to be self-evident by the value of a calculated correlation coefficient, by the close parallelism of two curves, by the repetition of the same general form of "superposed-epoch" variation in a two- or three-fold subdivision of data, or by the coherence in time and space of statistically derived parameter-isopleths. In these searches

for short-period connexions (in contrast to those of longer period) there is usually no lack of fresh data for demonstration of the gradual elimination of "casual" effects and the clearer emergence of the suggested solar-induced effect with increase of material considered. Verification of this kind is so far completely lacking.

Berg painstakingly examines the evidence presented and finds that all the positive claims lack conviction. Where statistical considerations have been taken into account by the authors Berg finds the familiar faults of lack of appreciation of the effects of geographic and time coherence, of "curvature", and even of selection—witting or unwitting—of the data. Surprisingly, he discusses in some detail difficulties of reconciling the different natures of "near-significant" results obtained in roughly parallel investigations. Not all the investigations discussed have led to the making of positive claims: in particular, it is of interest that more recent studies have failed to support an earlier suggestion of the presence of solar-induced short-period variations in the ozone layer. A final chapter in the meteorological section is devoted to an uncritical account of the various proposed mechanisms by which the solar wave and particle streams may exert an influence on the weather.

The final part of the book—about one fifth—is concerned with investigations of the effects of short-period solar variations in biology—birth and death, disease, accident, etc.—and in various types of chemical reaction. Berg discards most of the positive claims made but professes himself convinced by a few. On the evidence presented this is not a conviction shared by the reviewer.

It is a sad fact that most of the meteorological studies discussed by Berg date from 1950. During the past 40 years powerful voices, including those of W. H. Dines, Jeffreys, Walker, Marvin, Bartels, have been raised in protest against the misuse of the statistical method in just those ways that we find here repeated. An unfortunate consequence of the extension of regular observations into the stratosphere and ionosphere and of more detailed observation of the sun is that these new data have invited the further application of inadequate statistical methods. One would hope that in future editors will protect their readers from further inevitable investigations which are not conducted in a reasonably rigorous and scientific fashion.

D. H. MCINTOSH

Some applications of statistics to meteorology. By Hans A. Panofsky and Glenn W. Brier. 9 in. × 6 in., pp. x + 224, *illus.*, Pennsylvania State University, University Park, Pennsylvania, 1958.

The time is past when the word "statistics" implied all that is dead and dull, but the fact remains that many of the more exciting modern developments in statistical technique are difficult to apply to meteorological data. Reading books on statistics is often a frustrating occupation for a meteorologist, because so often he finds an elegant and erudite account of many aspects of the subject which, meteorologically speaking, do not matter, and a perfunctory dismissal of those aspects which do.

This little book is a welcome exception. It is well written, containing little irrelevant matter, and its value is enhanced by the fact that much of the work described is to be found elsewhere only in publications which are not well

known or easy to find on this side of the Atlantic. The omissions I noticed are mostly of very recent work.

The first two chapters deal with frequency distributions, while the third, on sampling theory, includes a description of the most generally useful tests of statistical significance. The fourth chapter, on analysing the relationship between two variables, deals mainly with correlation coefficients and regression equations and points out several of the pitfalls to be avoided when these are used on meteorological data. Chapter V, on multivariate analysis, is rather unsatisfying, which in our present state of knowledge is probably unavoidable. Chapter VI, dealing with the analysis of meteorological time series gives a clear and coherent account of much recent work in this field. Chapter VII deals with objective analysis of weather maps and related topics and Chapter VIII with statistical forecasting by what are essentially regression methods. The last chapter, concerned with forecast verification does little beyond setting out the problems inherent in this difficult subject.

The authors say in their foreword that the book has two purposes: to serve as a text for meteorological students, and to acquaint active forecasters and research personnel with modern statistical techniques. I am not sure that it quite fulfills the first purpose, because the treatment seems rather too superficial to satisfy the intellectual curiosity of, say, a good mathematical undergraduate. However, there is at the end of each chapter a list of suggestions for further reading.

The book can, however, be recommended strongly to the practising meteorologist, whether forecaster or research worker, who wishes to keep abreast of modern developments in statistics applicable to meteorology without necessarily devoting a great deal of time to the subject.

J. M. CRADDOCK

The United Kingdom contribution to the International Geophysical Year 1957-58. 8½ in. × 10 in., pp. 72, illus., Royal Society, London, 1957. Price: 10s.

This book, which became available soon after the beginning of the International Geophysical Year on 1 July 1957 sets out in some detail the planned contribution of this country. At the time of review it is possible to say that practically all the plans for the taking of observations were realized, and that systematic preparations for publications are in hand. It will be many years before we are able to assess the full scientific value of the enterprise.

After a foreword by the President of the Royal Society and a brief history of the birth of the project the organization of the British effort is set out in some detail, with lists of committees and even of committee-men. The fifteen individual disciplines are then surveyed in turn, discussion of the broad scientific aspects being followed by details of the measurements concerned, arrangements for interchange and publication of results, and a list of stations with the tasks allotted to each. The station lists are then re-grouped in various ways in a section entitled "Geographical distribution of the United Kingdom stations", a section which also contains a number of large diagrams remarkable mainly for their very low information content.

The final chapter records "The establishment of Royal Society Base, Halley Bay, Antarctica", and it is pleasant to see recorded the names of members of the main and advance parties, with their individual contributions to the work

up to the date of publication. It is pleasant also, writing a year later, to know how well a promising start has been followed up.

My only complaint about the book is that it seems to me far too expensively produced. I have already remarked on the lavish use of space, and the binding is even more lavish. I have no puritan objection to the spending of money and would not have remarked on these linen boards, gilt, had their appearance not coincided with a severe reduction in the Royal Society's traditional financial support of the publication by its poorer brethren of the results of original research.

G. D. ROBINSON

NOTES AND NEWS

Gornergletscher Glaciological Survey 1959-60

In June 1959 the Gornergletscher Glaciological Survey will begin a fourteen month series of observations on the Gorner glacier above Zermatt. The object of the research is to obtain as complete a picture as possible of the velocity distribution of the glacier by surveying the movement and distortion of stake patterns from the head to the tongue at approximately two-week intervals throughout the year, and to examine seasonal changes of velocity and strain rates. Observations also include measurements of firn compression, snow creep, cold wave progression in the upper surface of the glacier and possibly depth velocity measurements by inserting pipes into the body of the glacier.

Since the main interest of the expedition is the response of the glacier to short-term climatic change, and to try to elucidate some of the causes for observed changes in velocity, a meteorologist is needed to study the heat balance of the glacier over the period of measurement. It is proposed to recruit for the Survey on a shift system, each member of the party spending from three to twelve weeks on the glacier before being replaced by another. Cost will be about £10 per month, for food, plus travel. Would anyone interested in taking part in the programme of the Survey please contact G. R. Elliston at the Department of Geography, Downing Place, Cambridge.

OBITUARIES

Sir Gilbert Thomas Walker, C.S.I., Sc.D., M.A., F.R.S.

Meteorologists all over the world, and in India in particular, will mourn the death of Sir Gilbert T. Walker in November last. Much of Sir Gilbert's scientific work was devoted to the meteorology of India during the 20 years he was the Director-General of Observatories of the India Meteorological Department, succeeding Sir J. Eliot in 1904.

A distinguished alumnus of Cambridge, with conspicuous original work in mathematical physics to his credit, Sir Gilbert was able to bring a fresh and scientific outlook on the development of Indian meteorology and especially the investigation of Indian monsoon rainfall, the vagaries of which so considerably affect the agricultural economy of the country.

It had been generally the belief that the summer heat or winter in central Asia and Tibet and the local snow accumulations in the Himalayan mountains determined the weather pattern over India. Sir Gilbert Walker showed, however, that the winter rains of northern India were in association with storms



Photograph by D. Thomas

THE FLAG MOUNTING
(See p. 67)

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O.W.S. "WEATHER WATCHER" IN THE DENMARK STRAITS AT 1400 G.M.T.,
22 DECEMBER 1959

which had their origin in the Atlantic and travelled down from Persia. His search for correlation between meteorological events over India and weather factors in other parts of the world, such as conditions in Mauritius, Rhodesia, South America and other centres much farther afield, led to the most outstanding of his contributions to long-range weather prediction. This was his work on correlation coefficients leading to the very practical forecasting formulae used in the foreshadowing of seasonal rainfall in India. These methods enable forecasts to be made, purely on a statistical basis, of the total rainfall of the south-west monsoon season over peninsular and north-west India as well as the total winter precipitation over north-west India. Later he extended his search for correlation coefficients between factors spread over almost every part of the globe, and this led to the postulating of the three big swayings or oscillations of the atmosphere, namely (i) the North Atlantic oscillation between the Azores and Iceland, (ii) the North Pacific oscillation between the high pressure belt and the winter depression near the Aleutian Islands and (iii) the southern oscillation between the South Pacific and the land areas round the Indian seas. The vigour of his scientific work did not abate, even when he was 75 years of age or more; for during the War he worked for the Meteorological Research Committee of the Air Ministry and contributed *Meteorological Research Papers* on long-range forecasting.

It is a tribute to Sir Gilbert Walker's personal efforts and his capacity as an organizer and administrator that, despite difficulties by way of lack of officers during World War I and threatened retrenchments and financial stringencies, he was able to initiate and encourage research and investigations in several branches of meteorology. The Upper Air Observatory at Agra was started which has led, in the course of years, to the establishment of the present country-wide organization for upper air soundings on modern lines; Sir George Simpson was engaged at Simla in his classical researches on atmospheric electricity; while at Kodaikanal Observatory John Evershed made valuable contributions to solar physics. Sir Gilbert was also able to bring about an expansion in the meteorological services rendered to shipping and other interests in the country.

Sir Gilbert took keen interest in the scientific research carried out in the Indian universities and every year he used to participate actively in the deliberations at the sessions of the Indian Science Congress of which he was the General President for the 1918 Session.

His association with India and Indians continued after his retirement from the Indian Meteorological Service in as much as a number of students of science of the Indian universities studied meteorology at the Imperial College of Science and Technology, London, under Sir Gilbert when he was the Professor of Meteorology there. Some of his students were later appointed to the Indian Meteorological Service and have filled their respective posts with distinction.

Sir Gilbert was known to be a very genial person of varied interests and was a very popular figure at Simla, held in high esteem and affection alike by his colleagues and other friends.

S. BASU

Mr. John Crichton, M.A., B.Sc., F.R.S.E. died on 26 August 1958 at the age of sixty-six. After graduating at Edinburgh University and teaching science for a short time in Scotland he served during the 1914-18 War as a meteorological

officer with the Royal Naval Air Service and, later, the Royal Air Force. Thereafter his career lay in the Meteorological Office to which he was appointed at the beginning of 1920. In mid-1921 he went to Lerwick to establish a new geomagnetic observatory. This task gave full scope for his capacity for strenuous physical effort and ability to improvise with limited material resources. Leaving Lerwick in 1924 on promotion he served in the course of the next fifteen years in the Forecast Division, London, as a senior forecaster; in the Meteorological Office, Edinburgh; as Superintendent of Eskdalemuir Observatory and again in the Forecast Division. In September 1939 he returned to Eskdalemuir Observatory and remained there in charge until his retirement in July 1953. He was a Principal Scientific Officer for a period preceding the termination of his established service in 1951. Amputation of the right foot early in 1939 proved a great handicap to a man built on generous lines and of active habit, though he largely overcame the limitations imposed. The other foot was amputated in May 1953.

No essential addition is required to the portrait¹ (by another hand) of this memorable personality. Characteristic of his high spirit and attitude towards physical disability was the visit with his wife to friends and relations in North America in 1955. After retirement to Kirkcudbright he kept in touch with former colleagues in Scotland and London and was present at Eskdalemuir Observatory in May 1958 on the occasion of a visit by the Scottish Centre of the Royal Meteorological Society. Those who knew John Crichton will always remember his independence, a very personal sense of humour and, above all, the long heroic battle with his affliction.

REFERENCE

1. London, Meteorological Office; Retirement.—Mr. J. Crichton. *Met. Mag.*, London, **82**, 1953, p. 348.

Mr. Leonard Henry Powers.—By the death of Mr. L. H. Powers on 15 January—within a month of his 90th birthday—there passes one of the few remaining links with the Meteorological Office of the 19th century. Len Powers joined the Office as a Junior Assistant in June 1882 when all the staff, numbering less than forty, were accommodated in the upper part of No. 63 Victoria Street, London. Most of his service, extending to 52 years, was spent in the Climatological Division but he worked intermittently in the Forecasting and Administrative Divisions. He rose to the grade of Principal Assistant by April 1920 and, when the Meteorological Office staff became Civil Servants in 1923, he became a clerk Grade II. After his retirement in 1934 he moved to Dunmow, Essex. His interest in Office affairs continued to the end of his long life. He eagerly read the “Notes” in the *Meteorological Magazine* and derived pleasure from correspondence with former colleagues. Latterly, unfortunately, his writing was restricted through failing eyesight. Powers was a likeable chap, a lover of the countryside and a competent musician. It is on record that as a violinist he entertained his fellows at several staff dinners held at the now defunct Holborn Restaurant in the 1890’s. The writer remembers him as an enthusiastic fellow member of the Meteorological Office Cycle Club in the first decade of the present century. He leaves a widow and a son to whom the sympathy of colleagues and friends is extended.

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H. E. CARTER

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. L. G. Hemens, Senior Scientific Officer, who retired on 26 January, 1959. He joined the Office in October 1913 at South Kensington as a Probationer. In the following year he was transferred to Kew Observatory and in 1916 volunteered for service with the Artists Rifles. At the end of the First World War he was granted special leave for the purpose of taking a degree. He returned to Kew Observatory in 1922. During the greater part of his subsequent career he was associated with services for the Army and the Ministry of Supply. From 1951 until his retirement he served at Eskmeals. Mr. Hemens has accepted a temporary appointment in the Meteorological Office.

Mr. W. L. Pepper, Senior Assistant (Scientific), who retired on 31 January, 1959. He joined the Office in February, 1928 after service in the Royal Field Artillery during the First World War and in the Royal Air Force at the Royal Aircraft Establishment from 1920 to 1927. The greater part of his service was spent at army and aviation outstations and at radio-sonde units. From 1947 until his retirement he served in the Instruments Division at Harrow.

Mr. F. J. Stevens, Senior Assistant (Scientific), who retired on 31 January, 1959. He joined the Office in February, 1928 after service in the Royal Navy from 1915 to 1919 during the First World War and with the Royal Air Force from 1920 to 1927. The greater part of his service was spent at aviation outstations. From 1948 until his retirement he served in the London Forecast Office. Mr. Stevens has accepted a temporary appointment in the Meteorological Office.

WEATHER OF NOVEMBER 1958

Northern Hemisphere

As in the previous two months the Icelandic low was deeper than usual, this time by 7 millibars, and there was an area of negative pressure anomaly over the north-east Atlantic. A feature of the month was the blocking over Europe which began on the 15th, with the formation of an upper low over the Mediterranean and a high cell near the British Isles, and persisted for the remainder of the month. Mean pressures were above normal over all Europe with the maximum anomalies of +11 millibars occurring over Scotland and southern Scandinavia. The abnormally strong south-westerly flow from the Atlantic to Scandinavia noted in October was again present.

More cyclonic activity than usual over northern Siberia gave an area of negative pressure anomaly there with a central value of -6 millibars. Neither the Siberian nor the polar highs showed any significant departure from normal. Nearly everywhere in North America mean pressures were a little below normal, the largest anomaly being -5 millibars near the Great Lakes. The Aleutian low was near normal in both position and intensity although it was not as extensive as usual over the ocean to the South.

Apart from a few places in France and Spain it was a warmer month than average in Europe. The largest temperature anomalies, +6°C., were reported from Sweden and were a consequence of the strong south-westerly flow and a

pronounced Föhn effect across the mountains. Further south over Europe the anomalies were smaller and were mainly due to higher minimum temperatures than usual. Further positive temperature anomalies occurred over much of northern Asia, and reached $+5^{\circ}\text{C}$. in central Siberia. After many months of anomalous warmth in the Canadian Arctic mean temperatures there were as much as 6°C . below average. Over other parts of Canada and the United States there were no large anomalies of temperature despite some large fluctuations of temperature in some parts of the United States brought about by periods of advection of very warm tropical air followed by cold northerly outbreaks.

Much of Europe was drier than usual as would be expected from the positive pressure anomalies. The two main areas which had an excess of rain were the Norwegian coast, where the strong south-westerly flow gave increased orographic rainfall, and the central Mediterranean, where in the middle of the month a vigorous depression gave heavy rain over a wide area. However, in countries at the eastern end of the Mediterranean there was a widespread drought throughout the month. Over northern Siberia, snowfall was up to five times the average because of increased cyclonic activity. Northern Canada and southern regions of the United States had a drier month than usual but in other parts of North America rainfall amounts were above normal.

WEATHER OF DECEMBER 1958

Great Britain and Northern Ireland

The quiet foggy anticyclonic weather of late November continued during the first week of December, but for most of the second week weather was changeable and wet. From the 13th to the 17th pressure was unusually low over the British Isles although winds were light, but a vigorous depression in the eastern Atlantic brought mild southerly winds from the 18th to the 22nd. Subsequently, after a quiet, rather foggy period which lasted until Christmas Day, the month ended with nearly a week of fresh westerly winds.

From the 1st to the 4th fog was widespread over England and Wales, the most severely affected areas being central and eastern England and the Forth-Clyde Valley; Glasgow visibility was only three yards on the evening of the 1st. The fog thinned during the day over much of the country but remained denser throughout the 3rd and 4th in many parts of central and southern England where temperature was little above freezing all day. In fog-free areas temperature rose to the upper forties and there was a good deal of sunshine. On the 5th a cold front moving southwards over the country led to some improvement in the visibility but fog was again fairly widespread on the night of the 6th to 7th. The weather on the 8th was showery with local hail and thunder, but on the following day more continuous rain, associated with a slow-moving occlusion, spread to most districts. The rain was heavy locally and there was some sleet or snow in the north and Midlands, and this type of weather, with local thunder, occurred again on the 10th and 12th.

During the 13th a complex low pressure system spread from the Atlantic over the British Isles and slow-moving centres of low pressure, with light winds, remained in the neighbourhood for about five days. There were outbreaks of instability rain with some snow, the rain being heavy locally, chiefly in the

south, and at London Airport over one inch fell on the night of the 13th to 14th. Fog was fairly widespread from the 15th to the 17th and persisted over much of southern England throughout the 16th when at many places weather saw similar to that of the opening days of the month although pressure then was 50 millibars higher.

Between the 19th and the 21st there were severe gales to the west of the British Isles associated with an intense depression which moved slowly northward off our western seaboard. During the 19th winds over the British Isles freshened from the south reaching gale force at times and a belt of rain, heavy in places, moved northwards across the country. Temperature rose generally and reached 50°F. locally in south-west England on the 20th.

Winds fell light over much of central and eastern England on the 21st and that night fog formed in many areas, and this proved to be the beginning of a foggy spell which lasted until Christmas Day. Thick fog persisted throughout Christmas Eve and Christmas Day in parts of the south and Midlands but rain spreading from the west cleared the fog by Boxing Day. The remainder of the month was unsettled and mild with rain at times in all districts and with strong westerly winds which reached gale force locally in west Scotland on the 27th and 29th and on the Sussex coast on the 31st.

Mean temperatures were a little above the monthly average in south-east and the extreme south-west of England, elsewhere they were near or below normal. Sunshine was below average except locally in south-east and south-west England, and in some coastal districts of Scotland, in parts of central southern England, the Midlands and the Glasgow area it was less than 50 per cent of the average. Rainfall was 119 per cent of the average in England and Wales and 112–113 per cent in Scotland and Northern Ireland. Less than the average fell over Dartmoor, much of Wales, north-west England, most of western Scotland and parts of Northern Ireland. More than 150 per cent of the average was recorded in many eastern districts and twice the average was exceeded in East Lothian and Kinross-shire.

Ground conditions were generally very wet, and after a reasonable start most outside farm work was difficult, especially ploughing on the heavier soils. Fog also caused some dislocation of routine work and the mild periods brought about difficulties in glasshouse management encouraging diseases such as botrytis.

WEATHER OF JANUARY 1959

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Per-centage of average*	No. of days difference from average*	Per-centage of average†
	°F.	°F.	°F.	%		%
England and Wales ...	55	7	−3·7	113	−3	172
Scotland ...	52	0	−4·7	78	−5	168
Northern Ireland ...	51	13	−4·5	65	−5	180

* 1916-1950

† 1921-1950

RAINFALL OF JANUARY 1959

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
<i>London</i>	Camden Square Gdns.	2.21	97	<i>Pemb.</i>	Maenclochog, Ddolwen B.	5.69	80
<i>Kent</i>	Dover	3.13	112	<i>Cards.</i>	Aberporth	4.65	100
"	Edenbridge, Falconhurst	2.93	93	<i>Radnor</i>	Llandrindod Wells ...	4.83	106
<i>Sussex</i>	Compton, Compton Ho.	4.52	106	<i>Mont.</i>	Lake Vyrnwy	7.47	92
"	Worthing, Beach Ho. Pk.	3.15	107	<i>Mer.</i>	Blaenau Festiniog ...	7.84	62
<i>Hants.</i>	St. Catherine's L'thouse	3.19	95	"	Aberdovey	5.16	119
"	Southampton, East Pk.	3.38	99	<i>Carn.</i>	Llandudno	4.65	158
"	South Farnborough ...	2.58	96	<i>Angl.</i>	Llanerchymedd	5.03	118
<i>Herts.</i>	Harpenden, Rothamsted	3.19	118	<i>I. Man</i>	Douglas, Borough Cem.	3.64	73
<i>Bucks.</i>	Slough, Upton	2.21	92	<i>Wigtown</i>	Newton Stewart	2.27	40
<i>Oxford</i>	Oxford, Radcliffe	3.70	157	<i>Dumf.</i>	Dumfries, Crichton R.I.	1.80	38
<i>N'hants.</i>	Wellingboro' Swanspool	3.51	153	"	Eskdalemuir Obsy. ...	4.01	53
<i>Essex</i>	Southend W.W.	1.50	80	<i>Roxb.</i>	Crailling... ..	1.64	68
<i>Suffolk</i>	Ipswich, Belstead Hall	1.94	89	<i>Peebles</i>	Stobo Castle	1.54	35
"	Lowestoft Sec. School	2.63	118	<i>Berwick</i>	Marchmont House ...	1.56	54
"	Bury St. Ed., Westley H.	2.55	109	<i>E. Loth.</i>	N. Berwick58	27
<i>Norfolk</i>	Sandringham Ho. Gdns.	4.08	163	<i>Midl'n.</i>	Edinburgh, Blackf'd H.	.90	37
<i>Dorset</i>	Creech Grange... ..	4.64	111	<i>Lanark</i>	Hamilton W.W., T'nhill	1.08	24
"	Beaminster, East St. ...	7.12	163	<i>Ayr</i>	Prestwick	1.21	33
<i>Devon</i>	Teignmouth, Den Gdns.	5.05	134	"	Glen Afton, Ayr San.
"	Ilfracombe	5.11	124	<i>Renfrew</i>	Greenock, Prospect Hill	2.08	27
"	Princetown	11.56	107	<i>Bute</i>	Rothsay, Arden Craig...
<i>Cornwall</i>	Bude	4.22	114	<i>Argyll</i>	Morven, Drimnin	3.63	53
"	Penzance	7.10	142	"	Ardrihaig, Canal Office	2.01	26
"	St. Austell	7.34	130	"	Inveraray Castle	4.98	47
"	Scilly, St. Mary	4.46	126	"	Islay, Eallabus	2.35	41
<i>Somerset</i>	Bath	3.90	131	"	Tiree	2.08	44
"	Taunton	3.66	122	<i>Kinross</i>	Loch Leven Sluice	1.47	39
<i>Glos.</i>	Cirencester	4.54	136	<i>Fife</i>	Leuchars Airfield	0.88	36
<i>Salop</i>	Church Stretton	3.74	105	<i>Perth</i>	Loch Dhu	3.55	35
"	Shrewsbury, Monkmore	3.71	155	"	Crieff, Strathearn Hyd.	1.76	39
<i>Worcs.</i>	Worcester, Red Hill ...	3.29	134	"	Pitlochry, Fincastle ...	2.26	54
<i>Warwick</i>	Birmingham, Edgbaston	3.67	123	<i>Angus</i>	Montrose Hospital ...	1.14	46
<i>Leics.</i>	Thornton Reservoir ...	2.91	109	<i>Aberd.</i>	Braemar	2.22	54
<i>Lincs.</i>	Cranwell Airfield	2.46	118	"	Dyce, Craibstone	2.53	83
"	Skegness, Marine Gdns.	3.81	182	"	New Deer School House	5.04	162
<i>Notts.</i>	Mansfield, Carr Bank... ..	3.33	125	<i>Moray</i>	Gordon Castle	3.55	150
<i>Derby</i>	Buxton, Terrace Slopes	5.04	92	<i>Inverness</i>	Loch Ness, Garthbeg ...	3.22	68
<i>Ches.</i>	Bidston Observatory ...	3.14	123	"	Fort William	3.00	30
"	Manchester, Airport ...	2.78	93	"	Skye, Duntulm... ..	5.38	92
<i>Lancs.</i>	Stonyhurst College	3.18	64	"	Benbecula	5.28	112
"	Squires Gate	3.15	99	<i>R. & C.</i>	Fearn, Geanies	3.08	164
<i>Yorks.</i>	Wakefield, Clarence Pk.	2.72	108	"	Inverbroom, Glackour...	7.31	115
"	Hull, Pearson Park	2.39	101	"	Loch Duich, Ratagan...	4.42	48
"	Felixkirk, Mt. St. John...	2.67	95	"	Achnashellach	6.71	75
"	York Museum	2.21	94	"	Stornoway	7.56	181
"	Scarborough	3.55	140	<i>Caith.</i>	Wick Airfield	7.59	259
"	Middlesbrough... ..	2.57	120	<i>Shetland</i>	Lerwick Observatory ...	3.78	84
"	Baldersdale, Hury Res.	2.59	66	<i>Ferm.</i>	Belleek	3.08	66
<i>Nor'l'd</i>	Newcastle, Leazes Pk....	1.77	71	<i>Armagh</i>	Armagh Observatory ...	2.20	67
"	Bellingham, High Green	2.03	56	<i>Down</i>	Seaforde	2.36	54
"	Lilburn Tower Gdns. ...	2.20	76	<i>Antrim</i>	Aldergrove Airfield ...	1.97	54
<i>Cumb.</i>	Geltsdale	2.38	68	"	Ballymena, Harryville...	2.73	63
"	Keswick, High Hill	4.00	60	<i>L'derry</i>	Garvagh, Moneydig ...	2.94	71
"	Ravenglass, The Grove	2.06	47	"	Londonderry, Creggan	3.56	79
<i>Mon.</i>	A'gavenney, Plâs Derwen	6.16	121	<i>Tyrone</i>	Omagh, Edenfel	2.53	59
<i>Glam.</i>	Cardiff, Penylan	4.78	104				

* 1916-1950

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