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## THE JET-STREAM PROFILE AND ITS RELATIONSHIP TO THE THERMAL FIELD

By C. J. BOYDEN

**Summary.**—Wind speed profiles across jet streams at 300 mb were drawn from observations over the British Isles in winter. The variations of shear on the two sides are given and average values are compared with those found over North America. The position of the jet axis at 300 mb is related to the position of the maximum thermal winds in the 1000–500 mb and 500–300 mb layers. An expression is introduced for the magnitude of the flow across the contours. Forecasting the changes in a jet is regarded as the same problem as forecasting the thickness pattern, and this is discussed briefly.

**Introduction.**—Study of the jet stream is largely confined to the post-war years but even so the literature on the subject is extensive. A summary of it, together with a comprehensive bibliography, has been published by the World Meteorological Organization.<sup>1</sup> A monograph by Riehl and others<sup>2</sup> in 1954 covered many aspects of the jet stream, and Riehl has recently brought this up to date in a further résumé.<sup>3</sup> Reiter<sup>4</sup> has published what is doubtless the fullest work on jet streams, and his book includes nearly 60 pages of references.

Most of what has been written deals with observations of the jet stream and the analysis of its structure, and less frequently with the role of the jet stream in the mechanism of the atmosphere. The present paper and two others that are to follow are concerned mainly with problems in the day-to-day forecasting of the jet stream. Their aim is the location of the jet stream on an isobaric surface and the forecasting of its subsequent behaviour. Empirical rules are introduced for the more precise application of relationships which are already known, at least in general character.

Most observations used were taken over the British Isles or the nearby Continent and all during the months October to March, so some modification of the results may be necessary in other parts of the world. A two-dimensional approach was adopted using the 300 mb chart because on the average the jet stream is close to that level. In the United States, on the other hand, Endlich, Solot and Thur<sup>5</sup> found the average height of the jet stream to be only a little below the 200 mb level, and because of the greater range of latitude in their observations there was greater variability in this relationship than occurs over the British Isles.

A belt of strong upper winds qualifies for the name 'jet stream' or simply 'jet' when some arbitrarily chosen speed is reached. In this investigation a peak speed of 70 knots at 300 mb has been adopted and categories defined as 'strong' and 'very strong' have been introduced where necessary. In order to distinguish the jet proper from the jet at 300 mb, the line of maximum wind of the former has been referred to as the jet core and the line of maximum wind at 300 mb as the jet axis. For practical purposes the jet axis is regarded as being in the same vertical plane as the jet core.

#### **The height and strength of the jet in relation to the 300 mb pattern.—**

Nearly 50 jets over the British Isles in the winter of 1961–62 were examined in order to ascertain how satisfactorily their height and strength were represented by the 300 mb contour pattern. The data used were the reported 300 mb height and wind speed together with the height and speed of the maximum wind on the same upper air report. Observations were taken in a zone 200 nautical miles wide centred on the jet axis. On the average the maximum wind speed reported was 10 per cent higher than the 300 mb wind speed, the difference being greater the larger the gap between the jet core and the 300 mb level. Markedly greater differences were found occasionally and these were presumably due to stronger winds very close to the jet core, in a belt so narrow as to be of no great practical importance except in relation to turbulence.

The height of the strongest wind was much more variable than the height of the 300 mb surface and there was no general relationship between these two quantities. For a particular jet, however, there was a systematic difference in the relationship on the two sides of the jet. On the cold side of the jet axis at a distance of 50–100 n.miles the maximum wind occurred at a mean pressure of 300 mb. Within 50 n.miles of the axis the mean height of the maximum wind was 200 metres above the 300 mb level. At 50–100 n.miles distance on the warm side the strongest wind occurred at a mean height of 700 metres above the 300 mb level, although one maximum in three was below it. As many as 25 per cent of all maxima were more than 1 kilometre from the 300 mb surface, but on many of these occasions the wind speed difference between the two levels was not correspondingly large, the vertical profile of wind speed then being rather flat.

#### **The wind speed profile across a jet stream at 300 mb.—**

(i) *Jet streams over the British Isles.*—The meso-structure of jets was studied by means of profiles of 300 mb wind speed (see Figure 3) and thermal wind speed over the British Isles during the months October to March in the winters of 1959–60 and 1960–61. This limited area was chosen to ensure uniformity of observational procedure. The observations were restricted to occasions on which a wind of at least 100 knots at 300 mb was reported somewhere, with the further requirement that this speed should be reported at some point on the jet on three consecutive 12-hourly charts. Each cross-section was drawn through Aughton (Liverpool) perpendicular to the strongest observed winds. Soundings within about 200 n.miles of this line were used in constructing the profile unless there was marked confluence or diffuence within this distance, and in transferring observations to the cross-section it was assumed that the intervening contours were streamlines. Slight differences of wind direction were ignored. Large departures from the general 300 mb wind direction

were sometimes found in thermal winds, in which case components along the general flow were used. However, such winds were invariably light and were of little consequence in the analysis.

Sixty-two profiles were drawn and it was found that almost all the jets lay in the sector from about south-west through north to north-east, the distribution through the sector being remarkably uniform, though the criteria for selection introduced some bias.

It soon became evident that a profile of 300 mb wind speeds gives the position of a jet axis more precisely than is possible by inspection of the observations or the contours, as well as giving a clearer picture of the distribution of speed across the jet. Some error was introduced because of the use of upstream and downstream observations, but the main uncertainty was in the shape of the profile very close to the jet axis; only occasionally was this defined precisely by observations. Most profiles were considered to be fairly accurate in the zones 50–100 n.miles from the axis.

About one in seven of the profiles showed two jet axes, but to obtain the mean profile about the main axis all were included. This was inevitable since there were also occasions when it was uncertain whether the remnant of a second jet existed.

From measurements at 50 n.mile intervals on either side of 60 jet axes the distribution of mean 300 mb wind speed was found to be as in Table I.

TABLE I—MEAN 300 MB WIND SPEED ON THE JET AXIS AND AT VARIOUS DISTANCES ON EITHER SIDE

	Warm side			Jet axis	Cold side		
Distance from axis (n.miles)	150	100	50		50	100	150
300 mb speed (mean for 60 jets) (knots)	90	100	116	130	115	92	73

It will be noted that the innermost 100 n.miles of the jet showed an almost symmetrical profile. This arose partly from the subjective drawing of the profile, but since the shape depended on observations both inside and outside the zone this is not thought to have affected the mean profile appreciably except perhaps in the estimate of the speed on the axis. In the zones 50–100 n.miles from the axis the mean shear was 44 per cent greater on the cold side than on the warm side. This difference was still greater at 100–150 n.miles from the axis, partly because of a tendency for a minor jet axis to lie on the warm side. It is of interest, however, that as many as one in three of the jets showed the greater shear on the warm side.

An attempt was made to relate the profile to acceleration and deceleration of the air in the jet, but this was abandoned because of the difficulty of finding enough occasions when the changes in speed following the motion were beyond question. An alternative approach was made by classifying the jets as ‘strong’, when the peak speed on the profile was between 100 and 129 knots, or ‘very strong’, when it was 130 knots or more. Of the very strong jets, the occasions of acceleration over the past few hours must have exceeded those of deceleration for the reason that when a variable is close to its extreme level the chances of there having been a higher value some hours earlier are small. This distribution of mean 300 mb wind speed in strong jets and very strong jets is given in Table II.

TABLE II—MEAN 300 MB WIND SPEEDS ON THE JET AXIS AND AT VARIOUS DISTANCES ON EITHER SIDE FOR STRONG AND VERY STRONG JETS SEPARATELY.

Distance from axis (n.miles)	Warm side			Jet axis	Cold side		
	150	100	50		50	100	150
300 mb speed (mean for 34 strong jets) (knots)	80	89	103	116	104	87	73
300 mb speed (mean for 26 very strong jets) (knots)	105	115	132	148	128	99	73
Difference (knots)	25	26	29	32	24	12	0

This table shows that the mean profile of strong jets was highly symmetrical and hence that the asymmetry noted in Table I at distances greater than 50 n.miles from the axis arose wholly from the skew distribution of mean speeds in very strong jets. In these the mean cyclonic shear was nearly double the mean anticyclonic shear. It is of interest that the speed at 150 n.miles distance on the cold side is the same in the two classes.

Figure 1 shows the relationship between the 300 mb wind speed on the jet axis and the cyclonic shear between 50 and 100 n.miles away. The mean curve shows a large increase in shear with jet speed, although the scatter is quite large. The broken line indicates a shear equal to the Coriolis parameter ( $f = 21$  knots/50 n.miles in latitude  $55^\circ$ ). The proportion of shears of at least this magnitude increases from 23 per cent for strong jets to 77 per cent for very strong jets. Five of the 60 jets showed a shear greater than  $2f$ .

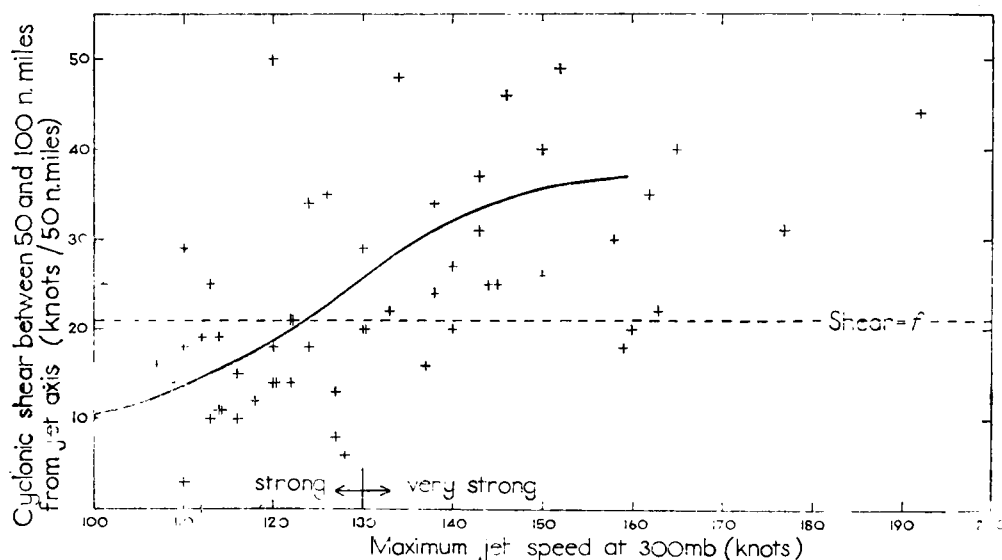


FIGURE 1—SHEAR ON THE CYCLONIC SIDE OF JETS

————— mean curve

Figure 2 is the corresponding diagram for anticyclonic shear at the same distance from the jet axis. Here the shear is limited by inertial instability and the mean curve remains below the ' $f$ ' line at all speeds. Nevertheless, 14 per cent of the strong jets and 31 per cent of the very strong jets had an anticyclonic shear at least equal to the Coriolis parameter. These figures suggest that inertial instability occurs at 300 mb on most very strong jets at some point along their length, though the uncertainties in an individual profile

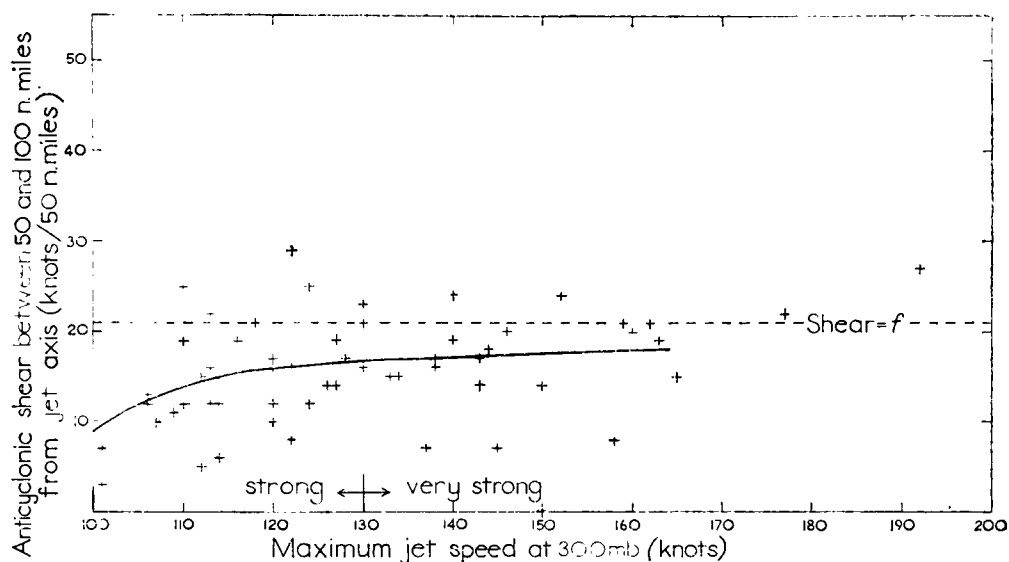


FIGURE 2—SHEAR ON THE ANTICYCLONIC SIDE OF JETS  
 ————— mean curve

should not be overlooked. Crossley<sup>6</sup> quotes a number of reported anticyclonic shears exceeding the Coriolis parameter, but regards the evidence for them as inconclusive.

(ii) *Comparison with results obtained over North America.*—A comparison was made between the wind speed profiles and those published by Endlich and McLean<sup>7</sup> and Reiter.<sup>8</sup> The first of these papers gives profiles constructed from observations by aircraft of Project Jet Stream during a variety of traverses extending from above the jet stream to 2 or 3 kilometres below it. Each profile was defined in terms of the percentage speed reduction at intervals of  $\frac{1}{2}^\circ$  latitude from the jet axis. The diagram in the paper was used to estimate mean percentages at 50, 100 and 150 n.miles from the jet axis. Rows *A* and *B* of Table III show how these figures compare with the corresponding figures for the profiles used in preparing Table I. The main difference is that the Endlich and McLean profile is the shallower of the two. The same difference appears between rows *D* and *E*, which were based on jets with peak speeds of 130 knots or more, and it seems likely that the differences are real rather than the outcome of different methods of observation. As the authors point out, the American jet streams were studied over the south-eastern United States, so there are large latitude differences between the two sets of observations. Moreover, the aircraft measurements were limited to occasions when the ground was visible.

TABLE III—MEAN OF PERCENTAGES OF PEAK SPEED AT VARIOUS DISTANCES ON EITHER SIDE OF THE JET AXIS OR CORE.

Row	Source	Range of speeds <i>knots</i>	Distance on warm side in n.miles			Jet axis	Distance on cold side in n.miles		
			150	100	50		50	100	150
			<i>mean percentage of peak speed</i>						
<i>A</i>	Boyden	$\geq 100$	70	77	89	100	89	72	57
<i>B</i>	Endlich and McLean	63–187	78	83	91	100	84	74	70
<i>C</i>	Reiter	?	70	79	89	100	82	67	55
<i>D</i>	Boyden	$\geq 130$	71	78	89	100	87	67	49
<i>E</i>	Endlich and McLean	$\geq 130$	75	82	90	100	82	71	61

The profile found for jet streams over the British Isles are very similar to those published by Reiter<sup>8</sup> for jet streams over the United States and southern Canada (and therefore mostly north of the area covered by Project Jet Stream). From radar-wind reports of maximum wind over a band extending 400 n.miles on either side of the jet Reiter derived regression equations for the wind speed profile on either side. Row *C* of Table III is composed of percentages given by these equations. Comparison with row *A* shows almost perfect agreement on the anticyclonic side of the jet and good agreement in the large mean shear over 150 n.miles on the cyclonic side.

**The estimation of cross-contour flow.**—The acceleration of a parcel of air moving horizontally is derived from the work done by the pressure gradient as the air passes through isobaric surfaces. If  $V$  is the wind speed,  $z$  the height of the isobaric surface,  $g$  the acceleration due to gravity,  $\rho$  the air density and  $n$  is the horizontal displacement of the air down the gradient, this relationship between work and kinetic energy is

$$\int_{n_1}^{n_2} g\rho \frac{\partial z}{\partial n} dn = \frac{1}{2} (\rho_2 V_2^2 - \rho_1 V_1^2), \quad \dots (1)$$

suffixes 1 and 2 referring to the initial and final states.

It will be assumed that  $\rho$  remains constant (as it would on an isobaric surface), that there is geostrophic balance in the initial and final states and that  $dz/dn$  changes at a uniform rate. Equation (1) then becomes

$$g \left[ \left( \frac{\partial z}{\partial n} \right)_1 + \left( \frac{\partial z}{\partial n} \right)_2 \right] \delta n = (V_2^2 - V_1^2).$$

Introducing the geostrophic relationship this becomes

$$f(V_1 + V_2) \delta n = V_2^2 - V_1^2, \\ \text{therefore } \delta n = \frac{V_2^2 - V_1^2}{f}. \quad \dots (2)$$

Thus, with the assumptions made, the distance moved across the contours (relative to the ground, not to the contours) is proportional to the change of wind speed and does not depend on its absolute value at any stage. If  $V$  is in knots and  $\delta n$  in nautical miles then  $\delta n = 2.3 (V_2 - V_1)$  in latitude  $55^\circ$  and  $\delta n = 2.7 (V_2 - V_1)$  in latitude  $45^\circ$ .

In passing it may be mentioned that equation (2), which can be written  $dV/dn = f$ , implies that if air moves horizontally across contours to higher pressures it will continue to do so for as long as its speed as given by this equation exceeds the geostrophic speed. Thus an anticyclonic shear equal to the Coriolis parameter is the criterion for inertial instability.

The angle of cross-contour flow is  $\tan^{-1} (1/f)(dV/ds)$  where  $s$  is measured along a streamline. Air moves towards lower contours on accelerating to jet speeds, and towards higher contours on deceleration at the jet exit. This effect is sometimes especially noticeable where the air from a jet enters a diffluent ridge. In general, therefore, a jet is more anticyclonic in shape than the corresponding contours, and its axis is determined better from wind profiles than from contours, however accurately these may be drawn. Since 500–300 mb thickness lines move roughly with the 300 mb flow there is a tendency for them to become aligned along the flow, and differences between the thickness pattern and the contour pattern often reflect the ageostrophic component of

flow. Thus thickness lines along a jet also tend to be more anticyclonic than the 300 mb contours. Again, the thickness lines at the base of a sharp thickness trough are often more bulbous than the trough itself through outflow resulting from the excess speed of the air. Dynamical temperature changes are of course also involved in both cases.

**The use of thermal fields as an aid to forecasting the 300 mb jet streams.—**

(i) *Associations between the 300 mb jet stream and thermal profiles.*—In principle the problem of forecasting the movement and development of a jet is best tackled by means of observations at the jet level. On the other hand the coherence of the atmospheric mechanism is an encouragement to use associations with lower levels, where moreover the flow patterns are known in some detail and can be forecast with fair success.

The height of the 300 mb surface is highly correlated with the mean temperature of the underlying atmosphere. Advection of warm air must be accompanied by a rise of 300 mb height unless there is compensating divergence, and such divergence rarely outweighs the advective thickness change unless the latter is very small. In the same way advection of cold air usually causes a fall of 300 mb height. In order to obtain a more specific relationship, changes of 300 mb height over Crawley in a 12-hour period were compared with the corresponding changes in 500–300 mb and 1000–500 mb thicknesses. For the 500–300 mb layer it was found that a thickness change of 4 decametres or more was almost always accompanied by a 300 mb height change of the same sign. Moreover the height change was approximately double the thickness change, as might be expected since the layer involved constitutes nearly half the atmosphere below 300 mb. For the 1000–500 mb layer the relationship was somewhat similar but not as uniform. The probable explanation is that thickness changes are greatest where thickness lines are crowded, and for the 1000–500 mb layer it is here that cyclogenesis takes place most frequently; consequently the thickness change is not dominated by advection to the same degree as in the 500–300 mb layer.

It follows that since a jet stream coincides with a concentration of 300 mb contours it is related, both in position and strength, to a concentration of 500–300 mb or 1000–500 mb thickness lines. In synoptic analysis, as distinct from forecasting, the relationship between the jet and the 500–300 mb thickness pattern has little application because if the thickness pattern is known so also is the 300 mb pattern. On the other hand the 500–300 mb thickness pattern has its use in forecasting jet changes since its evolution can often be foreseen without undue difficulty. Nevertheless the 1000–500 mb thickness field was found to be the more generally useful of the two, bearing in mind that any low-level pattern is known more precisely and can usually be forecast more successfully than a high-level one.

For most of the 60 jets it was possible to construct profiles of 300 mb wind speed and 1000–500 mb wind speed up to a distance of 150 n.miles on each side of the respective maximum. In general a peak in the thermal wind profile was associated with a peak in the wind at 300 mb but was displaced horizontally from it. The maximum wind at 300 mb was found to be roughly twice the maximum 1000–500 mb thermal wind speed, and a forecast from this relationship would have given the speed on the jet axis to within 25 knots on three occasions out of four.

Figure 3 shows the two mean profiles, the speeds being given as percentages of the maximum on each curve. It will be seen that the mean position of the maximum 1000–500 mb thermal wind was on the warm side of the jet axis and nearly 60 n.miles from it. The separation between the two was less than 100 n.miles for 70 per cent of the jets. The position of the 500–300 mb peak wind was less easy to locate on many occasions but tended to be about 40 n.miles from the jet axis on its cold side.

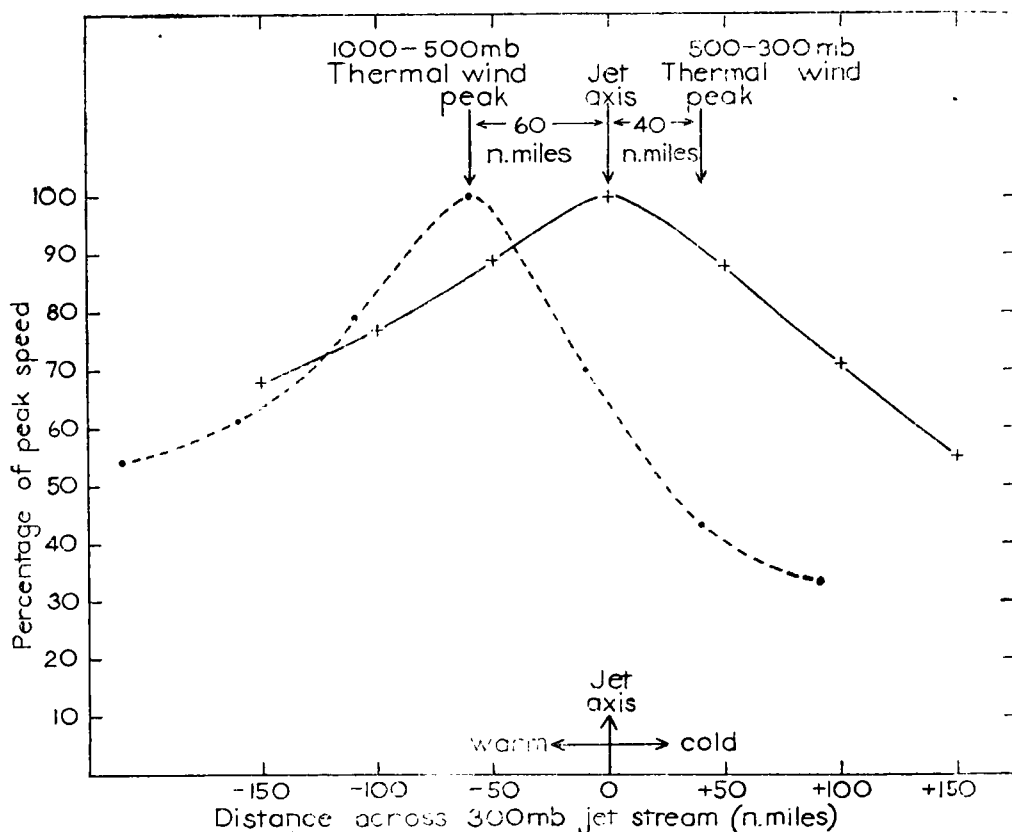


FIGURE 3—MEAN PROFILES OF 300 MB WIND SPEED AND 1000–500 MB THERMAL WIND SPEED ACROSS A JET

Speeds are shown as percentages of respective peak speeds.

x — x 300 mb wind    - - - - 1000–500 mb thermal wind

Another feature of the 1000–500 mb thermal wind profile which is useful in forecasting is the abrupt proportional decrease in speed which commonly occurs on the cold side of the thermal axis. At a distance of 60 n.miles from it, below where the jet axis is likely to be found, there is a reduction of 35–40 per cent in the thermal wind speed, an average decrease of about 25 knots.

Thus the 1000–500 mb thermal wind not only provides strong supporting evidence for the position of a jet axis but may be the only basis for locating it if the jet profile is rather flat. There are also occasions at isolated upper air stations when the decrease of the 1000–500 mb thermal wind is the only evidence that the jet has arrived. For if the jet is of cold-front type the thermal wind speed peak precedes the jet axis by about 60 n.miles, so not only is a decrease of thermal wind speed significant but it is a feature more easily recognizable than the eventual decrease of 300 mb wind on the cold side of the jet axis.



(ii) *The advection of thickness lines.*—The accuracy with which the lateral movement of a jet can be forecast is somewhat less than the accuracy of forecasting the movement of thickness lines since the jet remains tied to the line of strongest thermal wind, not to a particular thickness line. The difficulty of forecasting the thermal profile by subjective methods can be demonstrated by considering simply the non-advective movement of thickness lines which results from vertical motion.

The temperature change resulting from movement through an isobaric surface is given by

$$\frac{\partial T}{\partial t} = -w (\Gamma - \gamma),$$

where  $T$  is the temperature,  $t$  the time,  $w$  the upward velocity relative to the surface,  $\Gamma$  the adiabatic lapse rate (for dry or cloudy air as appropriate) and  $\gamma$  the actual lapse rate.

In consequence of vertical motion an isotherm (or thickness line) is moved in a direction  $s$  with a velocity

$$\frac{w (\Gamma - \gamma)}{\partial T / \partial s}.$$

If  $s$  is taken along a streamline and  $V$  is the wind speed, the thickness line moves with a speed  $V'$  given by

$$V' = V \left[ 1 + \frac{w (\Gamma - \gamma)}{V (\partial T / \partial s)} \right]$$

It is not easy to deduce how the second term on the right-hand side, representing the proportionate departure from wind speed of the movement of the thickness lines, varies with height. The 1000–500 mb layer and the 500–300 mb layer are roughly separated by the level of non-divergence so, with the usual assumption of little vertical motion near the tropopause, there should be no great difference in mean vertical velocity between the two layers. However the term  $(\Gamma - \gamma)$  should be greater at lower levels because the mean value of  $\gamma$  is smaller. Hence the numerator should usually be greater at lower levels. The denominator, on the other hand, is the product of two terms of which  $V$  is observed to increase with height and the magnitude of  $\partial T / \partial s$  to decrease. Thus the movement of the thickness lines in relation to the wind in the two layers cannot be compared from general reasoning.

In view of these uncertainties an attempt was made, by drawing 300 mb trajectories, to measure the non-advective component of 500–300 mb thickness change. This proved impossible with winds stronger than about 60 knots, primarily because thickness lines were then close to contours, so a small error in the direction of the estimated trajectory introduced considerable uncertainty in the thickness change undergone by the air. In addition strong winds often involve large ageostrophic flow and the contours are not then representative of the streamlines. It was therefore necessary to select situations of moderate or light 300 mb flow in which the thickness lines were more nearly across the flow than along it. Pairs of points A and B were chosen such that in 12 hours the air at 300 mb would travel from A to B with a mean velocity  $V$ . A further requirement was that A and B should be near radiosonde stations and that the thickness gradient along AB should be fairly uniform. If  $z_1$  and  $z_2$  were the initial 500–300 mb thicknesses at A and B respectively, the advective thickness

increase at B would be  $12V(z_1 - z_2)/AB$ . If the thickness lines in fact had a mean velocity  $V'$  along the trajectory, the thickness increase at B would be  $12V'(z_1 - z_2)/AB$ . Thus  $V'/V$  is obtainable from a pair of consecutive 300 mb charts.

From a total of 25 trajectories, 35 knots being the mean 300 mb wind speed, the mean speed of the 500–300 mb thickness lines was found to be 20 knots, a reduction to 55–60 per cent of the 300 mb wind speed. As far as could be judged the thickness lines moved further than the air on two occasions and in the opposite direction on two others. Thus the sign of the reported thickness change was the same as that of the advective thickness change on 23 of the 25 occasions.

The assumption that the 500–300 mb thickness lines move at rather more than half the 300 mb wind speed is perhaps the best guide in the absence of detailed computations. Nevertheless the rule is not easy to apply in regions of strong winds because ageostrophic components are often large; in consequence the advecting wind may differ significantly in direction from the 300 mb contours. As an example of this it is not uncommon to observe thickness lines lying nearly stationary across parts of a jet stream. This implies coincidence with the 300 mb flow which, as mentioned earlier, is usually more anticyclonic than the contour pattern.

Much the same reduction in speed is commonly applied in forecasting the movement of the 1000–500 mb thickness lines, though in this layer a more variable relationship is to be expected. In particular there are non-adiabatic changes which are of greater relative importance in a layer which rests on the earth's surface and is therefore affected by vertical transfer of heat and moisture. In forecasting the movement of thickness lines such complicating factors are allowed for with fair success and in addition consistency between the thermal pattern and the frontal pattern is a valuable aid in estimating thickness advection.

The general assumption that the thickness lines for any layer move on the average at rather more than half the wind speed in the layer is supported by the fact that an isobaric system moves at roughly the same speed at all levels in the troposphere. When allowance is made for the other factors mentioned above this assumption provides an adequate basis for estimating how a jet stream will move, whether it will back or veer, and whether it will strengthen or weaken.

#### REFERENCES

1. World Meteorological Organization: Observational characteristics of the jet stream. WMO Tech. Note No. 19 (WMO No. 71, T.P.27) Geneva, 1958.
2. RIEHL, H., ALAKA, M. A., JORDAN, C. L. and RENARD, R. J.; The jet stream. *Met. Monogr., Boston, Mass.*, 2, No. 7, 1954.
3. RIEHL, H.; Jet streams of the atmosphere. Tech. Paper No. 32, Fort Collins, Colorado, 1962.
4. REITER, E. R.; Meteorologie der Strahlströme (jet streams). Vienna, Springer-Verlag, 1961.
5. ENDLICH, R. M., SOLOT, S. B. and THUR, H. A.; The mean vertical structure of the jet stream. *Tellus, Stockholm*, 7, 1955, p. 308.
6. CROSSLEY, A. F.; Extremes of wind shear. *Sci. Pap. met. Off., London*, No. 17, 1962.
7. ENDLICH, R. M. and MCLEAN, G. S.; The structure of the jet stream core. *J. Met., Lancaster, Pa.*, 14, 1957, p. 543.
8. REITER, E. R.; The layer of maximum wind. *J. Met., Lancaster, Pa.*, 15, 1958, p. 27.

## THE WEATHER: PAST AND FUTURE

By H. H. LAMB

Last winter was the coldest in the English lowlands since 1740—that is to say for 223 years. With the ground under snow in many places for about 60 days, it was possibly the snowiest for 150 years. The closest parallel on most counts seems to have been with the winter of 1795. The average temperature for the three winter months was about freezing-point and by February sea temperatures between the Thames and Holland had been reduced to about this level also. Looking at it another way, conditions in the south of England last December, January and February were about what you would expect during an average winter in south-west Sweden, northern Poland, and the eastern marches of Germany beyond Berlin.

Does this mean we can say: 'No need to do anything about it. We won't see the like again'? I believe such a conclusion may be dangerous. One does not want, either personally or nationally, to embark upon excessively costly preparations to meet conditions that may only occur once in two centuries. But neither do we want to expose ourselves to needless losses on vulnerable crops and garden plants or to unnecessary discomfort if harsh frosts should prove more common. All sorts of things are involved, from fashions in clothing to house design, especially plumbing, and from fuel and power supplies to road versus rail transport and keeping roads clear.

This winter I envied an elderly gentleman I know who has a garden snow-plough, just a curved blade attached to handles like those of a lawn-mower and mounted on a skid. For all his years he cleared his paths and his drive far more easily than I did. Yet this bygone mail-order article seems to be no longer on the market. One wonders, is there room for enterprise in the development of gadgets like this, or setting up lampposts in the middle of riverside flood meadows for skating, as our grandfathers did? The more one looks into the variations of our climate the more it appears that there may be a case for doing some things not done in the recent past.

The first thing we should notice is that the early part of this century (or more precisely 1896 to 1937) was a period of exceptional immunity from difficult winter conditions: and this was just when most of those now in positions of management grew up. It still bulks large in most people's impressions of what is normal. Unfortunately, nearly all modern tables of climate statistics are based all too largely on this fairly recent period, and so serve to reinforce our false impressions of 'normality'. On a reasonable definition of what constitutes a cold winter there were only 2 during those 42 years. But there have been 7 since. In the same period there never was a month in central England with average temperatures below the freezing-point. Again, this has occurred once or twice in each decade since, a frequency that was normal in the nineteenth century.

Another respect in which the last 25 years (that is, since 1937) have established a return to the winter climate of, say, the 1880's or '90's is in the frequency of snow-covered ground (in the country, not in our artificially heated cities). Winters with 15 days or more of snow cover, that is at least half a month all told, were 1 in 7 both at Cambridge and in the Shetland Isles between the

wars; since 1938 they have risen to 1 in 3 at Cambridge and 4 out of 5 of all winters in the Shetlands. All our lowland districts show corresponding increases.

What does this mean? The early part of this century appears to have seen the culmination of a 200-year period of gradual warming of the climates in most parts of the world, especially in the Arctic. Our summers, as well as our winters, were affected and the other seasons too. Naturally, it was an uncommonly favourable time for growing delicate plants and crops in the open, and a time when many easy-going (possibly artless) habits grew up. We may have to go back to before the year 1300 to find a half-century of equal warmth (Figure 1).

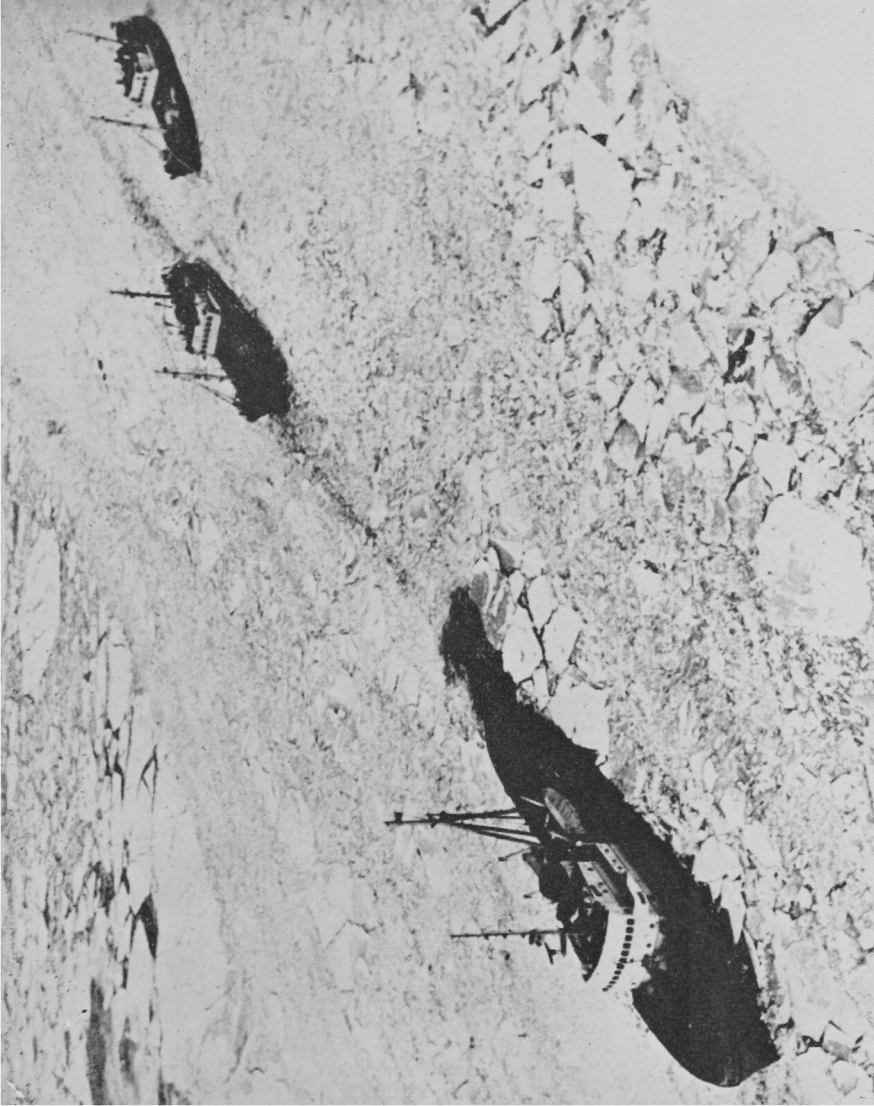


FIGURE 1—GATHERING GRAPES, PROBABLY IN AN ENGLISH MEDIEVAL VINEYARD\*

Between the wars the area of 'permanent' pack ice on the Arctic Ocean diminished by 10 to 20 per cent. In the late summer of 1938 there was so much open water all along the north coast of Asia that prospects for the Russians' northern sea route, the long sought after North-East Passage to the Orient, looked bright indeed. There were scientists who thought that there might be no part of the ocean permanently ice covered by the end of the century. But the changes we have seen since then show clearly that such bare extrapolation is not enough. We need a broader and deeper understanding of what is going on.

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\* From the calendar section of the Peterborough Psalter, executed about the middle of the thirteenth century, this picture is close to William of Malmesbury's description (c.1150) of Thorney, only 6 miles north-east of Peterborough—"so fully cultivated that no portion of the soil is left unoccupied. On the one hand, it may be seen thickly studded with apple trees; on the other, covered with *vines*, which either trail along the ground, or are *trained on high supported on poles*".



*Reproduced by courtesy of Planet News*

PLATE I—A SWEDISH ICEBREAKER CLEARING A PASSAGE FOR TWO FISHING  
VESSELS THROUGH THE FROZEN SEA OFF MALMÖ IN FEBRUARY 1963

(See page 271.)

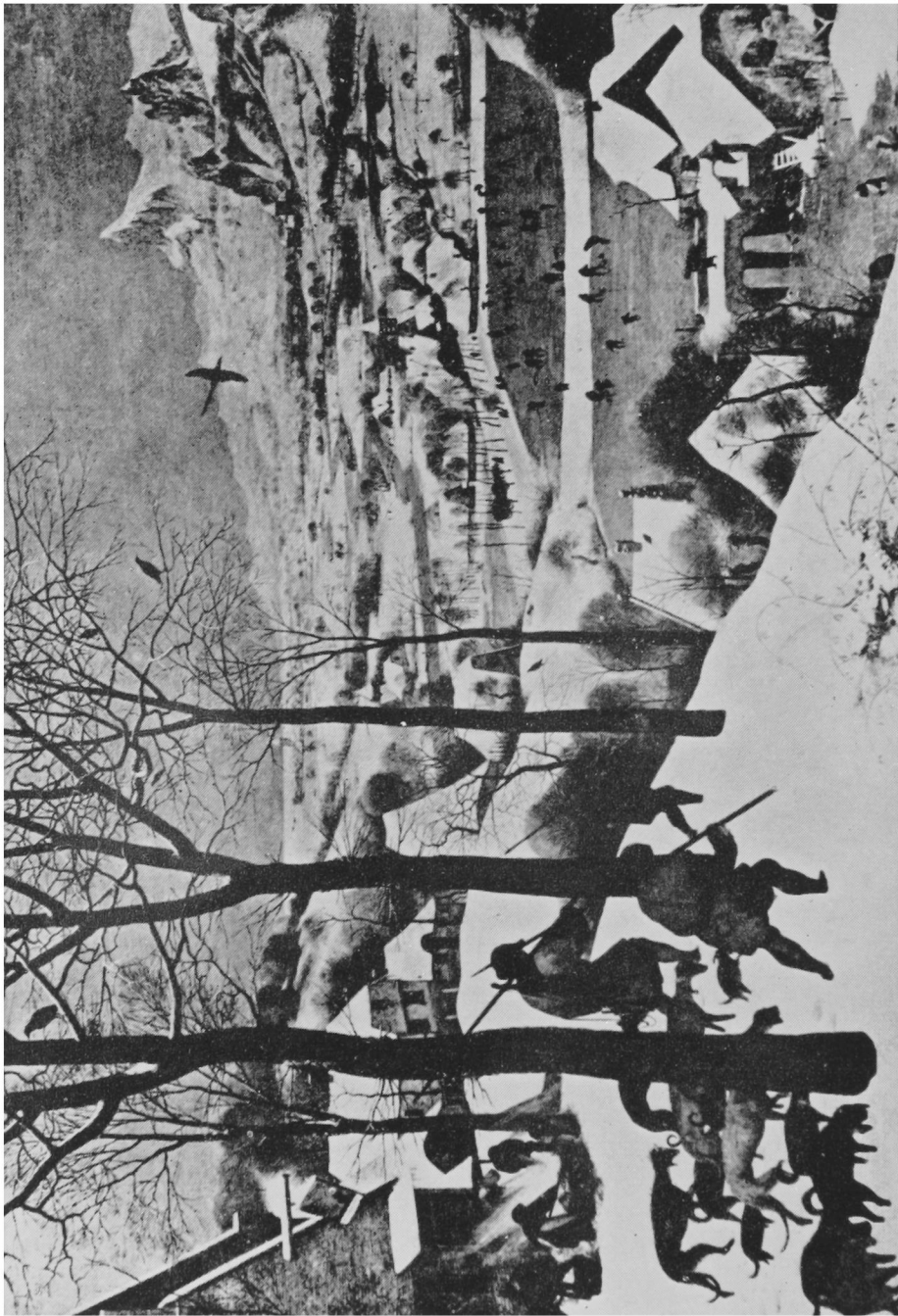


PLATE II—'HUNTERS IN THE SNOW' (1565), BY PIETER BRUEGHEL THE ELDER  
*Reproduced by courtesy of the Mansell Collection*  
(See page 271.)

The breadth of open water in the Arctic attained in September 1938 has apparently never been repeated. By the mid 1950's occasional severer years led people in Iceland to think that the epoch of warming had been succeeded by what they called one of 'unstable equilibrium'. But since the beginning of 1958 the Arctic has been colder almost all the time except for a few months in 1959, and the ice has been plainly increasing. The shipping season in Spitsbergen, which had lengthened from an average of three months a year before 1920 to seven months a year in the '30's and '40's was limited, last year, to a week or two. In February–March of this year we find the ice extending half way from Greenland to Norway, more extensive than ever recorded before and presumably comparable with some of the worst years of the seventeenth and eighteenth centuries (Plate I facing p. 270). The great tongue of ice in 1963 east and south-east of the island of Jan Mayen confirms guesses about the coldest climatic epoch which previously were thought by many to be rather bold.

One weighty element in the situation still remains virtually unaltered. Water temperatures in the broad Atlantic are close to the level of the 1920's and '30's despite a fall of 2°C from the peak level reached as late as 1950–54.

No meteorologist would expect an intimate relationship between the Arctic sea ice and British weather. Certainly not that every winter would be severe just because the ice margin up about 70 degrees north had come a good deal nearer. But the evidence from the past does suggest some relationship, and in particular that the oceanic influence on our climate is reduced at any rate in the colder seasons of the year.

There is another effect. Since snow and ice have a great power to reflect away (and so waste) the sun's radiation, one may suppose that the ice will not disappear as quickly as it formed. (There seems to be some support for this idea because a number of past climatic deteriorations were more abrupt than any of the recovery phases.)

Rather notable deteriorations of the climate of Europe and of the ice situation on the northern seas seem to have taken place in the mid sixteenth century, and again about 1740 and 1855. In each case what I have called cold winters, that is with temperatures generally below 3°C from December to February in central England, seem to have occurred 3 to 5 times a decade for the following half century or so, and the Arctic ice remained extensive. In one way, the situation that announced itself with the severe winter of 1564–65 was the closest parallel with that of today, because the Atlantic ocean was in all probability still rather warmer than it became between 1600 and 1900. That, incidentally, was the winter that led Brueghel to start the tradition of painting the dramatic Flemish and Dutch winter landscapes (Plate II facing p. 271). 1564–65 probably matched the recent winter for severity: and this occurred at least 5 times within 200 years. It may have occurred about 10 times. In other words, the frequency of this degree of severity probably rose to once in 20 to 40 years, and in the 1600's even higher.

Studies of the prevailing wind circulation and its changes, which I have been conducting in the Meteorological Office, throw some light on the mechanism of all this. It turns out that the average strength of the world's main wind-streams in all latitude zones was increasing during the long-period climatic warming. That is to say, the general atmospheric circulation was waxing in

vigour. The Atlantic depressions, with their thrusts of mild westerly winds from the ocean, were affecting Europe more, and were penetrating the Arctic more, as the ice retreated. The last two things went hand in hand. The mild air and storminess broke up, and restricted the growth of, the sea ice, and it could plausibly be argued that this opened up the area still more for the storm tracks.

Then a curious thing happened. From its peak about 1920 to 1930 the strength of the prevailing wind circulation began to wane again. Before long the depressions in this sector kept, to an increasing extent, to somewhat lower latitudes. We do not yet know the reason for this southward trend. It cannot be due to an extension of the ice because when it began the ice was, and for a decade continued to be, about its minimum extent. Perhaps it is something that happens automatically in this part of the hemisphere when the prevailing west winds weaken. This is not the occasion to discuss ideas about possible causes of the very long-term trend in the strength and prevalence of the westerlies. One aspect of it may be a cycle or oscillation eight or nine centuries long. But the trend away from the maximum strength of the westerlies and Atlantic storminess 30 years ago has already had some obvious consequences.

First, it has given the Arctic ice the chance to grow again. Secondly, it has meant that the Norwegian Sea has again become a favourite path for northerly winds at all times of the year to an extent unmatched for many decades past. This has helped to bring the ice forward. Thirdly, the accompanying southward trend of the depression tracks has brought the belt of frequent northerly and easterly winds nearer to this country. This has meant a rather narrow escape from severe weather in several recent winters, and most districts have had a considerably enhanced frequency of snow.

Depressions in summer have also shown a tendency to keep to more southerly tracks, between 55 and 65 degrees north, and this has produced some disappointing summers since 1954. It is a tendency that is likely to continue while the sea ice remains extensive. There is no rule about sizzling summers following severe winters. The best hope of a saving grace, if things go on this way, is that colder northern seas might favour rather more spells of what we call blocking anticyclones over the North Sea and Baltic in summer. In the later part of the cold epoch in the eighteenth century this apparently did happen sufficiently to make the peak summer months of July and August a shade warmer than in the best decades of this century. That meant a shorter, warmer summer, but of course it did not happen every year. In the 1500's and 1600's it was evidently much less frequent.

Recent changes in the ice situation, and the weakening of the general wind circulation that has been going on in the last three decades, suggest that our climatic situation now resembles that of the last century, or earlier, more than it does the recent warm decades. We should certainly be alert to possible advantages in changing our ways a little.

**Editor's note.**—Some repetition occurs in this article because it was originally a broadcast talk given by Mr. H. H. Lamb in the Science Survey series on the BBC Network Three (Thursday 2 May 1963) entitled 'Weather: Past and Future'. The talk was published in the *Listener* on 9 May 1963 and was mentioned very favourably by radio writer Lois Mitchison who found it interesting radio, especially since it merged a scientific background into a general picture without a flood of technical terms. We are grateful to the staff of the *Listener* for help in obtaining reproductions of the photographs used in the *Listener*.



## CONFERENCE OF COMMONWEALTH METEOROLOGISTS MAY 1963

By A. A. WORTHINGTON, B.Sc.

The seventh Conference of Commonwealth Meteorologists was held at the Meteorological Office Headquarters, Bracknell from 7–10 May 1963. It was attended by delegates from most of the Commonwealth Countries and Colonial Territories. An observer from the Republic of Ireland was also present. The Conference was opened by the Rt. Hon. Hugh Fraser, M.P., Secretary of State for Air.

A feature of the Conference was its informality. Discussion was largely an exchange of views. The Conference provided more an opportunity for Directors of Commonwealth Meteorological Services to meet one another and draw on one another's experience in tackling problems rather than an occasion for arriving at conclusions.

The main discussions are summarized below:

(a) *Trends in meteorological services.*—Dr. A. C. Best opened by talking of the meteorological services in the United Kingdom. He pointed particularly to the changing pattern of requirement for meteorological services in aviation and the firm upward trend in requirements of the public services.

Opinion, as a whole, was that though the accent was perhaps no longer on meeting aviation requirements and that meteorological services in other fields—public services, public utilities, agriculture, hydrology etc.—had established or were establishing equal claims for consideration, this did not mean a falling off in aviation requirements; it meant rather an increasing recognition of the need for meteorological services in those other fields. It was felt that a proper assessment of the requirements of the various fields of meteorological service and the striking of a reasoned balance in meeting requirements was now, more than ever, important.

(b) *Numerical weather prediction.*—Mr. Knighting presented a paper on 'Numerical weather prediction'. The important point which he made was that the stage has now been reached when computed forecasts of isobaric surfaces for up to 24 hours ahead are as good as those produced by experienced forecasters.

(c) *Organization of research.*—Dr. R. C. Sutcliffe opened by giving an account of research in the Meteorological Office. He particularly stressed the advantages of a research organization within the Office; the close contact with the operational services; the awareness of the need for results which would be practical and of benefit in the provision of meteorological service; and he drew a parallel with the proved importance of scientific research departments in industry.

Dr. Sutcliffe was followed by Dr. McTaggart-Cowan who spoke of research in the Canadian Meteorological Service. Mr. Rao then gave an account of the place of research in the Indian Meteorological Service and Mr. Gibbs outlined the organization of research in the Australian Meteorological Department.

The general feeling was that there is a need for organized research and this more in the nature of team work rather than work of the individual.

(d) *The high atmosphere*.—Dr. R. Frith presented a paper on ‘The high atmosphere’, in which he gave a brief survey of the atmosphere between 30 and 100 kilometres.

(e) *The training of meteorologists*.—Dr. P. D. McTaggart-Cowan (Canada) opened by describing the system now in use in Canada. It had been found advantageous, in spite of the size of the country, to centralize meteorological training and the present system was an integrated one between the Meteorological Branch and certain of the universities. Moreover, by including training and research in one administrative division of the meteorological service, new advances and techniques had been more easily and quickly incorporated into the training curricula.

In discussion, special consideration was given to the role of universities. Practice varied between countries; some countries had developed an integrated system with the universities whilst in others meteorological training was given almost entirely in the training schools of the meteorological services. It was agreed, however, that meteorology should not be a mainly post-graduate subject and that the development of undergraduate courses in classical physics and environmental sciences, including meteorology, would be beneficial.

(f) *Agricultural meteorology*.—Mr. L. P. Smith presented a paper on the principles to be followed in agricultural meteorology. Two matters were of particular importance: firstly, the need for the closest possible co-operation between the meteorologist and the agriculturalist at every stage in the tackling of agricultural problems; secondly, the exercise of care in the choice of problems on which to concentrate. Priority should be given to those problems which seem capable of solution and the answers to which seemed likely to be of practical economic significance.

In the general discussion that followed, several interesting examples were given of the results of co-operation in agricultural problems. Mr. Smith described the success attained in the United Kingdom in the control of the liver fluke disease in sheep, and in the prevention of the growth and spread of applescab. Others told of the work on cotton planting problems in East Africa and the study of potato diseases in Ireland.

(g) *Assistance to meteorological services of Commonwealth Countries*.—The discussion, which was opened by Mr. Akingbehin (Nigeria) showed that in several Commonwealth countries which were about to become independent or had recently done so, there was difficulty in maintaining and developing the meteorological services due to shortage of financial and professional staffing resources. Aid under United Nations or bilateral schemes was inadequate and had to compete, within a limited budget, with pressing requirements in other fields.

(h) *Trends in the development of meteorological instruments*.—Dr. Robinson described briefly some of the activities within the Meteorological Office on the development of instruments intended for ordinary operational use. An exchange of views followed in which the main problems discussed concerned various aspects of radiosonde operation, including measures being taken to improve the increased height performance of balloons.

(i) *Meteorological satellites*.—Several directors reported on the uses made of information obtained from U.S. meteorological satellites, such as the location of tropical storms in areas of sparse surface observations and the study of ice



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PLATE III—DELEGATES AT THE SEVENTH CONFERENCE OF COMMONWEALTH METEOROLOGISTS IN MAY 1963.

*Standing, left to right:* Mr. J. S. Sawyer and Mr. B. C. V. Oddie (United Kingdom), Instructor Captain J. R. Thorp (Naval Weather Service (NWS)) Mr. Hwang Tiaw Sooi (Singapore), Instructor Commander J. D. Booth (NWS), Mr. F. T. Hannan (Australia), Mr. E. G. Davy (Mauritius) Mr. J. P. Henderson (East Africa), Dr. R. C. Sutcliffe (United Kingdom), Mr. F. B. A. Giwa (Nigeria), Mr. S. E. Tandoh (Ghana), Mr. P. M. A. Bourke (Ireland, attending as an observer), Mr. P. J. Meade and Dr. A. C. Best (United Kingdom). *Sitting, left to right:* Mr. K. Rajendram (Malaya), Dr. I. E. M. Watts (Hong Kong), Mr. N. A. Akingbehin (Nigeria), Dr. P. D. McTaggart-Cowan (Canada), Sir Graham Sutton (United Kingdom), Mr. P. R. Krishna Rao (India), Mr. W. J. Gibbs (Australia), Dr. R. G. Simmers (New Zealand), Mr. J. O. Belford (Sierra Leone). (See page 273).



*By courtesy of BOAC*

PLATE VI—PRESENTATION OF METEOROLOGICAL AWARDS TO CAPTAINS OF CIVIL AIRCRAFT

*Left to right:* Captain B. J. Thwaites, D.F.C., Mr. P. J. Meade, O.B.E., Mr. A. M. A. Majendie, Master of the Guild of Air Pilots and Navigators and Captain Bernard C. Frost, O.B.E. (see page 282).

conditions on the oceans and large river estuaries. It was agreed however, that although satellite information was operationally valuable, it could not replace conventional observations or diminish the need for them. Indeed, to enable full value to be got from satellite data, better surface coverage was needed, particularly over those areas where the surface and radiosonde networks were now deficient.

(i) *Long range forecasting*.—In a general exchange of views it was agreed that the issue of reliable long range forecasts was the greatest contribution the meteorologist could make to a nation's economic welfare. Progress in this field had shown little sign of significant success but this must not cause a slackening of research and experiment.

Arrangements were made for the delegates to visit the  
Central Forecasting Office  
Meteorological Telecommunications Centre  
Meteorological Office electronic computer  
Instrument Development Branch  
High Atmosphere Research Branch  
Instrument and Equipment Building, Bracknell  
Instrument Experimental Site, Easthampstead

The delegates also attended on one occasion the midday conference of the Central Forecasting Office. As relaxation from its discussions the Conference enjoyed the hospitality of the United Kingdom Government and of the Royal Meteorological Society.

551.509.317:551.577.38

**THE 100 MB CHART AND DRY SPELLS AT LONDON (HEATHROW) AIRPORT**

By N. E. DAVIS, M.A.

In a recent paper<sup>1</sup> the author cited a case in which a change in the circulation pattern at 100 mb was followed by a change in the weather type over the United Kingdom. The present note deals with the reverse of that situation and investigates the relationship between the 100 mb pattern and persistent dry weather at London (Heathrow) Airport.

The investigation was begun with an examination of the rainfall record at London Airport (51°29'N 00°27'W) for the period June 1960 to August 1962, during which time 100 mb charts had been drawn daily. Periods were classified as dry if no measurable rain fell over a period of three days or more. There were 52 dry spells comprising 349 days, 355 days with rain, but only 118 odd dry days. The lengths of the 52 dry spells were distributed according to the following table which gives the number of occurrences (in the period June 1960 to August 1962) of dry spells which lasted a specified number of days.

		Length of spell in days										
		3	4	5	6	7	8	9	10	11	12	13
Number of occurrences		9	11	8	2	5	3	3	5	1	1	2

The examination of the 100 mb charts for the 349 days within dry spells represented a considerable task and initially the investigation was confined to

examining the cases when the dry spell lasted 10 days or more. Six of them occurred in the winter half-year and 5 in the summer—though all but three fell in the 4 months February 13 to June 10.

If there were any feature of the flow at 100 mb which was common to all these dry spells then it would be expected to show on a mean 100 mb chart.

Figure 1 shows the mean flow at 100 mb for the 5 occurrences in summer on the first day of a long spell. The first day of a long spell is defined as that day on which measurable rain had fallen during the 24 hours ending at 0600 GMT, but no measurable rain was thereafter recorded for at least 10 days. The mean flow was determined by estimating the 100 mb heights at 13 grid points in the vicinity of the British Isles from the completed 0001 GMT 100 mb contour map on the day in question, averaging over the 5 occurrences and drawing contours to fit these mean values. Figure 2 shows the mean flow for the second day of a summer dry spell, Figure 3 the mean flow for the fifth day and Figure 4 the mean flow for the last day.

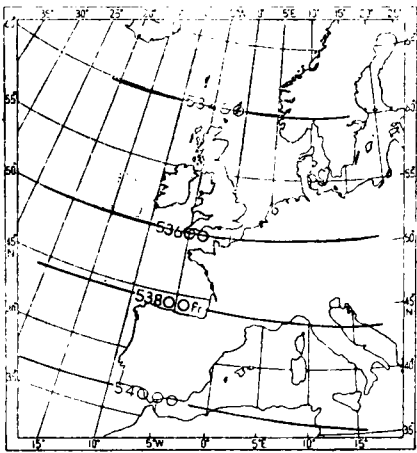


FIGURE 1—SUMMER DRY SPELLS—  
MEAN 100 MB CONTOUR CHART—  
FIRST DAY

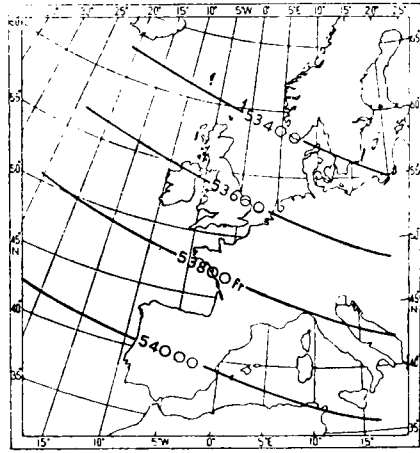


FIGURE 2—MEAN 100 MB CONTOUR  
CHART—SECOND DAY

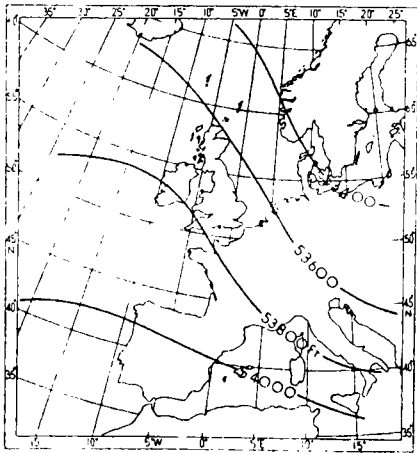


FIGURE 3—MEAN 100 MB CONTOUR  
CHART—FIFTH DAY

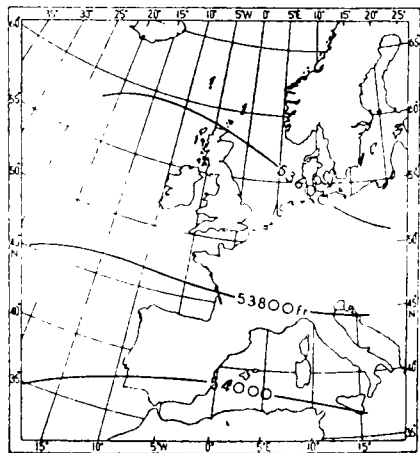
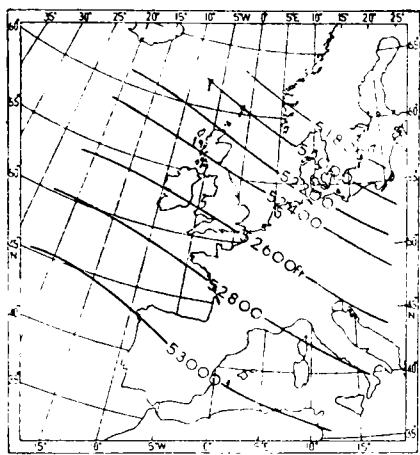


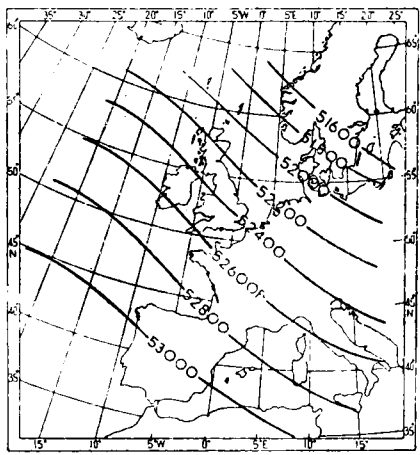
FIGURE 4—MEAN 100 MB CONTOUR  
CHART—LAST DAY

The mean flow is flat and featureless on the first day. This is not surprising as by definition measurable rain fell at some time during the 24 hours preceding 0600 GMT on the first day, so that it might even have been raining at chart time. On the second day however a definite ridge appears to the west of the British Isles and by the fifth day this has advanced eastwards—the axis then being located at about 15°W. By the last day the ridge has weakened considerably and moved across the British Isles to the North Sea.

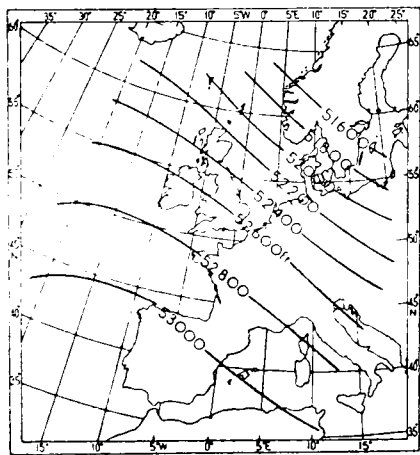
Winter long spells show a similar story (Figures 5–8) except that the gradient is much stronger.



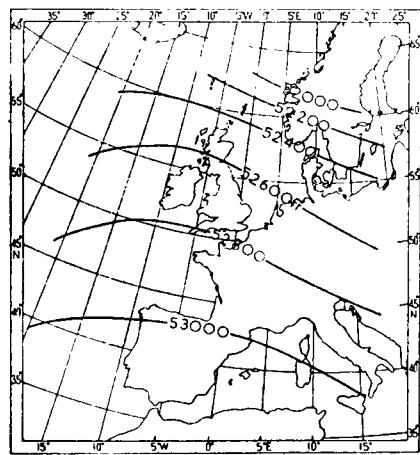
**FIGURE 5—WINTER DRY SPELLS—  
MEAN 100 MB CONTOUR CHART—  
FIRST DAY**



**FIGURE 6—MEAN 100 MB CONTOUR  
CHART—SECOND DAY**



**FIGURE 7—MEAN 100 MB CONTOUR  
CHART—FIFTH DAY**



**FIGURE 8—MEAN 100 MB CONTOUR  
CHART—LAST DAY**

As it would appear from these mean charts that a ridge at 100 mb to the west of the British Isles is frequently associated with a dry spell at London Airport, an examination of the individual cases was made to see how the ridge

arose. The axis of the ridge at 100 mb nearest to the British Isles was located at the positions of longitude and on the days quoted as shown in Table I.

TABLE I—LONGITUDE OF 100 MB RIDGE AXIS DURING DRY SPELLS OF TEN DAYS OR MORE

		Summer			
Date		Day 1	Day 2	Day 4	Day 5
		<i>Longitude</i>			
1961	7 May	12°W	12°W	12°W	13°W
	17 July	22°W	20°W	15°W	13°W
1962	24 Apr.	12°E	9°E and 29°W	17°W	14°W
	30 May	35°W	30°W	24°W	10°W
	30 June	27°W	30°W	33°W	33°W
		Winter			
1961	13 Feb.	5°W	2°E	2°E	3°E
	2 Mar.	1°W	5°W	6°W	5°W
	19 Mar.	34°W	32°W	27°W	20°W
	14 Nov.	23°W	12°W	18°W	11°W
1962	13 Feb.	45°W	34°W	22°W	20°W
	12 Mar.	12°W	20°W	22°W	20°W

After the first day, all cases show a ridge to the west of the British Isles (except 13 February 1961 when the ridge was just to the east). The ridge either moved slowly towards the British Isles (17 July and 19 March 1961, and 24 April, 30 May and 13 February 1962) or remained more or less stationary. The greatest speed of movement occurred during the dry spell of 30 May, when the associated ridge moved 20 degrees of longitude between day 2 and day 5, which at 55°N represents a speed of some 9 knots.

The number of cases considered (5 in summer and 6 in winter), is rather small and a further examination was made of those dry spells which lasted 7, 8 or 9 days. There were 8 of these in summer and 3 in winter. The axis of the ridge was located at the positions shown in Table II.

TABLE II—LONGITUDE OF 100 MB RIDGE AXIS DURING DRY SPELLS OF 7-9 DAYS

		Summer			
Date		Day 1	Day 2	Day 4	Day 5
		<i>Longitude</i>			
1960	15 June	14°W	8°W	5°W	14°W
	7 Sept.	18°W	10°W	6°W	3°E
	23 Sept.	30°W	22°W	9°W	5°W
1961	18 June	—	—	—	—
	3 July	27°W	27°W	30°W	28°W
	25 Aug.	25°W	3°E	3°E	2°W
1962	19 June	30°W	20°W	25°E	24°W
	27 July	15°W	8°W	20°W	8°W
		Winter			
1961	9 Oct.	16°E	9°E	5°W	5°W
	14 Dec.	5°W	5°W	7°W	8°W
1962	27 Feb.	19°W	29°W	33°W	48°W

These additional cases show much the same story except that 2 of the winter cases showed considerable retrogression, whilst during the dry spells of 19 June and 27 July 1962, two ridges moved across (at a speed of about 30 knots) with traces of rain during the passage of the weak trough between them. On the other hand during the dry spell of 18 June 1961, there was no ridge present. This dry spell began with a closed high cell over northern France which moved away southwards. The fronts which subsequently crossed southern England produced only a trace of rain at London Airport.



From the foregoing it would seem that there should be a definite correlation between the 100 mb wind direction over south-east England and rainfall at London Airport. The twelve months January–December 1961 were examined to test this. The wind direction reported by the radiosonde station at Crawley ( $51^{\circ}05'N$   $00^{\circ}13'W$ , 26 miles bearing  $160^{\circ}$  from London (Heathrow) Airport) was used when available, otherwise it was estimated from the chart. The winds were grouped into two sectors:  $290^{\circ}$ – $020^{\circ}$  (i.e. north-west and north) and  $030^{\circ}$ – $280^{\circ}$  (remaining directions). The following table gives the number of occasions of rain or no rain at London Airport for these two sectors. The wind direction was measured or estimated at 0001 GMT and the rainfall was measured for the 24 hours commencing 0600 GMT on the same day.

Wind direction at 0001 GMT	No rain measured in 24 hours commencing 0600 GMT on the same day	Measurable rain in 24 hours commencing 0600 GMT on the same day
	<i>number of occasions</i>	
$290^{\circ}$ – $020^{\circ}$	121	35
$030^{\circ}$ – $280^{\circ}$	104	102

This table shows a highly significant absence of rain with winds between  $290^{\circ}$  and  $020^{\circ}$  (significant at the one per cent level, even on the assumption that only one in six of the observations are independent). Of the failures, the majority were marginal in that though the wind was from the north-west sector either the trough line to the east was close to London Airport or the ridge to the west was very minor and moved across rapidly during the period.

If the 100 mb wind can be forecast to remain between 290 and 020 degrees (i.e. with a marked ridge to the west of the British Isles) there is a strong probability of dry weather. This use of the 100 mb chart is currently being tested by the production of experimental 4-day forecasts of precipitation at London Airport.

#### REFERENCE

1. DAVIS, N. E.; The 100 mb chart and a change of surface weather type near the British Isles. *Met. Mag., London*, **92**, 1963, p. 183.

551.510.7:551.513:551.574.1:061.3

## SYMPOSIUM ON TRACE GASES AND NATURAL AND ARTIFICIAL RADIO-ACTIVITY IN THE ATMOSPHERE

By J. B. STEWART, B.Sc., D.I.C.

The Symposium was held at Utrecht in the Netherlands from 8–14 August 1962 under the joint auspices of the International Union of Geodesy and Geophysics and the World Meteorological Organization. In all 51 papers were presented, divided into four main groups:

- (i) water vapour, oxygen-18, deuterium and tritium,
- (ii) natural and artificial radio-activity other than tritium and carbon-14,
- (iii) carbon dioxide and carbon-14, and
- (iv) trace gases in the atmosphere.

It should be noted that this is a relatively new branch of geophysics—less than half a dozen measurements of the carbon-14 concentration were made before the nuclear tests held in the Pacific by the U.S.A. in 1952—so that the value of radio-active trace materials (in particular some of the naturally occurring ones), as research tools, is only just becoming appreciated. As a

result, a considerable part of the symposium was taken up by the presentation of series of radio-activity measurements which could not be directly useful in meteorological problems. However, there was also a number of papers related to cloud physics and the general circulation.

Three papers were given which suggested the use of techniques involving isotopes in cloud physics research. Dr. Friedman (U.S. Geological Survey) presented data on the distribution of deuterium in water. He showed that the ratio of deuterium to hydrogen in the water of a condensed droplet depends on the temperature at which the droplet formed. He therefore suggested that by measuring the deuterium to hydrogen ratio of precipitation in clouds or just below cloud base, so that no evaporation could take place, it may be possible to determine the mean temperature at which the drops formed.

Dr. Rama (India) presented a paper suggesting that by measuring the concentration of radium C (half-life 19 minutes) in precipitation, it would be possible to deduce the life time of the drops. However, the interpretation of the results of these suggested methods will be complicated by the effect of the growth process of the precipitation drops. These drops are formed by accreting many other smaller drops which have greatly varying ages and temperatures of formation, thus there is no precise age or temperature of formation, only a spectrum of values.

Some French workers under M. Facy have also been using the deuterium to hydrogen ratio in cloud physics. To determine the life history of a hailstone, they measured the deuterium to hydrogen ratio of each layer, removed one at a time by sublimation under vacuum. These measurements then gave the temperatures at which the drops had been added on to form the layers. Thus the motion of the hailstone in the cloud is deduced. M. Facy presented the results of this technique used on a 20 millimetre diameter hailstone, which suggested that it had grown (from 4 mm diameter) while ascending to near the top of the cloud.

A number of papers presented work on the general circulation using trace gases.

Dr. Machta (U.S. Weather Bureau) used radon as the tracer. This is a natural radio-active gas with a half-life of 3.8 days, which is liberated only from the land masses. From measurements of the concentration at various heights above and below the tropopause, he computed the time for the radon to be transferred through the tropopause and hence the mean vertical velocities, which were typically of 100 to 400 metres per day.

Dr. Keeling (Scripps Institute of Oceanography) presented very comprehensive measurements of the carbon dioxide concentration taken from 90°N to 90°S over the Pacific. The distribution of the natural sources is known and the other source—industry—is almost entirely concentrated between 30° and 60°N. So, from these data, Dr. Bolin (Sweden) has been able to determine a mathematical model to describe the transfer of carbon dioxide from the northern to the southern hemisphere.

Dr. Newell (Massachusetts Institute of Technology, MIT) presented a long and detailed paper based on measurements of the wind and temperature structure over the world (part of the Planetary Circulations Project of MIT) and of the concentrations of radio-active material at heights up to 24 kilometres,

and on some observations from the Meteorological Rocket Network at higher altitudes. From these data he has computed meridional cross-sections of the vertical motion, wind velocity and its variance for the four seasons. From data on fission-product radio-activity, tungsten-185 and ozone, he has deduced that eddy processes are of equal, if not of greater, importance than mean motions in redistributing trace substances throughout the stratosphere. His results agree generally with those of Murgatroyd and Singleton<sup>1</sup> and Tucker,<sup>2</sup> but not completely in detail.

A number of other papers, for example by Dr. Kalkstein (U.S.A.F. Cambridge Research Laboratory), Dr. Friend (Isotopes Inc.) and Dr. Machta (U.S. Weather Bureau), gave measurements of the concentration of various artificial radio-active fission products which have been introduced into the stratosphere. These measurements were then used to compute the time taken for transfer to the troposphere and from one hemisphere to the other. Typical of their results were those given in Dr. Kalkstein's paper. He found that the data indicated that there was fairly even distribution between the two hemispheres in the high stratosphere, i.e. at heights of 100 to 150 kilometres. From there the fission products were brought down to the lower stratosphere in high latitudes by mixing associated with the development of disturbances in the polar-vortex region. This was followed by circulation towards the lower latitudes at these lower altitudes.

Another radio-active material that appeared to be interesting was tritium. This is the naturally-occurring radio-active isotope of hydrogen, which has a half-life of 31 years. It is formed by cosmic rays in the high atmosphere. In the form of water vapour, the tritium diffuses down to the upper troposphere and then falls out as precipitation. Since the tritium becomes concentrated in the oceans, these then act as the apparent source. This isotope is thought to be useful in providing information about the hydrological cycle. Dr. Bolin (Sweden) has studied its distribution in precipitation using a network of collecting stations in Scandinavia. To obtain data on the global distribution of tritium, the International Atomic Energy Agency, with Dr. Eriksson in charge, is setting up a network of 90 stations, 60 in continental areas and 30 in oceanic areas (ocean weather ships and Pacific islands). The preliminary analysis will probably be carried out in Sweden. These data will probably be sufficiently detailed for hydrologists, but for any meteorological work, a more complicated programme would be required. This would entail measuring other radio-active materials in the precipitation as well as the tritium content and also the tritium concentration in water vapour.

Other interesting lectures were those by Dr. Möller (Germany) on the effects of variation of carbon dioxide, by Dr. Junge (Germany) on stratospheric aerosols and by Dr. Chamberlain (Harwell) on the interchange of iodine between air and vegetation.

The papers presented at this symposium have now been published.<sup>3</sup>

#### REFERENCES

1. MURGATROYD, R. J. and SINGLETON, F.; Possible meridional circulations in the stratosphere and mesosphere. *Quart. J. R. met. Soc., London*, **87**, 1961, p. 125.
2. TUCKER, G. B.; Mean meridional circulations in the atmosphere. *Quart. J. R. met. Soc., London*, **85**, 1959, p. 209.
3. American Geophysical Union. International Symposium on trace gases and natural and artificial radioactivity in the atmosphere. *J. geophys., Washington, D.C.*, **68**, 1963, p.3745

## NOTES AND NEWS

### **Meteorological Office awards to captains and navigators of civil aircraft**

On Thursday, 11 July 1963, the annual Meteorological Office awards for 'long and meritorious service in the provision of weather reports from aircraft' were presented to Captain Bernard C. Frost, O.B.E., the flight manager of the BOAC 'Seven Seas' fleet and to Captain B. J. Thwaites, D.F.C., a senior captain of the Comet flight of BEA. The presentation ceremony took place at the Royal Aero Club, Fitzmaurice Place, London, W.1 under arrangements made by the Guild of Air Pilots and Air Navigators with the Master of the Guild, Mr. A. M. A. Majendie, M.A., F.R.Ae.S., F.I.N., F.R.G.S. presiding. Mr. P. J. Meade, O.B.E., Deputy Director (Outstations Services), Meteorological Office, presented each captain with a briefcase on behalf of the Director-General of the Meteorological Office. (See Plate IV facing p.275)

Before making the awards Mr. Meade thanked the Guild for their continued support in sponsoring the presentation ceremony each year and, on behalf of the Director-General, invited the Guild to visit the new Meteorological Office Headquarters at Bracknell. Mr. Meade described the awards as a small acknowledgement of the debt which meteorology owed to aviation. With the coming of aviation the importance of meteorology grew enormously. As aviation developed, the demands upon meteorology increased and this led to vast extensions of our knowledge of the atmosphere and also to advances in forecasting. Observations formed the essential basis for forecasting and for many years aircrews had given invaluable help in providing meteorological services with weather reports in flight which were used to supplement the data obtained from the national reporting networks.

Presenting the awards, Mr. Meade said that Captain Frost had an outstanding record of weather reporting over more than twenty years. He was extremely well known to meteorologists because of the keen interest he had always shown in the problems of aviation forecasting. Captain Thwaites also had an excellent record for weather reporting over many years and Mr. Meade recalled with pleasure that Captain Thwaites had spent a short period in the service of the Meteorological Office before joining the RAF as a pilot during the last war.

Finally, Mr. Meade thanked BEA, BOAC and the Independent Air Lines for encouraging pilots to make weather reports in flight and took the opportunity of expressing gratitude to the Corporations for granting facilities for forecasters to make familiarization flights over air routes. He mentioned especially Mr. Chambers and Mr. Wood, the Meteorological Superintendents of BOAC and BEA respectively, and said that the Meteorological Office valued very highly their advice on all aspects of aviation meteorology.

The Director-General is also awarding books to the following for their weather reports: Captains R. H. Payne, D. B. Wilkie, P. Bray and D. B. White of BEA; Captains G. Thomas and P. Siegel of British United Airways; Captain C. M. Argles of Morton Air Service; and Captains G. R. Buxton, L. O. Barnett, T. M. Bulloch and D. B. McGregor of BOAC. Similar awards go to BOAC navigators T. A. Anderson, D. E. Campbell, J. G. Goodwin and J. E. Goulden.

## REVIEWS

*Vegetation and hydrology*, by Dr. H. L. Penman, O.B.E., F.R.S. 8½ in. x 5½ in., pp. viii + 124, Commonwealth Agricultural Bureaux, Farnham Royal, Bucks., 1962. Price: 20s.

In this admirable survey Dr. Penman discusses one of the most important and perplexing aspects of the hydrological cycle, the role of vegetation in the cycle with particular reference to the disposal of soil moisture. It is important because the management or mismanagement of vegetation presents man with what is at present his most effective opportunity to alter the natural hydrological cycle. It is perplexing because, as the welter of conflicting evidence and opinion gathered in this book shows, the circulation of moisture in and through the soil is still imperfectly understood.

The first chapter discusses the general problem, akin to that of the hen and egg, of whether vegetation is the result of rainfall or whether rainfall can be induced by vegetation. Circumstantial evidence is generally in favour, and meteorological evidence overwhelmingly so, of the belief that vegetation is the result and not the cause of precipitation.

In the second chapter which is devoted principally to the interception of precipitation by vegetation and the disposal of the intercepted water, the author has a cautionary note on the problem of adequate exposure of a rain-gauge and on the incautious use of rainfall data in assessing general rainfall over an area.

Infiltration, run-off and erosion are discussed briefly in Chapter 3. Erosion is a world-wide problem and requirements for its prevention or reduction are high infiltration rates and minimal surface run-off. Experimental data show clearly that forest floors or humid pastures afford the greatest protection against erosion, and row crops or fallow the least. Reference might have been made in this chapter to wind erosion which is generally complementary to water erosion and may be the dominant form in arid regions.

The key chapter to the book is the fourth, where the most important part of the hydrological cycle, the transfer of water vapour to the atmosphere, is very succinctly and ably discussed. After a brief reference to the biological approach to the transpiration of water, the author deals with evaporation as a weather phenomenon, first discussing the basic physical problems and then referring to special difficulties which include temporal difficulties (different lengths of growing seasons), edge effects, crop management, anomalous stomata closure, interception differences and many others. Of the numerous evaporation formulae, four are discussed in some detail (those of Blaney and Criddle, Thornthwaite, Turc and the author). After reference to evaporation from bare soil (where evaporation rates are quickly reduced with drying out of the top few centimetres of the soil, and the amount and frequency of rainfall is the only weather factor of importance), the author introduces the concept of potential transpiration. He discusses the strong clash of opinion among experts as to whether soil moisture is freely available from transpiration by plants up to a point at which growth and vigour cannot be maintained, or whether the actual rate of transpiration falls below the potential shortly after the start of

drying out of soils. This question of the availability of water is one of great importance in water balance studies and is an aspect of the soil-moisture problem about which, at present, almost all evidence is empirical.

The last three chapters deal with (i) water-use when water supply is non-limiting, (ii) evaporation at and between extremes of water supply and (iii) experiments on water-use on catchment areas. These chapters are valuable for the presentation of a great amount of data, drawn from truly world-wide experience, on water-use by vegetation.

The reviewer takes issue seriously with only one of the opinions expressed by the author where (page 103) in discussing a water balance study of the Sperbelgraben and Rappengraben (Switzerland) catchments, he says it is doubtful if any meteorologist would accept either part of the assumption that rainfall at any altitude inside a catchment area is the same as that outside at the same altitude, and the catch of any gauge is the mean catch over an altitude range of the order of  $\pm 500$  metres. On the contrary, with regard to the first part of the assumption, it has been the practice from the earliest days of the systematic study of rainfall in Britain to extrapolate isohyets in this way and data obtained subsequent to the drawing of isohyetal maps by such workers as Mill, Carle Salter and Glasspoole have shown how accurate such extrapolation can be. The second part of the assumption made in the Swiss paper is perhaps more open to doubt but at least the assumption shows an awareness that rainfall varies with altitude and that some allowance should be made for this fact. Indeed, it is felt that many water balance studies have been vitiated from the start by unsophisticated use of rainfall data. All too frequently one reads of experimental studies in rugged terrain where estimates of area rainfall are based on readings of a single gauge or the arithmetic mean of a few gauges. The author is, of course, aware of this problem in general and, as has been noted, refers to it in Chapter 2.

The book is written with great economy of style, with scarcely a word wasted, and this, coupled with the great amount of tabular data needing careful study, demands a very close though fully rewarding attention from beginning to end. A valuable bibliography of some 300 references is included.

J. GRINDLEY

*Exploring the atmosphere*, by G. M. B. Dobson. 8½ in. x 5½ in., pp. xi + 188, illus., Clarendon Press, Oxford., 1963. Price: 21s.

Hoar frost and noctilucent clouds; fine weather potential gradient and the aurora; carbon dating and solar flares; there is something about all of them in this little book. The whole of the earth's atmosphere from the surface up to heights of 10,000 kilometres and above is surveyed. Inevitably the treatment must be superficial; here and there it is facile—as in the account of anticyclonic inversions—and there are indications that the volume was hastily written. However the chapters on the higher parts of the atmosphere, especially those on ozone, aurora, airglow and the ionosphere, provide a useful and simple introduction to these regions.

There are no references nor any suggestions for further reading.

R. FRITH

## OFFICIAL PUBLICATION

The following publication has recently been issued:

*Pictorial guide to the maintenance of meteorological instruments*, London, HMSO, 1963. Price: 10s.

This book has been compiled on the assumption that, if a task is made easy, more people who attempt it will achieve results. The presentation is in picture form; technical names of instrument parts are not common knowledge and the parts to which these names apply are indicated on the diagrams. The directions are based on those given to students arriving at the Meteorological Office Training School, some of them with no previous knowledge of meteorology and most of them having little experience with instruments.

The methods used to keep the instruments in good order are those the author has found to be efficient during 21 years in the Meteorological Office both in the British Isles and abroad. The ideas are sometimes original but a great deal was learnt in the Meteorological Office Instrument Branch test room. The section on fault-finding is intended to stimulate critical examination of charts and, with the rest of the book, teach a technique of maintenance which will be applicable to meteorological instruments in general.

Observers at independent meteorological stations, especially those who supply information to the Meteorological Office, may find this book useful; students from foreign countries who have attended instrument courses at the Meteorological Office Training School have found that a poor command of English is less of an obstacle when using this publication.

## PUBLICATION RECEIVED

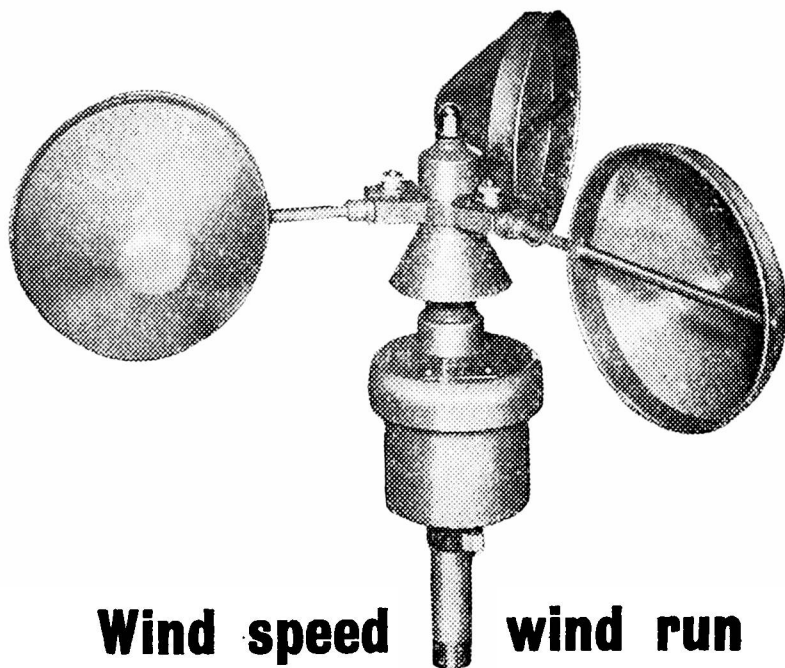
*The Weather: formation of clouds* (in the series "Geography-Meteorology"). 30 in. x 40 in., Wallchart (C.857) in three colours, Educational Productions Ltd., East Ardsley, Wakefield, Yorkshire, 1962. Price: 10s.

## METEOROLOGICAL OFFICE NEWS

**Bracknell Chess Club.**—The Bracknell Meteorological Office Chess Club in their first year of competitive chess, have succeeded in leading Division II of the Berkshire County Chess League for 1962–63.

## CORRIGENDA

*Meteorological Magazine*. Vol. 92, p. 219, on line 24 for *ue* read *ug*.



**Wind speed      wind run**

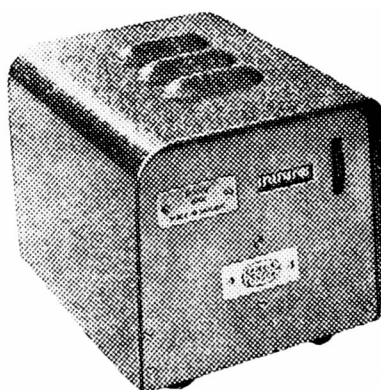
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