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THE ROYAL VISIT TO THE METEOROLOGICAL OFFICE HEADQUARTERS

On 25 June, Her Majesty The Queen and His Royal Highness The Duke of Edinburgh visited Berkshire. The tour included a short visit to the Meteorological Office Headquarters, where the Royal Party were received by Mr. W. J. Taylor, Parliamentary Under-Secretary of State for Air, who presented Lord Hurcomb (Chairman of the Meteorological Committee), Sir Maurice Dean (Permanent Under-Secretary of State for Air) and Lady Dean, Sir Graham Sutton (Director-General of the Meteorological Office) and Lady Sutton, Dr. R. C. Sutcliffe (Director of Research), Dr. A. C. Best (Director of Services) and Mr. G. R. R. Benwell (Vice-Chairman of the Local Whitley Committee).

After the presentations in the Entrance Hall, the Royal party were taken to the Central Forecasting Office, the Communications Centre and one of the laboratories of the High Atmosphere Research Branch. In the Central Forecasting Office Her Majesty was able to see the preparation of the midday forecast for the BBC as well as some historic documents including FitzRoy's first published forecast and also the forecasts made for the Normandy landings in the last war and for the Coronation in 1953.

In the Communications Centre, Her Majesty received the following message over the teleprinter circuit:

> On the occasion of the visit of Your Majesty and His Royal Highness, The Duke of Edinburgh to the Headquarters of your Meteorological Office, the staff at Lerwick, the most distant outstation in the United Kingdom and one of the oldest, send loyal greetings on behalf of the staff of all Meteorological Office outstations.

The text of her reply, which was broadcast to all Meteorological Office outstations, was as follows:

> I thank the staffs of the Lerwick Meteorological Station and of all other outstations for the loyal greetings which they have sent to me and my husband on the occasion of our visit to the Meteorological Office Headquarters at Bracknell. We send our greetings and good wishes to them all and assure them of our interest in the important and invaluable work which they are doing.

ELIZABETH R.

In the M.O.19 (High Atmosphere Research) laboratory, the Royal visitors saw the five-inch rocket now being developed for the Meteorological Office, as well as apparatus for the satellite which is to be placed in orbit by the United States of America in the near future. They also saw work in progress on the construction of rocket sondes, on a new method of measuring the water-vapour content of the atmosphere and on the calibration of the ultra-violet spectroscope to be used in the satellite for the determination of the ozone content of the high atmosphere.

On descending again into the Entrance Hall, Her Majesty and Prince Philip signed a specially illuminated page of the visitors' book as a memento of the occasion. They then left to continue their tour of the new town of Bracknell, concluding with lunch at Easthampstead College.

This is believed to be the first occasion on which the reigning Sovereign has visited the Meteorological Office. It is pleasant to record that on this occasion the weather also rose to the occasion, so that the new buildings were seen at their best.

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FORECASTING OF MAXIMUM SURFACE TEMPERATURE FROM 1000–500-MILLIBAR THICKNESS LINES

By C. J. BOYDEN

An earlier note[1] described how the daily mean temperature could be forecast from the expected 1000–500 mb thickness, allowance being made only for the season of the year. It would have been possible to incorporate other predictors, but the forecaster requires formulae that are simple and approximate rather than complex and precise, for the reason that most predictors themselves have to be forecast. It does not of course follow that an empirical relationship between two meteorological parameters ignores the physical effect of other elements, since an independent meteorological element is rare. Thus the thickness of the 1000–500 mb layer is basically a measure of mean virtual temperature, yet it is also related in a loose way to stability, cloudiness, precipitation and even wind.

It was not expected that thickness alone would prove a useful indicator of maximum surface temperature. It was evident that separate allowance would have to be made for cloudiness, whereas in a forecast of mean temperature this is not critical, largely because warm, sunny days are often followed by clear, cold nights. Nevertheless it was found that on about 70 per cent of days during the six summer months a useful indication of maximum temperature was given by the midday 1000–500 mb thickness, the recent history of the air, the sunshine total and the month. Wind speed, humidity and often rainfall were found to add little or nothing to the accuracy of the forecast. Thus we are left with predictors which, apart from sunshine, are given by routine forecast charts of the surface pressure pattern and the 1000–500 mb thickness, and call for no knowledge of current or past temperatures.

The assumption that maximum temperature can be related to 1000–500 mb thickness requires that the thickness shall define the mean temperature of the layer of air in which daytime heating is concentrated. The diurnal temperature rise will depend largely on the insolation which penetrates any cloud existing during the morning or early afternoon. Thus it is not surprising that the 1000–500 mb thickness proved to be the major factor in determining the maximum temperature in unstable air, since temperatures build up to give a lapse rate close to the adiabatic. On the other hand the thickness of a layer of warm air from the Continent bore little relationship to its temperature structure and could not be used as a predictor of maximum temperature.

The relationships found were based mainly on the maximum temperature and other surface observations at Kew Observatory, and midday upper air soundings from Crawley. Data were examined for the years 1956–60, and initially for the months of June, July and August taken together. The methods of forecasting maximum temperature in these months were then modified if possible for the months of April, May and September, each being treated separately.

In addition to using the observations from Kew and Crawley it was important to include a stability parameter which could be forecast without undue difficulty. This factor was allowed for by classifying the air in which the maximum temperature was reached according to its trajectory over the previous 24 hours as given by surface geostrophic winds, the classification being determined by the sector in which most of the trajectory lay. The period of 24 hours was an arbitrary choice and no doubt a longer time would be better but is impracticable because of the uncertainty in the construction of long trajectories. Incidentally, the length of the 24-hour trajectory did not seem to influence the maximum temperature in a systematic way.

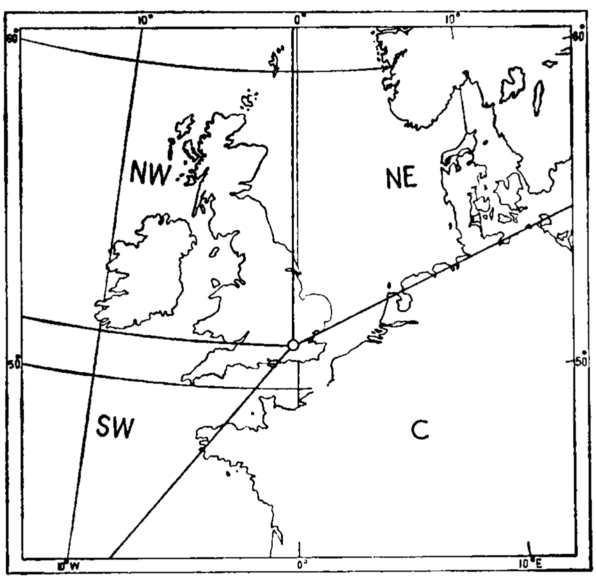


FIGURE 1—TRAJECTORY SECTORS

The trajectory sectors were eventually reduced to four, and to these was added a class to cover occasions when the trajectory had no definable direction. The classification (Figure 1) was as follows:

NW (north-west)	Trajectories from between north and west.
NE (north-east)	Trajectories from between north and about east-north-east, thus excluding air which crossed the Netherlands and northern Germany.
SW (south-west)	Trajectories from between about south-west and west.

C (Continental)	Trajectories from the mainland of Europe, disregarding Denmark and Scandinavia.
St (stationary)	Trajectories having no significant direction because the wind was light, or occasionally because the trajectory was more nearly circular than straight.

The distribution of trajectories during the years 1956–60 is given in Table I.

TABLE I—DISTRIBUTION OF TRAJECTORIES

	April	May	June	July	August	September	Total
NW	26	29	57	75	62	33	282
NE	56	34	22	12	8	15	147
SW	26	46	29	33	41	39	214
C	21	29	25	19	26	44	164
St	21	17	17	16	18	19	108

Maximum temperature in air from north-west sector

June, July and August.—A linear relationship was found between maximum temperature and the midday 1000–500 mb thickness, and the use of this single predictor gave a r.m.s. error of a little over 3°F. At the higher thicknesses there was a substantial temperature variation with sunshine, so allowance for this was made by incorporating the total sunshine for the day, this being regarded as a satisfactory substitute for the sunshine up to the time of maximum temperature. The forecasting diagram is shown in Figure 2, in which the maximum

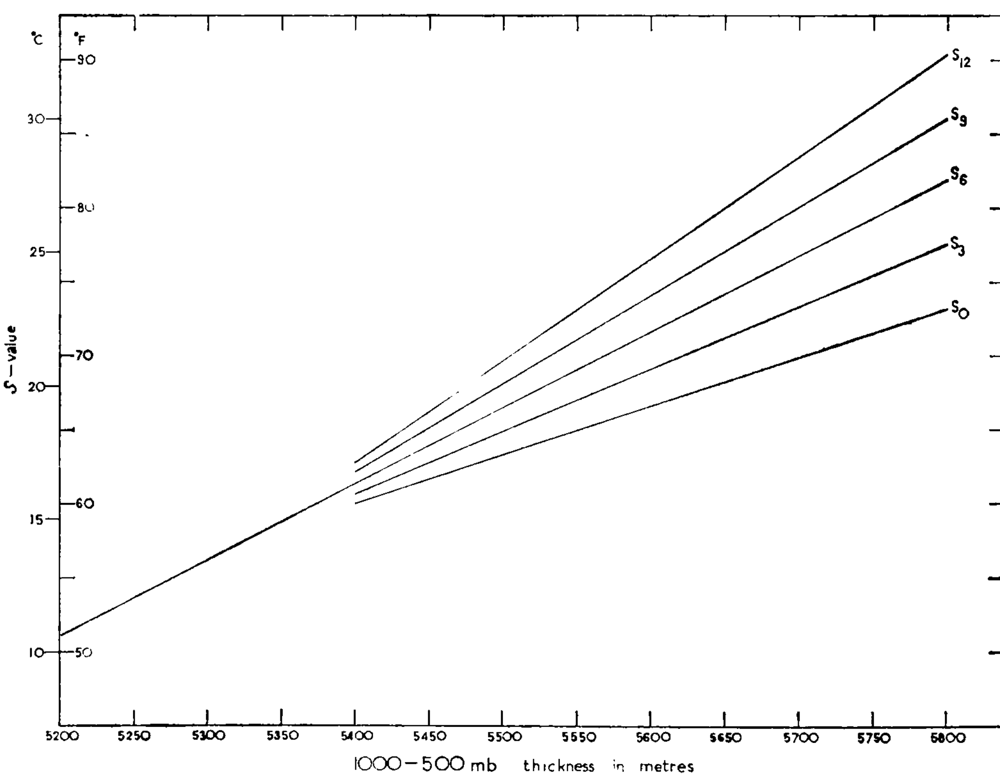


FIGURE 2—FORECASTING DIAGRAM FOR MAXIMUM TEMPERATURE

temperature for a forecast thickness is read against the expected hours of sunshine. The allowance for sunshine reduced the r.m.s. error to 2.3°F. (The temperature read on these lines will be referred to as S_0, S_3, S_6, S_9 and S_{12}, the suffix denoting the total sunshine except that S_{12} includes all totals above 12 hours.)

April.—The method was found to be unsuitable and north-west winds were too infrequent for a satisfactory alternative to be established.

May.—The diagram was satisfactory provided 2°F was subtracted from all temperatures. The r.m.s. error was then 2.5°F.

September.—It was found that S_0 was a reasonable forecast regardless of the amount of sunshine. The r.m.s. error was 2.9°F, but because of the small slope of the S_0 line the relationship with thickness must be regarded as a loose one.

Maximum temperature in air from north-east sector

June, July and August.—The method developed for the north-west sector was applicable in air from the North Sea, and again precipitation could be ignored. One important modification was necessary, however, when the cloud remained unbroken all day. The comparatively small number of observations suggested the temperature was then best given by $S_6 - 9$. That a sunless day is much colder than one with only an hour of sunshine may reflect a substantial difference in the cloud thickness and therefore of its absorption of insolation.

Disregarding sunless days, the r.m.s. error was 2.8°F. Since sunshine in a north-easterly airstream is very difficult to forecast, the result of ignoring the amount was examined. The assumption of six hours sunshine on every occasion gave a r.m.s. error of slightly under 3.0°F. Thus a substantial error in cloud amount can be tolerated in forecasting the maximum temperature, provided the completely sunless day can be foreseen.

April.—April again proved a difficult month, and a curious feature was that sunshine appeared to be as important an independent parameter at low thicknesses as at high ones. The formula $T = S_6 + N - 12$, where N is the number of hours of sunshine, gave a r.m.s. error of 3.3°F, and no special allowance for sunless days seemed necessary. In view of the difficulty of forecasting N this result cannot be regarded as very helpful.

May.—With fewer observations than in April, $T = S_6 + N - 10$ gave a r.m.s. error of 3.1°F, which again is barely satisfactory.

September.—North-easterly winds were too infrequent for any relationship to be derived but, as with north-westerly winds, sunshine seemed to be of little importance as an independent predictor.

Maximum temperature in air from south-west sector.—The main characteristic of air from the south-west would seem to be its lack of uniformity. Fairly unstable maritime polar air may arrive from the same direction as subsided air of continental origin. Frontal cloud and precipitation occur frequently. The long sea passage tends to bring temperatures to a common level but nevertheless a worthwhile relationship emerged between maximum temperature, thickness and sunshine. R.m.s. errors lay between 2.4° and 2.8°F, values which reflect to some extent the rather small range of temperature that occurs with south-westerly winds. The relationships found were as follows:

April	$T = S_6 + N - 9$
May	$T = S_6 + N - 8$
June, July and August	$T = S_6 + N - 6$
September	$T = S_6 + N - 8$

Maximum temperature in air from Continental sector.—It was found impossible to derive the maximum temperature on the basis of the 1000–500 mb thickness because of the variability of the temperature distribution within the layer. The lowest 3000 feet or so were often isolated from the rest of the layer by an inversion or stable boundary, and significant day-to-day warming near the ground was not adequately reflected in the thickness rise. It soon became clear that temperatures in air from the Continent could be forecast only from consideration of individual upper air ascents, or by some method based on maximum temperature anomalies upstream. This limitation is unfortunate since 40 per cent of temperatures of 80°F or more occurred in air from the Continent, but it emphasizes the difficulty of forecasting successfully the very hot days. It seemed, too, that cloudiness was not particularly important in relation to maximum temperature but an outbreak of heavy rain lowered it substantially, so an almost random element is unavoidable on many occasions.

Maximum temperature in stationary air.—It was necessary to include this category but it relates to a situation which will often be forecast incorrectly or will occur without being forecast. When stagnant air can be forecast with a fair degree of certainty the maximum temperature can be estimated satisfactorily on the basis of its small day-to-day changes. Nevertheless, it is of interest that the maximum temperature during the months June, July and August was given by S_{12}, regardless of the amount of sunshine, with a r.m.s. error of about 3°F. An exception occurred when there was continuous rain during the normal period of temperature rise, in which case the maximum temperature was lower than S_{12} by about 6°F. The method was not applicable in April, May or September.

Summary.—The rules put forward in the preceding paragraphs are summarized in Table II (or Table III).

TABLE II—MAXIMUM TEMPERATURE AT KEW IN °F

	April	May	June, July and August	September
NW	—	Appropriate S - value less 2°	Appropriate S - value	S_0
NE	$S_6 + N - 12$	$S_6 + N - 10$	Appropriate S - value but $S_6 - 9$ if sunshine zero	—
SW	$S_6 + N - 9$	$S_6 + N - 8$	$S_6 + N - 6$	$S_6 + N - 8$
C	—	—	—	—
St	—	—	S_{12} but 6° lower if continuous rain occurs	—

Table III represents Table II transferred to °C, a small allowance being made in converting the constant for the fact that $N/2$ is used as an approximation to $5N/9$.

TABLE III—MAXIMUM TEMPERATURE AT KEW IN °C

	April	May	June, July and August	September
NW	—	Appropriate S - value less 1°	Appropriate S - value	S_0
NE	$S_6 + \frac{N}{2} - 6$	$S_6 + \frac{N}{2} - 5$	Appropriate S - value but $S_6 - 5$ if sunshine zero	—
SW	$S_6 + \frac{N}{2} - 5$	$S_6 + \frac{N}{2} - 4$	$S_6 + \frac{N}{2} - 3$	$S_6 + \frac{N}{2} - 4$
C	—	—	—	—
St	—	—	S_{12} but 3° lower if continuous rain occurs	—

REFERENCE

1. BOYDEN, C. J.; The forecasting of daily mean surface temperature from 1000–500 millibar thickness lines. *Met. Mag., London*, **87**, 1958, p. 98.

551.509.326 : 551.515.4 : 551.578.71

THUNDERSTORMS IN GREAT BRITAIN

By Lt. Col. ROBERT C. MILLER, U.S.A.F. and Major LOYD G. STARRETT, U.S.A.F.

Summary.—Problems of forecasting thunderstorms and related phenomena in Great Britain are discussed in the light of daily operational experience in a centralized forecasting facility. Particular attention is given to the thermal stability of the atmosphere, its measurement and its rôle in the forecasting process. It is found that severe convective activity is most closely related to the 500 mb temperature. The prevalence of activity with tops well below the 500 mb level is mentioned and the basis for forecasting the size of hail is discussed.

Climatology.—Great Britain has a great many thunderstorms, considering that it is located from about 50° to 59° N. Even in winter, thunder is heard somewhere in Great Britain about one day out of three, while in summer this ratio increases to three out of four. The geographic distribution of the storms varies somewhat from year to year, but may be best described as moderately frequent in the Midlands and south-east England, and relatively rare elsewhere[1]. Figure 1 shows the distribution for the five years 1955–59[2].

The great majority of thunderstorms are reported during the normal season from early May to September. Figure 2 shows only the average distribution of thunderstorm *days*. To complete the picture, the activity in summer is normally much more intense and widespread than in winter. During the winter, the few thunderstorms that occur are found mostly on the western shores. In spring, the maximum activity is in south-eastern England and East Anglia. In summer, there is a marked increase in and north of the eastern Midlands, a normal northward migration for the season. Autumn has a relatively uniform distribution so that the annual pattern is determined almost entirely by the spring and summer storms.

The diurnal variation, Figure 3, shows no unusual characteristics. Coastal regions during the summer and inland areas at all seasons have a strong maximum of thunderstorms at about 1500 hours and a minimum at about 0700 hours. In the winter, coastal regions have their maximum number several hours after sunset and a pronounced minimum just before noon. Of course, these winter thunderstorms are relatively few and normally less vigorous than the summer variety. From the Kew Observatory records, it may be inferred that thunderstorm duration in winter averages about 20 minutes and frequently only one clap of thunder is heard. In the summer, the average is nearly 50 minutes. Convective activity just short of thunderstorm intensity is common in all seasons. Cumulonimbi are often reported hour after hour, sometimes by every station in a large area, without a thunderstorm report.

Summer thunderstorms also give rise to more reports of cloud-to-ground lightning, such being reported for about 60 per cent of the thunderstorms in summer and some 45 per cent in winter. About six times per year thunderstorms sweep across Great Britain in such waves that over half the area is affected. Nearly all these extensive storms occur during the months May to August[2].

While summer thunderstorms normally extend well above the 500 mb level, the winter type often do not. Tops of the latter average about 17,000 feet and have been reported at least as low as 12,000 feet.

Thunderstorm gusts in excess of 30 knots are quite rare in Great Britain. The great windstorms, for example, 26–27 November 1703[1] and 29 July 1956,

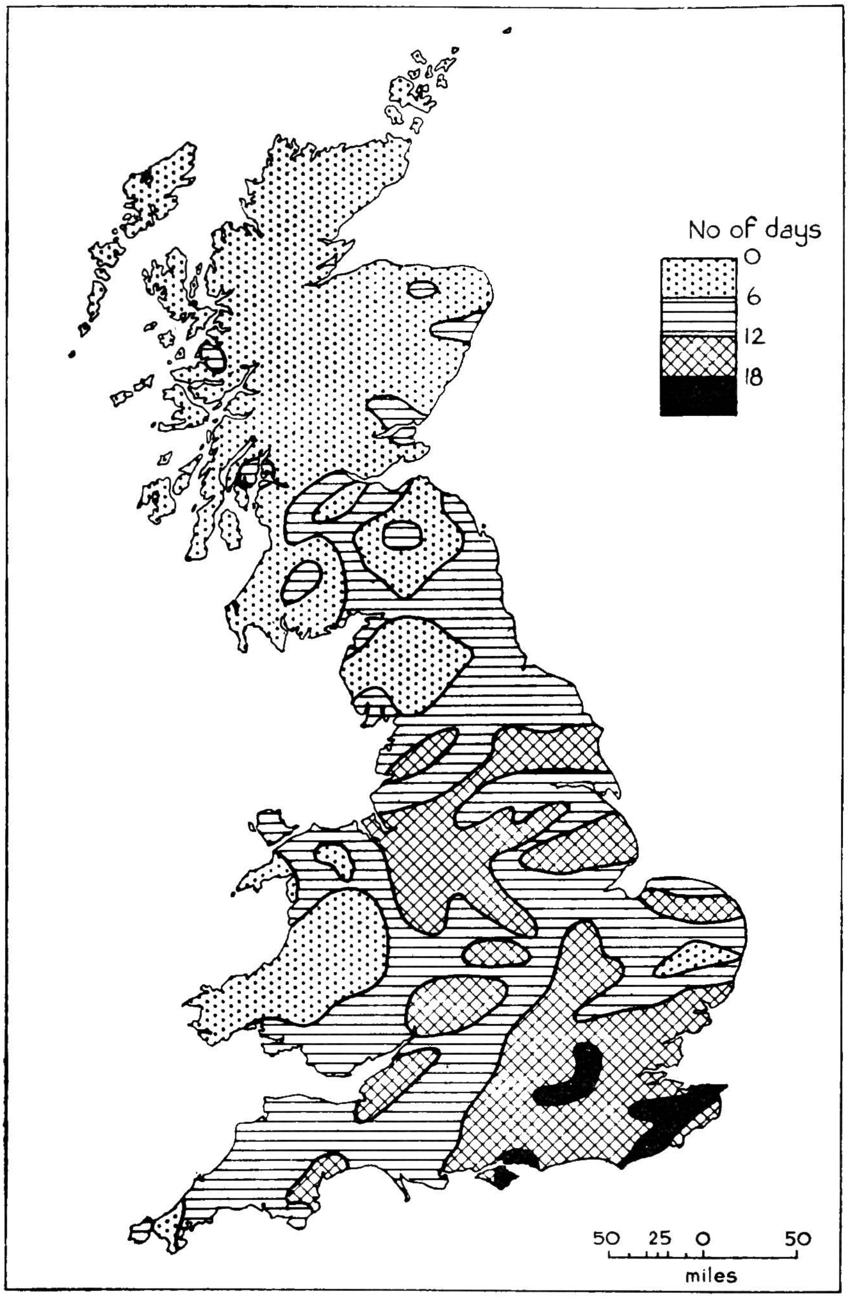


FIGURE I—AVERAGE ANNUAL FREQUENCY OF THUNDERSTORMS IN GREAT BRITAIN, 1955–59

By courtesy of the Electrical Research Association.[2]

appear to be due almost entirely to extreme pressure gradients with no significant convective activity. It may be that damaging downdraughts in thunderstorms are due to local moisture discontinuities. Where relatively dry air meets cloud droplets or rain, evaporative cooling may result in rather extreme temperature gradients[3]. Such situations do occur in England, as on 5 September 1958, but they are uncommon.

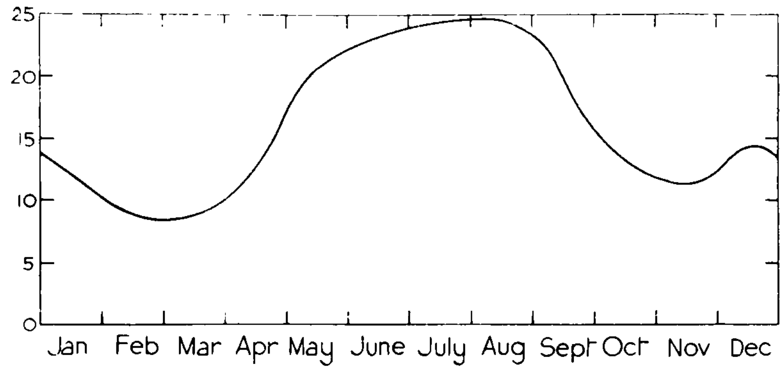


FIGURE 2—AVERAGE NUMBER OF THUNDERSTORM DAYS PER MONTH IN GREAT BRITAIN

These data represent neither intensity nor geographic extent.

In winter-type situations, showers of small hail frequently fall, either with or without thunder. These are common throughout Great Britain and are damaging chiefly when the amount of fall is excessive. Hail larger than a quarter-inch is relatively rare, especially north of 53°N and on the coasts. It occurs in summer-type situations, mostly during the season May through September. In the Horsham hailstorm of 5 September 1958, stones reached a diameter of three inches and weighed up to half a pound. At Tunbridge Wells on 6 August 1956, drifts of hailstones reached a depth of four feet.

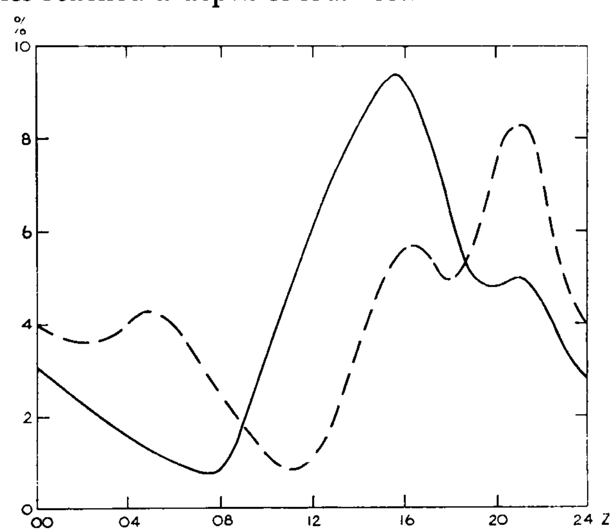


FIGURE 3—DIURNAL DISTRIBUTION OF THUNDERSTORMS IN GREAT BRITAIN

The solid curve is for inland areas at all seasons and also coastal regions during the summer. The dashed curve is for winter thunderstorms in coastal areas, i.e. within ten miles of the sea.

In England, tornadoes are commonly called "whirlwinds". Like large hail, the majority occur south of the fifty-third parallel during the summer season, though they have occurred in every month of the year. These storms are reported in the newspapers, with pictures and descriptions of the damage. Some are discussed or described in meteorological literature, but no complete compilation seems available. Brooks[1] (page 39) has mapped 23 of the most notable tornadoes in Great Britain.

The greatest thunderstorm flying hazard in winter is the rapid accumulation of ice. Radiosonde analyses justify forecasts of seldom more than moderate turbulence and small hail. Convective cells are normally isolated or scattered and of limited height, very rarely forming anything like a solid squall line.

On the other hand, representative soundings for summer-type storms show rising parcels will be much warmer than the ambient air, requiring forecasts of severe turbulence and frequently large hail. Squall lines occasionally become continuous and thunderstorm gusts at the earth's surface can become damaging, as on 5 September 1958. No incident of aircraft encountering hail damage in the clear air outside the thunderstorm clouds has been noted in Great Britain, though this is rather common in America. It goes without saying that icing continues to be a major hazard.

A large portion of England's thunderstorms form to the south or south-west and drift over the Island. These form first over the water, France or Spain, then move with the deep wind flow, usually at about 15 knots. Those that develop early in the day over the English Channel and the south-west approaches, travel inland and cause a moving line of maximum thunderstorm activity that sweeps across England as indicated by the isochrones in Figure 4. The migration of later thunderstorms, together with those arriving from more distant

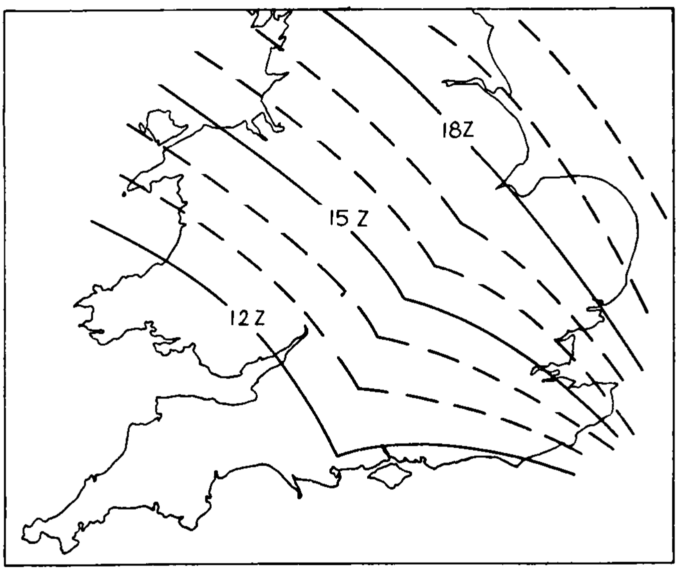


FIGURE 4—ISOCHRONES OF MAXIMUM THUNDERSTORM ACTIVITY IN GREAT BRITAIN

areas, form the nocturnal maximum that moves as shown by the isochrones in Figure 5[4]. The rapid dissipation of nocturnal thunderstorm activity in the west is probably due to the effectiveness of the Cotswold Hills and even the Chilterns in choking off the very low-level warm, moist air.

Forecasting.—Basically, there are three prerequisites for the formation of thunderstorms: thermal instability, moisture and trigger action. There have been numerous attempts to combine the first two in a stability or instability index. Most such indices are determined by raising a parcel of air from 850 mb to 500 mb and comparing it with the ambient air at this and lower levels. All indices examined are well founded and should be of some help, provided only that the data used are representative of the time and place for which the forecast is made. Any index used should be computed from a forecast sounding, valid at the time of interest, for no stability index is conservative. Furthermore, each situation should be examined for a typical characteristics, which might require modification or adjustment of the pseudo-objective index.

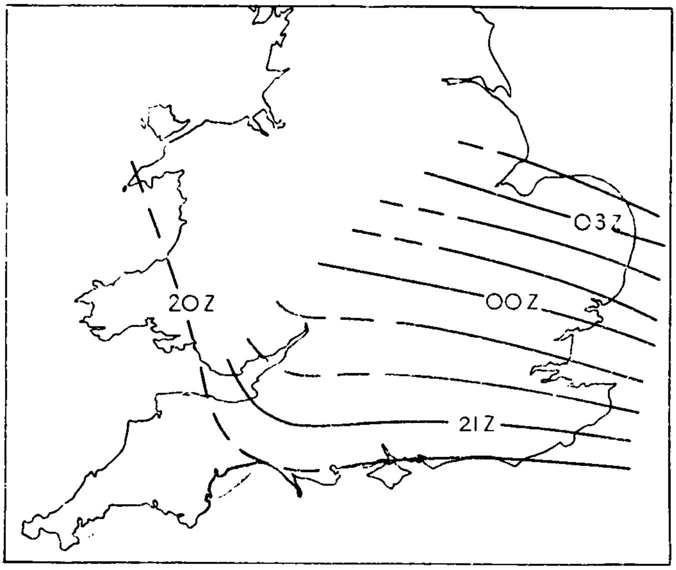


FIGURE 5—ISOCHRONES OF MAXIMUM NOCTURNAL THUNDERSTORM ACTIVITY IN GREAT BRITAIN

Since all known attempts to combine two or more of the above criteria in one index seem to have severe limitations when used in forecasting, this paper will discuss the three parameters separately. But first, some general observations are in order.

Modern practical forecasting leans heavily on electronic computer and centralized analyses and prognoses. These are excellent for the gross patterns and movements, but need to be supplemented in three ways:

(i) Local charts are needed to identify small, transitory perturbations, to locate features more precisely, and to time movements more accurately.

(ii) The product of the centralized facility must be adjusted in the light of later and locally more complete data. Its interpretation must be based on special knowledge of terrain and local effects.

(iii) Three-dimensional temperature, moisture, and stability analyses and prognoses must be provided locally, for they are not yet adequately furnished by centralized units.

Most thunderstorms in Great Britain, especially in the winter, occur under cold pools at 500 mb. They grow taller and more vigorous under and to the left of the jet stream. Inland thunderstorms of the winter type dissipate with spectacular suddenness at sundown, except for the stronger ones intensified by the jet stream. These sometimes persist most of, or even the whole night.

In order to determine the threshold thermal instability for thunderstorms, data for a hundred cases were collected. The 850–500 mb temperature lapse is plotted against the 500 mb temperature in Figure 6. The line of best fit, not shown, derived by the method of least squares, is $T_8 - T_5 = 20.7 - 0.3T_5$, where T_8 is the 850 mb temperature and T_5 is the 500 mb temperature. Correlation is about 0.7 and the standard error of estimate 2.2°C. Subtracting the latter from the line of best fit gives $T_8 - T_5 = 18.5 - 0.3T_5$ as the tentative threshold of thunderstorm activity. This is shown in Figure 6 as a solid line, rising from left to right.

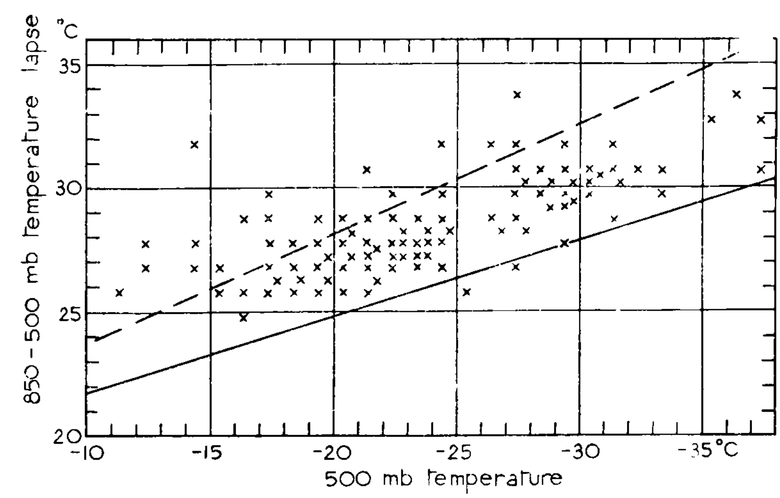


FIGURE 6—850–500 MB TEMPERATURE LAPSE AND 500 MB TEMPERATURE FOR THUNDERSTORMS

The solid line is the tentative threshold thermal instability for thunderstorms in Great Britain. It is one standard error of estimate below the line of best fit, derived by the method of least squares. The dashed line is the locus of 30-knot thunderstorm gusts. Only those cases lying above the dashed line were expected to produce gusts in excess of 30 knots. The total number of cases is 100.

It should be noted that low thermal stability, i.e., conditional instability, is a necessary but not a sufficient condition for thunderstorms to develop. Whenever the 850–500 mb temperature lapse exceeds $18.5 - 0.3T_5$, the moisture patterns and the possible trigger actions must be examined before a decision is made as to the forecast to be issued.

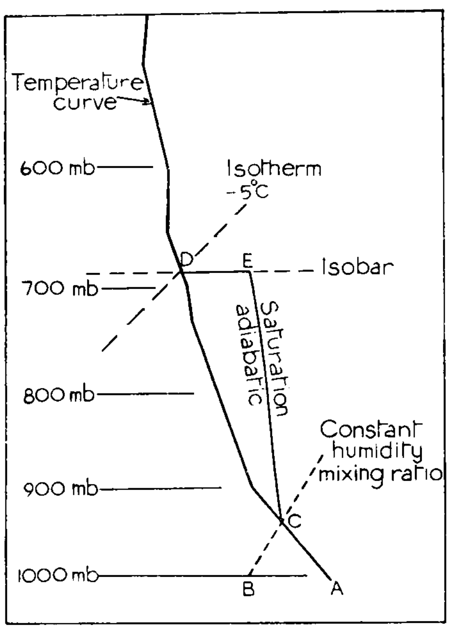
In order for thunderstorms to develop in Great Britain, in all except the most severe summer-type situations, the air at 700 mb and below must have relative humidity of 70 per cent or more. But when the temperature lapse, lower moisture and trigger action are strong enough, then thunderstorms will develop in spite of dryness in the middle layers and they will be especially severe. Middle-level dryness has the effect of dissipating cumulonimbi, but intensifying those that develop in spite of its presence.

Frequently air with rich moisture content and large temperature lapse rate persists in place for many hours and even days. Since its great energy can be released only when suitably triggered, the forecaster must be alert for any perturbation that may lift the air column. While fronts and troughs are sufficient, it must not be assumed that they are necessary to trigger thunderstorms or that their positions on the weather map are accurate. In fact, examination of past maps revealed that many of the fronts and troughs had their position and orientation greatly altered after reports of severe thunderstorm activity were received.

The rarity of thunderstorm gusts in excess of 30 knots has already been mentioned and illustrated in Figure 6. Whirlwinds or tornadoes are also relatively infrequent, probably due to the size of the Island, and no serious study of them has been attempted by the authors. They should probably be predicted when a thunderstorm situation is exceptionally strong, with very large hail indicated and vigorous trigger action expected.

Hail.—It is well to understand the reasoning behind forecasting aids, not only for background, but also as a basis for modification of results. Even the more objective aids require judgment and skill in application. The following discussion leads to a graph, Figure 8, that is essentially equivalent to one used with considerable success in America[5].

It is assumed that hailstones grow to sizes over one quarter inch only if supported for a time above the freezing-level and that this support is provided by the impact pressure of an updraught against a spherical stone. Large hail is common only in summer-type situations, when the wet-bulb freezing-level is 2500 metres or so above the terrain, so it is assumed to form slightly above this level. Following Fawbush and Miller[5], the computation will be made where the ambient temperature is —5°C. Air density at this level is estimated to be roughly 9×10^{-4} gm/cm³.



Liverpool sounding for 1200 GMT, 27 August 1960

FIGURE 7—ANALYSIS OF TEPHIGRAM FOR HAIL FORECASTING

In this example portion *AC* of the temperature curve falls on a dry adiabatic. *B* is the surface dew-point and *C* is the convective condensation level. *DE* and the thickness from *C* to *DE* are used in forecasting hail, see Figure 8.

To estimate the speed of an updraught from a sounding, it is assumed that a parcel of air is accelerated upward from rest at the convective condensation level. In Figure 7, *ACD* is the temperature curve and *BC* is the humidity mixing ratio line through the surface dew-point, making *C* the convective condensation level. Assume that the temperature of the rising parcel follows saturation adiabatic *CE*, while the temperature of the ambient air remains *CD*.

For practical purposes, the average difference in temperature may be taken as $\frac{1}{2}$ DE and the absolute temperature as 270°K. By the principle of Archimedes, the upward acceleration on the parcel is proportional to the difference in specific volumes and by Charles' Law, this is proportional to the difference in temperature. Let g stand for the acceleration due to gravity and H for the thickness of the air stratum between C and DE. Since the square of the speed of a particle starting from rest is twice the average acceleration times the distance, the square of the upward speed of our rising parcel is estimated at $(DE \times H \times g)/270$.

The density of a hailstone[6] is roughly 9/10 gm/cm³, so its mass is about

$$\frac{\pi d^3}{6} \times \frac{9}{10} \text{ grams,}$$

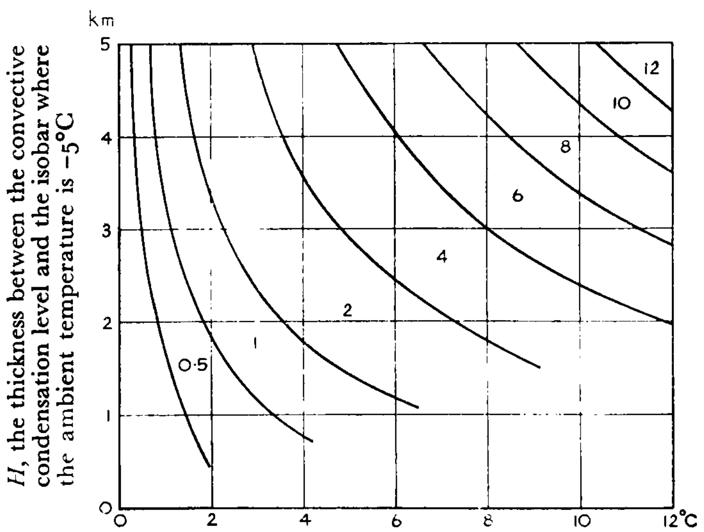
where d is the diameter in centimetres. From Humphreys' discussion of wind pressure[7], the impact force of the updraught may be estimated as 3/4 the kinetic energy, or 3/8 of the air density times the square of the updraught speed, times the cross-sectional area of the hailstone. Equating the weight of the stone to the acceleration upward due to the updraught, it is seen that:

$$\frac{\pi d^3}{6} \times \frac{9}{10} \times g = \frac{3}{8} \times 9 \times 10^{-4} \times \frac{DE \times H \times g}{270} \times \frac{\pi d^2}{4},$$

$$\text{or } d = \frac{DE \times H}{48} \times 10^{-4}$$

d and H being in centimetres and DE in degrees Celsius. If H is measured in kilometres, then

$$d = \frac{DE \times H}{4.8}$$



DE, the excess of temperature of a parcel of air raised along the saturation adiabatic from the convective condensation level to the isobar where the ambient temperature is −5°C

FIGURE 8—FORECAST DIAMETER OF HAIL IN CENTIMETRES

A sounding may be evaluated by either this last equation, or its graph, Figure 8. For example, the sounding in Figure 7 indicates a possibility of two-centimetre hailstones.

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EVALUATION OF THE CYCLOSTROPHIC CORRECTION TO THE GEOSTROPHIC WIND

By M. H. FREEMAN, O.B.E., M.Sc.

Summary.—The magnitudes of the errors in the measurement of curvature of contours caused by map distortion are examined. For the most part the errors are not serious, but in certain circumstances, e.g. strong anticyclonic winds in low latitudes, allowance should be made for them. A simple method of evaluating the cyclostrophic corrections to the geostrophic wind is presented; it uses the same pair of tables for both cyclonic and anticyclonic motion.

Introduction.—Consider a particle of air moving on the earth's surface in a circle whose radius subtends an angle α at the centre of the earth. In Figure 1 *P* and *Q* are points at the ends of a diameter of this circle and *S* is its centre. If *R* is the radius of the earth, the radius of the circle will be $R \sin\alpha$ and the air must be subject to an acceleration $V^2/R \sin\alpha$ (where *V* is the speed) along *PS*. The component of this acceleration in the plane tangential to the earth's surface (along *PT*) is $V^2\cos\alpha/R\sin\alpha$ and this is the term which must balance the accelerations due to the pressure gradient and the Coriolis force in the gradient

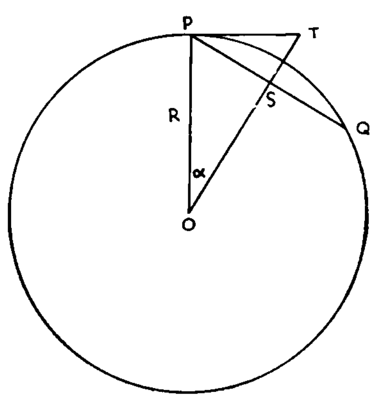

FIGURE 1—MOTION IN A CIRCLE ON THE EARTH'S SURFACE

wind equation. The effective radius of curvature is therefore $R \tan\alpha$, but this is not exactly what is normally measured from synoptic charts. For air moving cyclonically along the circle of latitude 60°, $R \tan\alpha$ is 1980 nautical miles; the contours are not effectively straight and the true correction for a geostrophic speed of 200 knots is −32 knots. On a chart drawn on a conformal conic projection with standard parallels at 60° and 30° the circle of latitude 60° has a radius of 2400 nautical miles and the correction that would be calculated from this is −27 knots. In this example the discrepancy is not serious, but it is large enough to suggest that significant errors might arise in some circumstances. The electronic computer METEOR was used to evaluate the corrections for numerous small circles in various latitudes.

The effect of map distortion on radius of curvature.—The general formula for the radius of curvature at a point on the transformation onto a map of a circle on the earth's surface is much too complicated to be readily

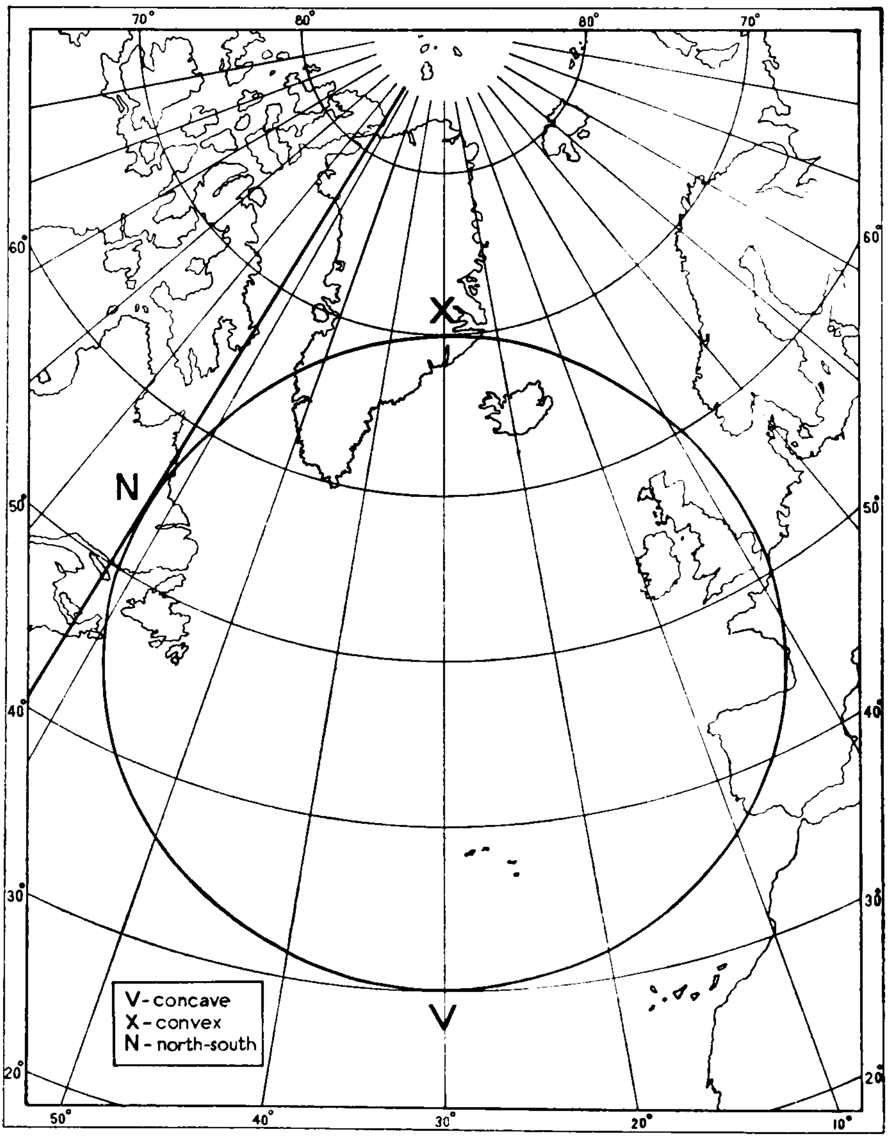

FIGURE 2—A SMALL CIRCLE ON A CONFORMAL CONIC PROJECTION WITH STANDARD PARALLELS AT 60°N AND 30°N

used. For selected circles the curvature on the map was therefore calculated using finite differences at three points as shown on Figure 2, namely (i) V the point farthest from the North Pole when the curve will be concave to the north and winds will be west in the cyclonic and east in the anticyclonic case,

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PLATE I—H.M. THE QUEEN AND H.R.H. THE DUKE OF EDINBURGH ARRIVING AT THE METEOROLOGICAL OFFICE, BRACKNELL ON 25 JUNE 1962

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PLATE II—H.R.H. THE DUKE OF EDINBURGH AND DR. R. C. SUTCLIFFE STUDYING THE CURRENT SYNOPTIC CHART

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PLATE III—H.M. THE QUEEN AND SIR GRAHAM SUTTON EXAMINING THE INSTRUMENT RING OF A SKYLARK ROCKET

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PLATE IV—H.M. THE QUEEN SIGNING THE VISITORS' BOOK

(ii) X the point nearest to the North Pole when the curve will be convex to the north and winds will be east for cyclonic and west for anticyclonic curvature, and (iii) N a point where a line of longitude is a tangent; winds will then be north or south. The three cases will for brevity hereafter be called concave, convex and N–S respectively.

For a given radius of curvature as measured on the map r_m, the correct value of the effective radius of curvature (R tanα) was calculated for each of the three cases. These radii will be denoted by r_v for the concave, r_x for the convex and r_n for the N–S case.

TABLE I—RADII OF CURVATURE CORRECTED FOR MAP DISTORTION FOR A CONFORMAL CONIC PROJECTION WITH STANDARD PARALLELS AT 30°N AND 60°N

		Measured radius r_m (n mile)					
Latitude	Shape of contours	500	1000	2000	3000	4000	5000
	Convex	470	1190	5120	Large	Large	Large
80°N	N–S	390	770	1550	2330	3090	3880
	Concave	330	580	910	1140	1300	1430
	Convex	520	1100	2430	4070	6160	8890
60°N	N–S	500	1000	2000	3000	4000	5000
	Concave	480	920	1700	2380	2960	3480
	Convex	510	1000	1950	2850	3700	4510
40°N	N–S	520	1030	2060	3090	4120	5150
	Concave	520	1060	2190	3380	4650	6010
	Convex	450	850	1550	2140	2630	3060
20°N	N–S	470	950	1890	2840	3780	4730
	Concave	500	1060	2420	4220	6720	10450

Table I shows for various latitudes and measured radii of curvature the correct effective radii of curvature in the three cases for a conformal conic projection with standard parallels at 30°N and 60°N. When the radius of curvature is small the errors due to map distortion are small except in the extreme north. For large radii of curvature the map errors become much larger, but then the cyclostrophic correction to the geostrophic wind is small and fortunately the discrepancies due to map distortion are mostly not serious. Table II(a) shows the corrections required to a geostrophic wind of 150 knots for cyclonically and anticyclonically curved isobars of various radii.

TABLE II(a)—CORRECTIONS REQUIRED TO A GEOSTROPHIC WIND OF 150 KT FOR (a) CYCLONIC (NEGATIVE FIGURES) AND (b) ANTICYCLONIC CURVATURE (POSITIVE FIGURES)

Conformal conic projection with standard parallels at 60°N and 30°N

		Measured radius r_m (n. mile)											
Latitude	Shape of isobars	500		1000		2000		3000		4000		5000	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
	Convex	−45	–	−25	112	−8	10	0	0	0	0	0	0
80°N	N–S	−50	–	−34	–	−21	50	−15	26	−12	18	−10	13
	Concave	−54	–	−40	–	−30	–	−26	–	−24	77	−22	59
	Convex	−46	–	−29	–	−16	29	−11	15	−7	9	−5	6
60°N	N–S	−47	–	−31	–	−19	40	−14	22	−11	15	−9	11
	Concave	−48	–	−33	–	−21	54	−17	30	−14	22	−12	18
	Convex	−54	–	−38	–	−24	82	−18	36	−15	24	−12	19
40°N	N–S	−54	–	−37	–	−23	69	−17	32	−13	21	−11	16
	Concave	−53	–	−36	–	−22	60	−16	28	−12	18	−10	13
	Convex	−73	–	−57	–	−42	–	−35	–	−30	–	−27	–
20°N	N–S	−72	–	−54	–	−37	–	−29	–	−24	74	−20	45
	Concave	−71	–	−51	–	−32	–	−22	56	−15	26	−10	14

Dashes indicate that balanced flow is not possible.

TABLE II(b)—CORRECTIONS REQUIRED TO A GEOSTROPHIC WIND OF 150 KT FOR (a) CYCLONIC (NEGATIVE FIGURES) AND (b) ANTICYCLONIC CURVATURE (POSITIVE FIGURES)

Equidistant azimuthal projection with standard parallel at 60°N

Measured radius r_m (n. mile)

Latitude	Shape of isobars	500		1000		2000		3000		4000		5000	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
80°N	Measured	−44	–	−29	–	−17	32	−12	18	−10	13	−8	10
	Convex	−34	–	−19	39	−7	9	−2	3	0	0	0	0
	N–S	−47	–	−31	–	−19	40	−14	22	−11	15	−9	11
	Concave	−43	–	−28	–	−19	40	−16	27	−14	22	−13	19
60°N	Measured	−47	–	−31	–	−19	40	−14	22	−11	15	−9	12
	Convex	−48	–	−33	–	−21	52	−16	29	−13	21	−12	17
	N–S	−47	–	−31	–	−19	39	−14	22	−11	15	−9	11
	Concave	−46	–	−30	–	−17	30	−11	15	−8	10	−6	7
40°N	Measured	−54	–	−38	–	−24	76	−17	33	−14	22	−11	16
	Convex	−61	–	−46	–	−32	–	−27	–	−23	69	−21	50
	N–S	−52	–	−35	–	−22	58	−16	28	−13	19	−10	14
	Concave	−58	–	−39	–	−21	54	−13	20	−8	10	−4	5
20°N	Measured	−71	–	−53	–	−36	–	−28	–	−23	64	−19	41
	Convex	−85	–	−69	–	−55	–	−48	–	−44	–	−41	–
	N–S	−64	–	−47	–	−31	–	−23	71	−19	39	−16	27
	Concave	−80	–	−60	–	−37	–	−23	66	−12	19	0	0

Dashes indicate that balanced flow is not possible.

The correction for N–S isobars always lies between the correction for convex and concave isobars, and for cyclonic curvature r_n is a good approximation to r_x and r_v, and r_m is very nearly as good. For anticyclonic curvature the discrepancies are greater but in most of the circumstances which are likely to occur in the atmosphere r_n will still be a reasonably good approximation to r_x and r_v. This will not always be so in high and low latitudes, nor when the wind is strong in middle latitudes. It is noteworthy that for an anticyclonic wind of 150 knots and a radius of curvature as great as 2000 nautical miles the correction to the geostrophic wind can range from 29 to 54 knots in latitude 60° and from 60 to 82 knots in latitude 40°.

Similar sets of figures were computed for the two map projections most commonly used for circumpolar hemispheric charts. For the polar stereographic with standard parallel at 60° the pattern of results followed those for the two standard parallel conic projection fairly closely. For the equidistant azimuthal projection on the plane of 60°N, used in the Meteorological Office, the relations between r_x, r_v and r_n are more complicated. From latitude 60°N to 20°N r_x is the smallest of the three but otherwise there is no consistent pattern of their relative sizes. The measured radius r_m always lies somewhere between the greatest and least of r_x, r_v and r_n, and r_m is probably the best single value to use. Table II(b) shows the corrections to a 150-knot geostrophic wind for various radii of curvature on an equidistant azimuthal projection.

In the method of evaluating the cyclostrophic correction given in the next section the tables required will use r_m, the radius as measured. The more precise values, r_x, r_v and r_n can readily be incorporated for those occasions when the refinement is justified and the necessary figures are presented in Tables III(b) and (c).

Evaluation of the cyclostrophic correction to the geostrophic wind.— A number of practical methods of evaluating the cyclostrophic correction to the geostrophic wind have been described. Gilbert's[1] method is one of the most complete, but it requires three fairly large tables and gives the answers as percentage corrections, whereas it is often more convenient to find directly the absolute magnitude of the correction. For balanced motion under the pressure gradient, Coriolis and cyclostrophic forces, the gradient wind equation can be written:

$$V = G - \frac{V^2}{fr'} \qquad \ldots (1)$$

where V is the gradient wind, G the geostrophic wind, f the Coriolis parameter and r' the radius of curvature of the air trajectory, taken positive for cyclonic and negative for anticyclonic curvature. The curvature of the trajectory is related to r, the radius of curvature of a contour line or isobar by the formula:

$$\frac{1}{r'} = \frac{1}{r}\left[1 - \frac{C\cos\psi}{V}\right] \qquad \ldots (2)$$

where C is the speed of movement of the pressure system and ψ is the angle between the direction of motion of the pressure system and the contour lines, and the motion is balanced. (See, for example, Petterssen[2]). After substituting for r^1 from equation (2) and putting $G - C\cos\psi = D$ the gradient wind equation (1) can be solved to give:

$$G - V = \tfrac{1}{2}\left[(fr + G + D) \pm \sqrt{(fr + G + D)^2 - 4GD}\,\right]$$

The negative square root is taken for cyclonic curvature and the positive root for anticyclonic.

For cyclonic curvature, $(fr + G + D)$ is positive and equal to $+Q$, say; $G - V$ is the correction which has to be subtracted from the geostrophic wind and its magnitude is $\tfrac{1}{2}\,[Q - \sqrt{(Q^2 - 4GD)}]$. For anticyclonic curvature, $(fr + G + D)$ is negative and equal to $-Q$, say, and $V - G$, the correction which has to be added, is also given by $\tfrac{1}{2}\,[Q - \sqrt{(Q^2 - 4GD)}]$. In both cases the correction takes the same form, being subtracted for cyclonic and added for anticyclonic curvature. When $(fr + G + D)$ and GD have been evaluated the size of the cyclostrophic correction to the geostrophic wind can be obtained from a single table.

The steps necessary are:

(i) Measure r, the radius of curvature (in nautical miles) of the contour and calculate fr. Table III(*a*) has been constructed to give this directly. If account is to be taken of the distortions due to map projection Table III(*b*) or (*c*) can be used; the necessary adjustments to allow for the contours being convex, N–S, or concave have been incorporated. Interpolation will be needed when the orientation of the contour is intermediate between two of these three values.

TABLE III(*a*)—VALUES OF fr WHERE f IS THE CORIOLIS PARAMETER AND r THE RADIUS OF CURVATURE

Measured radius of curvature (n. mile)

Lat.	200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
80°	100	150	210	260	310	410	520	620	770	1030	1290	1550	2060	2580
70°	100	150	200	250	290	390	490	590	740	980	1230	1470	1970	2460
60°	90	140	180	230	270	360	450	540	680	910	1130	1360	1810	2270
50°	80	120	160	200	240	320	400	480	600	800	1000	1200	1600	2000
40°	70	100	130	170	200	270	340	400	500	670	840	1010	1350	1680
30°	50	80	100	130	160	210	260	310	390	520	650	780	1050	1310
20°	40	50	70	90	110	140	180	210	270	360	450	540	720	900

TABLE III(*b*)—VALUES OF *fr*, WHERE *f* IS THE CORIOLIS PARAMETER AND *r* IS THE RADIUS OF CURVATURE CORRECTED FOR MAP DISTORTION

Conformal conic projection with standard parallels at 60°N and 30°N.

Latitude	Shape of isobars	Measured radius of curvature (n. mile) 200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
	Convex	90	130	190	240	300	440	610	820	1260	2640	7790	∞	∞	∞
80°	N–S	80	120	160	200	240	320	400	480	600	800	1000	1200	1600	2000
	Concave	70	110	140	170	200	250	300	340	390	470	540	590	670	740
	Convex	90	140	200	250	300	420	550	690	930	1400	2030	2890	6170	∞
70°	N–S	90	140	180	230	270	360	450	540	680	910	1140	1370	1820	2270
	Concave	90	130	170	210	250	320	390	450	540	670	790	890	1070	1210
	Convex	90	140	190	240	290	390	500	610	780	1100	1450	1850	2790	4030
60°	N–S	90	140	180	230	270	360	450	540	680	910	1130	1360	1810	2270
	Concave	90	130	180	220	260	340	420	490	600	770	930	1080	1340	1580
	Convex	80	130	170	210	250	340	420	510	640	870	1100	1340	1830	2350
50°	N–S	80	120	170	210	250	330	410	500	620	830	1040	1240	1660	2070
	Concave	80	120	160	200	250	330	400	480	600	790	980	1160	1510	1850
	Convex	70	100	140	170	200	270	340	400	500	660	810	960	1250	1520
40°	N–S	70	100	140	170	210	280	350	420	520	690	870	1040	1390	1730
	Concave	70	110	140	180	210	280	360	430	540	740	930	1140	1570	2020
	Convex	50	80	100	130	150	200	240	290	350	460	550	650	810	960
30°	N–S	50	80	100	130	160	210	260	310	390	520	650	790	1050	1310
	Concave	50	80	110	140	160	220	280	340	440	610	800	1000	1470	2050
	Convex	30	50	60	80	100	120	150	180	220	280	330	380	470	550
20°	N–S	30	50	70	80	100	140	170	200	250	340	420	510	680	850
	Concave	30	50	70	90	110	150	190	230	300	430	580	760	1200	1870

TABLE III(*c*)—VALUES OF *fr*, WHERE *f* IS THE CORIOLIS PARAMETER AND *r* IS THE RADIUS OF CURVATURE CORRECTED FOR MAP DISTORTION

Equidistant azimuthal projection with standard parallel at 60°N.

Latitude	Shape of isobar	Measured radius of curvature (n. mile) 200	300	400	500	600	800	1000	1200	1500	2000	2500	3000	4000	5000
	Convex	140	220	300	390	480	690	920	1180	1660	2780	4680	8710	∞	∞
80°	N–S	90	130	180	220	270	360	450	540	680	900	1130	1360	1810	2270
	Concave	130	190	250	300	360	450	540	630	740	900	1040	1160	1350	1510
	Convex	110	160	220	270	320	430	540	640	800	1060	1320	1580	2080	2570
70°	N–S	90	140	190	230	280	380	470	560	700	940	1170	1410	1880	2350
	Concave	110	160	220	270	330	440	550	660	830	1110	1400	1690	2280	2880
	Convex	90	130	180	220	260	340	420	500	610	780	950	1100	1380	1630
60°	N–S	90	140	180	230	270	360	450	550	680	910	1140	1360	1820	2280
	Concave	90	140	190	240	290	390	490	600	770	1070	1410	1780	2630	3720
	Convex	70	110	140	170	200	270	330	380	470	590	710	810	990	1150
50°	N–S	80	130	170	210	250	340	420	510	630	840	1060	1270	1690	2110
	Concave	70	110	150	190	230	320	410	510	660	950	1280	1680	2730	4370
	Convex	50	80	100	130	150	200	240	280	340	430	500	570	700	800
40°	N–S	70	110	150	190	220	300	370	450	560	750	940	1120	1500	1880
	Concave	60	90	120	150	180	250	320	400	520	770	1070	1450	2590	4900
	Convex	40	50	70	90	100	130	160	190	230	280	330	380	450	520
30°	N–S	60	90	120	150	190	250	310	370	470	620	780	930	1240	1560
	Concave	40	60	80	100	120	170	220	280	370	560	790	1110	2190	5240
	Convex	20	30	40	50	60	80	90	110	130	160	190	220	260	290
20°	N–S	50	70	90	110	140	180	230	270	340	460	570	690	920	1150
	Concave	20	40	50	60	70	100	130	170	230	340	500	710	1530	∞

(ii) Measure G, the geostrophic wind (in knots), and $C \cos\psi$, the component of the motion of the pressure system along the direction of G, and find the difference $D = G - C \cos\psi$. If $C \cos\psi$ and G are in opposite directions $C \cos\psi$ will be negative and D will be greater than G. This will occur, for instance, to the north of an eastward-moving depression.

(iii) Evaluate $fr + G + D$ and GD, taking r as positive for cyclonic curvature and negative for anticyclonic.

(iv) Read off the correction from Table IV, the correction being subtracted when the curvature is cyclonic and added when it is anticyclonic. Dashes in the table indicate that balanced motion is not possible.

If the motion of the pressure system can be ignored D is equal to G, and GD becomes G^2. A second column, containing $\sqrt{(GD)}$ has been included in Table IV, so that when $C \cos\psi$ is zero the table can be entered knowing G, and GD or G^2 need not be evaluated.

TABLE IV—CORRECTIONS TO GEOSTROPHIC WIND FOR GIVEN VALUES OF $| fr + G + D |$ AND GD

		Values of $\| fr + G + D \|$																
GD	$\sqrt{GD}$	100	150	200	250	300	400	500	600	700	800	900	1000	1200	1500	2000	2500	3000
1000	32	11	7	5	4	3	3	2	2	1	1	1	1	1	1	1	0	0
2000	45	28	15	11	8	7	5	4	3	3	3	2	2	2	1	1	1	1
3000	55		24	16	13	10	8	6	5	4	4	3	3	3	2	2	1	1
4000	63		35	23	17	14	10	8	7	6	5	4	4	3	3	2	2	1
5000	71		50	29	22	18	13	10	8	7	6	6	5	4	3	3	2	2
6000	78		–	37	27	22	16	12	10	9	8	7	6	5	4	3	2	2
7000	84			45	32	26	18	14	12	10	9	8	7	6	5	4	3	2
8000	90			55	38	30	21	17	14	12	10	9	8	7	5	4	3	3
9000	95	–		68	44	34	24	19	15	13	11	10	9	8	6	5	4	3
10000	100			100	50	38	27	21	17	15	13	11	10	8	7	5	4	3
12000	110		–	–	65	48	33	25	21	18	15	14	12	10	8	6	5	4
14000	119		–	–	85	58	39	30	24	21	18	16	14	12	9	7	6	5
16000	127		–	–	–	69	45	34	28	24	21	18	16	13	11	8	6	5
18000	134		–	–	–	83	52	39	32	27	23	20	18	15	12	9	7	6
20000	141	–	–	–	–	100	59	44	35	30	26	23	20	17	13	10	8	7
22000	148	–	–	–	–	128	66	49	39	33	29	25	23	19	15	11	9	7
24000	155	–	–	–	–	–	74	54	43	36	31	28	25	20	16	12	10	8
26000	161	–	–	–	–	–	82	59	47	39	34	30	27	22	18	13	10	9
28000	167		–	–	–	–	90	64	51	43	37	32	29	24	19	14	11	9
30000	173		–	–	–	–	100	70	55	46	39	35	31	26	20	15	12	10
35000	187	–	–	–	–		129	84	65	54	46	41	36	30	24	18	14	12
40000	200	–	–	–	–		200	100	76	63	54	47	42	34	27	20	16	13
45000	212		–	–	–			118	88	72	61	53	47	39	31	23	18	15
50000	224			–	–			138	100	81	68	59	53	43	34	25	20	17

The correction should be subtracted for cyclonic curvature and added for anticyclonic curvature. Dashes indicate that balanced motion is not possible.

For most purposes corrections smaller than 10 per cent of the geostrophic wind can be ignored. If the value of fr is greater than about $8G$ for cyclonic curvature or $12G$ for anticyclonic curvature the correction will be less than 10 per cent. If Table III(*a*), or (*b*) or (*c*), indicates a value of fr greater than these limits there is no need to carry the evaluation further. With strong winds in low latitudes, especially if the curvature is anticyclonic, very large radii of curvature can still produce important corrections to the geostrophic wind.

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FLUCTUATIONS IN STRATOSPHERIC WINDS OVER ASCENSION ISLAND

By R. A. EBDON

Recent articles[1, 2, 3, 4] have drawn attention to a fluctuation with a period of 23–29 months in the zonal component of stratospheric winds over tropical regions. The evidence for suggesting this fluctuation came principally from stations situated either in the northern hemisphere or very close to the equator. In extending the work farther into the southern hemisphere Veryard[5] was able to show that the fluctuation existed over Australia, and Farkas[6] has drawn attention to the fluctuation in the stratospheric zonal wind components at Nandi (17°45′S, 177°27′E). It has now been possible to analyse high-level data for Ascension Island (07°58′S, 14°24′W) using data on microfilm supplied by the United States Weather Bureau for the period September 1957–August 1961. The purpose of this note is to record that the data for Ascension Island confirm some of the main findings regarding stratospheric zonal wind components published earlier for other tropical stations.

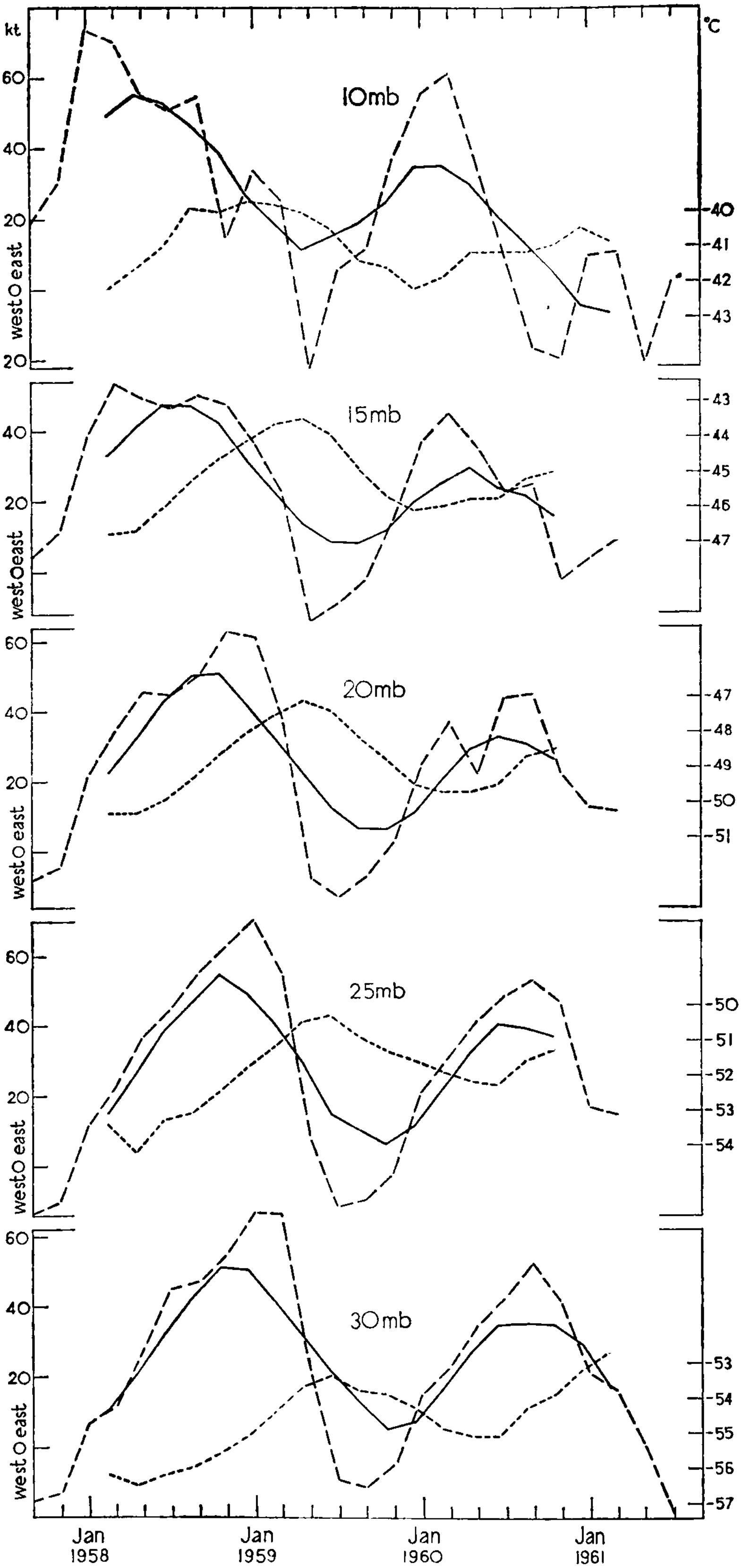

FIGURE I—ZONAL WIND COMPONENTS AND TEMPERATURES AT ASCENSION ISLAND

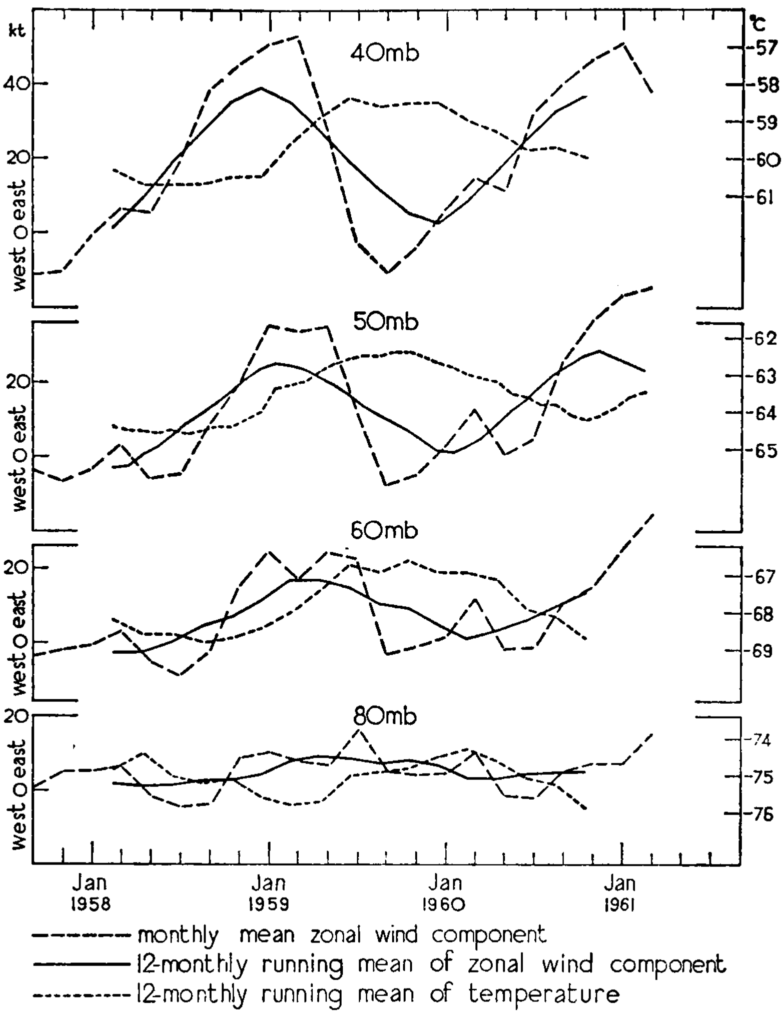

FIGURE I—ZONAL WIND COMPONENTS AND TEMPERATURES AT ASCENSION ISLAND (*continued*)

Monthly mean zonal wind components and temperatures were obtained for alternate months for the 100, 80, 60, 50, 40, 30, 25, 20, 15 and 10 mb levels using two ascents per day. The levels for which data are available changed to 100, 50, 30 and 10 mb from April 1961. (The only monthly means based on less than 10 observations were those for May 1959, July and September 1960 at the 10 mb level, but in May 1959 there were more than 10 temperature observations.) The zonal wind component curves in Figure 1 show that during the short period for which data are available there was a fluctuation in the zonal wind component with a periodicity of about 20–25 months. As at other tropical stations the range of the fluctuation decreases with diminishing height and the estimates of the range at Ascension Island based on measurements from the first peak to the trough and from the trough to the second peak on the curves of 12-monthly running means are given in Table I. These figures suggest that the range of the fluctuation probably reaches a maximum near 25 mb and it is of interest to note that the mean easterlies of the stratosphere at levels up to 10 mb also show a maximum at this level.

TABLE I—RANGE OF FLUCTUATION AT ASCENSION ISLAND

Level *mb*	Range from 1st peak to trough *kt*	Range from trough to 2nd peak *kt*	Mean zonal wind speed (Sept. 1957–July 1961) *kt*
10	45	25	+24.1*
15	41	22	+23·7
20	47	28	+24.6
25	48	36	+27.0
30	47	32	+21.7
40	37	34	+20.5
50	24	27	+12.4
60	16		+ 7·9
80	8		+ 5·4

* easterly wind indicated by + sign.

Vertical profiles of the mean monthly zonal wind component between 100 mb and 10 mb were drawn for alternate months from September 1957–March 1961 and, as would be expected, the year-to-year variations for individual months were very considerable. To illustrate this point Figure 2 shows the vertical profiles for September for the years 1957–60 and for March for the years 1958–61.

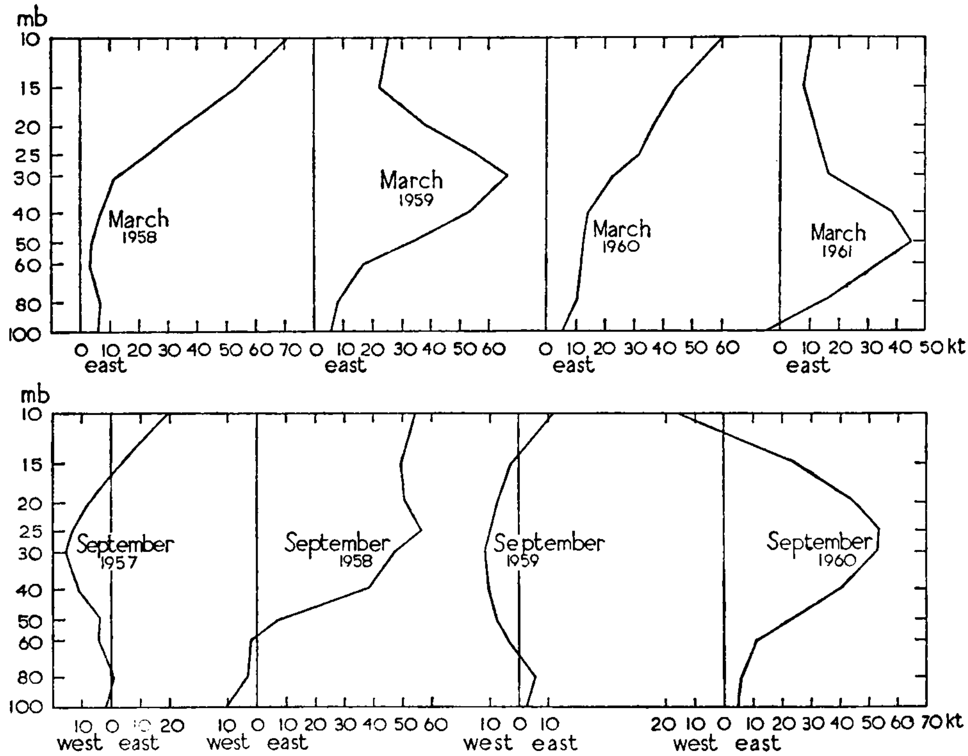

FIGURE 2—VERTICAL PROFILES OF THE MEAN MONTHLY ZONAL WIND COMPONENT (KT) ABOVE 100 MB AT ASCENSION ISLAND

In spite of the short period of record at present available it will be seen from Figure 1 that the 12-monthly running means of stratospheric temperatures also display a fluctuation with a similar period to that found in the zonal wind components. At Ascension Island it appears that the wind and temperature curves are out of phase by about eight months at all the levels considered. The curves show that the range of the fluctuation increases with height—from 1.5°C at 80 mb to 2–3°C at 30 mb and above (it may be that the range is decreasing again at 10 mb). At Canton Island (02°46′S, 171°43′W) however the curves showed quite clearly that the range, as indicated by 12-monthly running means, decreased from 3–4°C at 80 mb to 1.5–2.5°C at 30 mb and the lag between the temperature change and the wind change increased with height from 1–2 months at 80 mb to about 7 months at 30 mb.

The curves of 12-monthly running means of the zonal wind components at 60 mb for Aden (12°49′N, 45°02′E), Nairobi (01°18′S, 36°45′E), Lae (06°44′S, 147°00′E) and Ascension Island are shown in Figure 3. (For Lae wind data at 65,000 feet supplied by the Australian Commonwealth Bureau of Meteorology were used.) The use of 12-monthly running means removes the marked annual variation (from strong easterly in summer to light easterly or light westerly in alternate winters) at Aden and facilitates comparison with the other stations

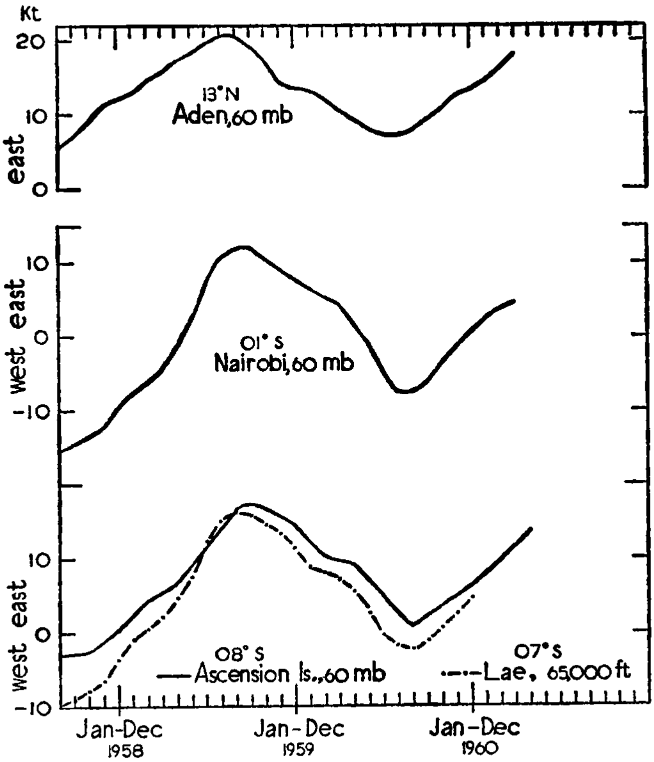

FIGURE 3—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 60 MB

which are situated nearer the equator where, during the last ten years or so at least, the behaviour of the stratospheric winds has been dominated by a periodicity of about 26 months. It will be seen that the fluctuation appears to be in phase from 13°N to at least 8°S and that the latitudinal variation of the fluctuation is such that the range apparently increases from Ascension Island to Nairobi and then decreases to Aden. The 50 mb zonal wind component curves for Canton Island and Ascension Island (based on values for every month) are given in Figure 4. These confirm the in-phase relationship and show a decrease (attributed to latitude) in the range from about 36 knots at Canton Island to about 27 knots at Ascension Island.

The results so far obtained suggest that the effects of the approximately 26-month periodicity, although decreasing with distance from the equator, are

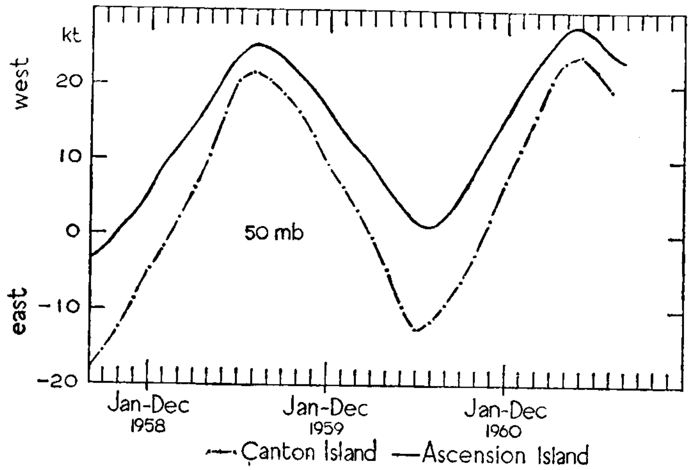

FIGURE 4—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT 50 MB

still discernible at about 20°N and 20°S. Zonal wind components for Khartoum (15°36′N) and San Juan (18°28′N)[2] and Nandi (17°45′S)[6], although all subject to a marked annual variation, do show the fluctuation.

It has been mentioned in earlier reports of the work on this subject that Canton Island provides one of the longest upper wind records in existence near the equator. Daily values are available in the New Zealand *Daily Weather Bulletin.* For reference purposes the monthly mean zonal wind components at 50 mb (based on one ascent per day) up to April 1962 are shown in Figure 5.

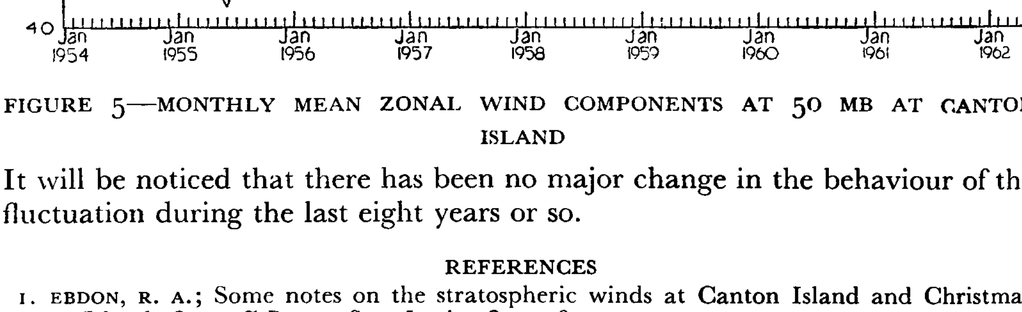

FIGURE 5—MONTHLY MEAN ZONAL WIND COMPONENTS AT 50 MB AT CANTON ISLAND

It will be noticed that there has been no major change in the behaviour of the fluctuation during the last eight years or so.

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NOTES AND NEWS

Meteorological Office Colloquium, 9 May 1962

On the afternoon of 9 May 1962, Professor J. Bjerknes, Head of the Department of Meteorology at the University of California at Los Angeles (U.C.L.A.), gave a talk at the Meteorological Office, Bracknell on "Climatic trends in ocean temperatures". He said that his basic aim was to introduce physical reasoning into the study of climatic change, with special reference to the interaction between ocean and atmosphere. Using mean annual pressure data for Vestmannaeyjar (Iceland) and Ponta Delgada (Azores) for the period 1895–1960, and mean sea surface temperatures for 5° "squares" at 30°N between the Azores and Iceland, graphs were drawn which show clearly a strong negative correlation between the anomalies of the annual mean pressure difference Azores/Iceland and the anomalies of the annual sea surface temperature in the vicinity of 30°W. This indicates a negative correlation between the strength of the westerlies and the sea temperature. Charts were then shown giving isopleths of the change of annual mean pressure (Δp) from 1902 (characterized by weak westerlies) to 1904 (characterized by strong westerlies), together with isopleths of sea temperature change (ΔT) over the North Atlantic between the Azores and Iceland. For a value of Δp of + 7 mb, ΔT was negative over a wide area and greatest (− 2.5°C) in the region 50°–55°N, 30°–35°W. This was also the region of the greatest increase of the westerlies. By contrast between 1904 (strong westerlies) and 1909 (weak westerlies) ΔT was positive over a wide area and was again greatest (+ 1.5°C) in the region 50°–55°N, 30°–35°W. Since westerly winds in this region are usually associated with cold air masses the sea temperature fall can be explained by an increased rate of loss of heat by evaporation and turbulent exchange between sea and atmosphere and by increased advection of colder water from the north-west by wind-produced ocean currents.

Professor Bjerknes then went on to consider sea temperature changes which occur when relatively weak or strong westerlies are maintained over a period of several years. He examined the difference in sea temperature between a long period of predominantly weak westerlies (1880s and 1890s) and one of predominantly strong westerlies (1900–30). Since the intensification of the Iceland low is linked with an intensification of the Azores high, isopleths of the change of mean annual sea surface temperature between the two periods showed west of 30°W a cooling north of 50°N, and a warming south of 50°N, the total relative change between 35° and 45°W amounting to 1.5°C across a few degrees of latitude in the vicinity of 50°N. This increase of sea surface temperature gradient is favourable for the deepening of polar front lows moving north-eastward in the vicinity of 50°N, 30°–50°W, and should therefore tend to maintain a negative anomaly of pressure near Iceland, although the history of any individual low will be determined by the large-scale atmospheric flow pattern at the time. Hence, owing to the ocean–atmosphere interaction a period of strong westerlies tends to be self-maintaining.

During a short discussion which followed the opening statement, Professor Bjerknes was asked whether there appeared to be any well marked period for trends towards stronger or weaker westerly situations. In reply he stressed that there was no identifiable period for such trends. The year 1921 marked the commencement of a trend towards weaker westerlies, proving that there are external factors, not yet understood, which can quite abruptly overcome the self-maintaining tendency which results from the interaction between ocean and atmosphere.

F. E. LUMB

Languages of meteorological literature

This note puts on record a count of the languages in which books and papers, excluding those, such as yearbooks, devoted solely to observations and summaries of observations, were received in the library of the Meteorological Office during the six months October 1960 to March 1961.

A general count was made and also a count of those publications classified under Universal Decimal Classification number 551.511, Mechanics and thermodynamics of the atmosphere in general. The count under 551.511 is the more important as giving an indication of the proportion in the various languages of the new research work which scientists may need to read. It is therefore given first in Table I.

TABLE I—BOOKS AND PAPERS CLASSIFIED UNDER 551.511

	Books and papers		Pages	
	number	percentage	number	percentage
English	96	55	2221	70
Russian	38	22	562	18
German	10	6	121	4
French	6	4	87	3
Japanese	8	5	53	2
Italian	2	1	26	<1
Bulgarian	3	2	20	<1
Hungarian	3	2	19	<1
Spanish	2	1	19	<1
Chinese	3	2	18	<1
Polish	1	<1	9	<1
Czech	1	<1	6	<1
Afrikaans	1	<1	3	<1

The general count, which is given in Table II, necessarily includes many minor notes and review articles as well as many pages of data.

TABLE II—BOOKS AND PAPERS IN GENERAL

	Books and papers		Pages	
	number	percentage	number	percentage
English	1369	51	28,562	52
Russian	659	24	14,510	26
German	184	7	4,145	8
French	98	3	1,418	3
Japanese	104	4	1,077	2
Italian	34	1	814	1
Spanish	21	<1	714	1
Polish	13	<1	610	1
Czech	24	<1	541	<1
Chinese	74	3	493	<1
Dutch	14	<1	405	<1
Hungarian	50	2	357	<1
Portuguese	6	<1	288	<1
Croat	19	<1	223	<1
Afrikaans	11	<1	78	<1
Norwegian	1	<1	10	<1
Swedish	1	<1	9	<1
Danish	1	<1	28	<1

The figures confirm what is common knowledge among meteorological librarians, that English is by far the major language of meteorological publication with Russian now easily second and German, French and Japanese next but well behind Russian. Table II is much less accurate than Table I as a measure of relative lengths of text in different languages but the order of the major languages is the same in both.

English is, of course, the major language of publication of meteorological research in many countries, notably the Scandinavian countries and Japan, besides the British Commonwealth and the United States.

The only other statement of the relative proportions of publications in various languages known to the writer is that due to Rigby[1] covering the over 24,500 abstracts published in the American Meteorological Society's "Meteorological abstracts and bibliography" during the years 1950 to 1954. Rigby's list of percentages for the first eight most frequently occurring languages in his count was:

	%		%
English	58	Spanish	2
German	21	Italian	2
French	7	Japanese	2
Russian	5	Dutch	1

The increase in the proportion of Russian in the Meteorological Office count for October 1960–March 1961 over Rigby's count for 1950 to 1954 is probably due more to the much greater ease of acquisition of Russian meteorological literature in western countries in recent years than to increase in publication in the U.S.S.R.

The importance of a knowledge of Russian, the second language of meteorological publications, or access to an adequate service of translation from that language is enhanced by the almost total absence of foreign language abstracts in Russian publications. Most of the research papers in languages other than Russian are accompanied by an abstract in English at least.

It should be mentioned in conclusion that the figures for individual months differ markedly because publications of some languages, Russian in particular, arrive in large collections at intervals. Those for the first and second three months, however, differ so little from the overall values as to suggest the six-monthly ones give an adequate description.

G. A. BULL

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Circle of State Librarians

On Saturday, 16 June 1962 a party of members of the Circle of State Librarians —a professional association through which matters of interest to Government Libraries can be discussed and contacts between staff cemented—made the new Meteorological Office Headquarters the venue for its 1962 Summer Outing. The party totalling almost 50 with the attendant library staff was entertained to morning coffee, lunch and afternoon tea and a varied programme of business and entertainment was provided. In addition to the main attraction of the day—a tour of the library and its activities—visits to the central forecast office, communications centre, computer room, punched-card installation and archives were much enjoyed.

Meteorology in Scientific Papers

Approximately half of the effort of the Meteorological Office is devoted to research into meteorology. As in most government scientific establishments the emphasis is inclined towards applied research rather than to the pure research which is often undertaken within the various science departments of the universities. But whether man is searching for truth for its own sake, and his own satisfaction, or whether he is looking for new facts to be used to develop new methods and techniques which will accrue to the economic benefit of the community, and of the world, it is essential and right that his findings should be made known to the world and to his colleagues. Not only is a source of information thereby provided for all who need it, but also a forum for open discussion and free criticism of his work.

There are a number of ways in which the results of meteorological research may be presented in printed form. There are, of course, the Learned Journals and the specialist periodicals. These normally demand conciseness and brevity. The number of articles submitted is too great to admit undue length, either in the text, diagrams or by the inclusion of long tables of original data. It is, however, often necessary for long reports and detailed investigations to be made known, and it is the duty and function of the employing authority to provide a means through which this aim can be achieved. The Meteorological Office has faced the problem and supplied an answer since the beginning of the present century.

During the first years of the century there was no formal publication series. Individual reports appeared from time to time. One of the earliest was the "London fog inquiry, 1901–02" (1903). Another was "Barometric gradient and wind force" (1908), and the well known "The life history of surface air currents: A study of the surface trajectories of moving air" (1906). The latter, now out of print, foresaw the Norwegian polar front ideas which were to burst upon the meteorological world more than a decade later.

It was not until 1912 that the first number of the *Geophysical Memoirs* series appeared. This series has continued up until the present time. 1962 marks the fiftieth anniversary of the publication of the first number, now out of print. This was "Effect of the Labrador Current upon the surface temperature of the North Atlantic; and of the latter upon air temperature and pressure over the British Isles". The Memoir was, in fact, the first of two parts on the subject, part 2 following in 1914. The most recent *Geophysical Memoir* to be published is No. 105, "Upper winds over the world, Part III", while No. 106 in the press is entitled "A meso-synoptic analysis of thunderstorms on 28 August 1958".

The *Geophysical Memoirs* series is intended to be a medium for substantial researches, particularly those involving the presentation of a considerable mass of data in tables and charts. In general they serve as basic material for further research and do not bring novel and speculative theories to the attention of the scientific world.

It was soon found that there was a need for a less ambitious publication for individual investigations of a briefer and less profound kind. Thus in 1918 the first issue of a new series, called *Professional Notes* appeared. These continued until in 1959 the final title, No. 126, "A synoptic study of anomalies of surface air temperature over the Atlantic half of the northern hemisphere" concluded a long succession of personal contributions to meteorological knowledge.

In 1948 a third series commenced. It was called *Meteorological Reports* and the numbers contained surveys of the state of knowledge of aviation meteorology in certain parts of the world and reviews of what was known in certain specialized fields, also mainly related to aviation. This series had a relatively short life terminating in 1959 with No. 22, "Aviation meteorology of the West Indies".

Finally, it was decided to combine *Professional Notes* and *Meteorological Reports* in a new series called *Scientific Papers,* to be used for the publication of scientific researches which are not appropriate to *Geophysical Memoirs* and of the results of studies and inquiries of a practical or applied nature. The first number "Airborne measurements of the latitudinal variation of frost-point, temperature and wind" was launched in mid-1960. It is intended that *Scientific Papers* will consist of separately published monographs and include subjects both on pure meteorological research and on the application of meteorology to transport and industry. It is printed on a larger size of page than the discontinued series in order to enable the diagrams, an important feature of most meteorological publications, to be larger and clearer.

In just under two years a total of 15 numbers have appeared. Another two are in the press. The subject range over the field of meteorology from such geographical studies as "The rainfall of Malta", No. 3, to "Pressure variation over Malaya and the resonance theory", No. 4, and "Forecasting in the Falkland Islands and Dependencies", No. 7; and from the contemporary problems of heat balance and energy exchange "Some calculations of terms in the energy balance at ocean weather stations I and J in the North Atlantic", No. 11, to the latest work in numerical prediction "An experiment in the verification of forecast charts" No. 9, and "Three-parameter numerical forecasts at Dunstable—a study of the error fields", No. 13. The most recent results in the subject of numerical weather prediction will appear shortly in *Scientific Paper* No. 16, "An experiment in operational numerical weather prediction". Another interesting paper is No. 12 "Some statistical relationships between the temperature anomalies in neighbouring months in Europe and western Siberia". This not only makes a useful contribution in itself to long-range forecasting but it shows the kind of way in which this problem can be and is being attacked, and the brightness of the guiding light that shines, though but dimly, from the results.

A feature of the series is that H.M. Stationery Office will accept from customers a standing order for numbers as they are published. The cost is reasonable enough, even at the rate of a little over one every two months, which seems to be the present rate of production. Such a subscription will indeed ensure that the reader is kept up to date with the ever advancing expansion of knowledge in meteorological science. Meteorologists, students of weather science and workers in allied and fringe subjects will not find it unrewarding.

A. H. GORDON

New Zealand Meteorological Service

Dr M. A. F. Barnett retired from the post of Director of the New Zealand Meteorological Service on 30 June 1962. He has been succeeded by Dr. R. G. Simmers.

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 14—*Variation of the difference between two earth temperatures*, by P. B. Sarson, M.A.

In the study and analysis of earth temperatures it is often necessary to compare data from one station with those from another or with data from the same station at a different depth. Despite the natural smoothing of the data by the slow diffusion of heat from above or below, earth temperatures often show greater differences between neighbouring stations than between stations a hundred miles or more apart. These differences arise from variations in diffusivity: the diffusivity depends not only on soil type but also on drainage. Nevertheless, by forming simple systematic differences it is possible to compare data from such neighbouring stations in some detail, and even to make estimates of missing data or extend the period of means generally within ± 1.0°F accuracy. The method depends on the natural smoothing by heat diffusion, such errors as do arise being solely attributable to the variation with time of the coefficient of thermal diffusivity caused by large variations in sunshine or rainfall.

This paper gives a theoretical explanation of the types of variation over long periods of the differences observed between earth temperatures at the same or neighbouring stations. Illustrations are provided of the conclusions that can be derived from the study of these variations.

METEOROLOGICAL OFFICE NEWS

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

Mr. D. H. Clarke, Senior Experimental Officer, who retired on 3 June 1962 after over 35 years' service. After seven years in the Royal Air Force as a W/T operator, during which time he worked for the Meteorological Office at Cranwell and overseas, he joined the Office as a Temporary Clerk III at Aldergrove in 1926. In 1932 he was transferred to Croydon, was promoted to Assistant II in 1938 and to Assistant I in 1942. He will be remembered as the Head of the W.A.A.F. training school in 1942–43 and as an instructor at the Meteorological Office Training School in 1943–44. He will, however, probably be best remembered in his administrative capacity at Dunstable where he served from 1948 until he retired and was involved in the arrangements for the move to Bracknell last year.