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THE SNOW OF JANUARY AND FEBRUARY 1955

By R. E. BOOTH

The first two months of 1955 were notable for widespread and heavy snowstorms, the worst in the British Isles since 1947, which in many areas completely dislocated normal activities. The cold weather during January lasted about three weeks, but was separated into two clearly defined spells by a brief mild period about the 10th of the month. Easterly winds prevailed during the first spell and the snowfall during this period was mainly in the southern part of the country, but during the second spell winds were predominantly from a northerly direction and the northern part of the country was the more seriously affected by snow. The end of January and the first few days of February were comparatively mild, but during the second week of February polar air swept south over the country. This was a prelude to a prolonged spell of cold weather and severe snowstorms which lasted almost to the end of the month. These storms were worst in the northern part of the country at first, but during the last week of the month when the wind veered to an easterly point, the heaviest snowfalls were further south.

The closing months of 1954 were unusually mild so that the arrival on New Year's Day of cold weather associated with an easterly air stream which swept over the country from southern Russia was all the more striking. There were a few light snow showers, mainly in eastern coastal regions, for the first day or two, but on the 4th an occlusion associated with a depression in the western approaches moved slowly north-eastwards across our southern districts. Slight snow was reported at Plymouth and St. Eval at midnight; by 0600 snow had reached a line extending from Bristol to Portsmouth with moderate falls in places, and by 1800 it was snowing hard at Birmingham and Mildenhall but had ceased in London. Strong easterly winds, reaching gale force at times, caused considerable drifting especially in Devon and Cornwall where roads were reported to be blocked with drifts from 6 to 12 ft. deep, but in the extreme south of Cornwall the snow turned to rain in the late evening; the rain was heavy locally with occasional thunder. A map of the depth of undrifted snow, compiled from observations taken at 0900 on the 5th, shows that the area with more than 1 in. of snow lying was confined almost entirely to England and Wales south of a line from Mersey across the Peak to the Wash. Most stations recorded 2–4 in. and the largest area with as much as 6 in. was in east Kent. West London also had a fall of 6 in. which was the largest fall since 1947. Although there were further falls of snow during the day, a thaw soon followed and there was little snow remaining on the ground by the 8th.

An influx of polar air with northerly winds on the 10th, brought a sharp fall of temperature and renewed snow showers to Scotland and the north of England, but in the south the change was preceded by widespread rain, which later turned to snow. A vigorous depression, accompanied by gale-force winds, approached our south-western districts from the west during the 13th. Snow began in Cornwall during the morning and by 1800 was falling steadily over most of the southern half of England and Wales, and thereafter continued throughout the night. In the north, and particularly in Scotland, there were frequent and heavy snowstorms; two passenger trains on their way to Wick were snowbound, and in Caithness and Sutherland nearly every road was blocked by drifts several feet deep. The following morning 12 in. of level snow were reported from north Scotland, while snow lay to a depth of 4–8 in. over a wide area in the southern counties and 9–12 in. locally in Somerset and south Wales; nearly all parts of the country had some snow cover.

Another depression crossed southern England during the 16th with widespread snow on its northern side, and there were frequent snowstorms in Scotland in the strong northerly winds after its passage. At Rotherham, Yorkshire, rain turned to snow shortly after midnight and continued with only a break of half an hour for 17½ hr., while at Southport on the same day 3½ in. of snow fell in less than an hour. Caithness and Sutherland were the worst affected counties in Scotland, where there had been appreciable snowfalls almost daily since the invasion of the polar air on the 10th. In Sutherland the accumulated depth of undrifted snow increased from 10 to 24 in. at Elphin from the 16th to 18th, while at Glenrossal, the depth increased by 12 in. (to 18 in.) during the same period. Owing to the strong northerly winds nearly every road in the north of Scotland was blocked by drifts many feet deep; some drifts as much as 30 ft. deep were reported. The island of Orkney was paralysed on the 13th by the worst snowstorm for many years, described by some as the "worst in living memory"; every road on the island was blocked by drifts up to 7 ft. deep. Shetland too was in a similar plight; here the drifting was so bad that snow ploughs often proved useless.

A map of snow depths at 0900 on the 17th shows that level snow was lying to a depth of more than 12 in. over practically the whole of Caithness and Sutherland, and to a depth of more than 6 in. in Inverness-shire and northwards, in Northumberland, Durham, the North and West Ridings of Yorkshire, south Lancashire and north Wales.

Conditions in the north of Scotland became so bad that "Operation Snowdrop" was arranged for the relief of snowbound areas. The Admiralty sent five helicopters and a frigate to Wick, where the Royal Air Force had previously set up a centre from which they could call on a special fleet of aircraft based at Kinloss to undertake emergency flights as the occasion arose. In addition, the aircraft carrier *Glory* was anchored in Erriboll Bay, north Sutherland, to refuel the helicopters before they carried out their missions. The operation, the first of its kind, was begun on January 18, and was mainly concerned with dropping food and medical supplies to marooned farmers and villagers, and hay to cattle. The helicopters often landed on the snow at points where distress signals were displayed, so that in many cases personal contact could be made. Doctors were occasionally taken to medical cases, and some patients were flown out of the affected area to hospital. The Kinloss fixed-wing aircraft were used for dropping cattle fodder. In the upper photograph facing p. 137, which shows helicopters being loaded up with food at Wick during the operation, it will be seen that the engines were kept running for a quick turn-round. The area to which relief was afforded included parts of Ross and Cromarty and Inverness-shire as well as Caithness and Sutherland. So much public interest was aroused by the operation that 153 press reporters visited Wick on the first day.

Mild air from the south-west brought a thaw to most of the country on the 21st, but "Snowdrop" was continued till the 23rd. Most of the ground was clear of snow by the 25th.

Maximum depths of undrifted snow reported during the month included 14 in. at Elphin on the 19th and 20 in. at Glenrossal on the 18th (both in Sutherland); 14 in. at Glackour on the 18th–19th (Ross and Cromarty), 18 in. at Fersit on the 18th and 15 in. at Achnagoichan on the 18th–21st (both in Inverness-shire).

The wintry conditions returned on February 8 and 9 as polar air spread south over the whole country heralding the longest and most severe spell of the season. Temperature fell sharply 5–10°F. and the showers in the northerly air stream turned to snow. Thereafter, winds reaching gale force at times continued to blow from a northerly or north-easterly direction for about 12 days, and the accompanying snowstorms over north and east Scotland and eastern England became more and more frequent and prolonged as the cold weather continued. Minor troughs moved southwards in the air stream, locally increasing the snowfall; a more pronounced trough on the 16th gave a fall of 2 in. at Buxton (making a total depth there of 6 in.) and frequent snow showers in the London area during the afternoon. The following day a polar-air depression, embedded in the stream, moved south accompanied by heavy snowfalls and northerly gales in most northern districts; later in the day the Midlands and East Anglia were also affected.

The experience of Mr. Hay, meteorological assistant at Grimsetter, Orkney, is of interest as it shows the kind of conditions experienced fairly widely in the extreme north of Scotland during this period. During the early hours of the 17th, the northerly gale then blowing became severe and the frequent showers became continuous snow. Power lines at Grimsetter failed, as they did over most of the island, under the weight of snow and wind. Transport to the airfield had become impossible owing to snow drifts quite early, and the relief observer, who attempted to make the journey by foot during the morning had to turn back. Mr. Hay, who had been doing hourly observations all the previous night, had planned to walk to the nearest farmhouse for a meal, but bad weather and the deep snow prevented him from doing so. He began his second night duty by the light of a single paraffin lamp, having had no sleep the night before and with no food. His only link with the outside world was the G.P.O. line which fortunately held, so he was able to send observations till he was relieved at 1100 the following day, after a continuous watch of 40 hr. Unfortunately Mr. Hay had a similar experience at the end of the month when a southerly gale and severe drifting of the snow prevented relief from reaching him at the office for 36 hr. A photograph showing ice and snow on telegraph wires near the meteorological office at Grimsetter is reproduced facing p. 137.

During the 18th and 19th, as the strong northerly winds in Scotland moderated, a complex shallow depression formed over the country with a small centre off north-east Scotland and another over Norfolk. There were heavy

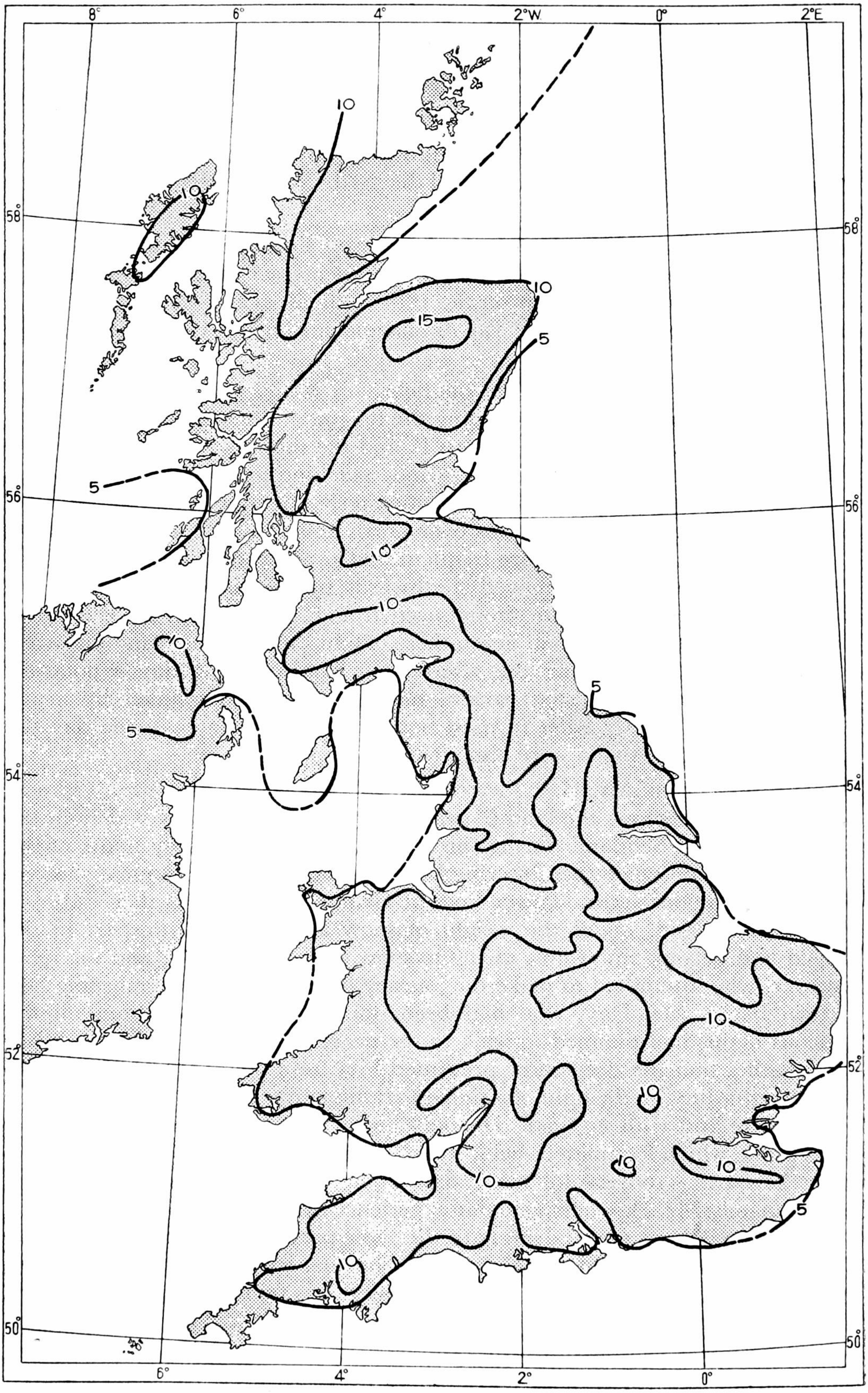


FIG. I—NUMBER OF DAYS OF SNOW FALLING, JANUARY 1955

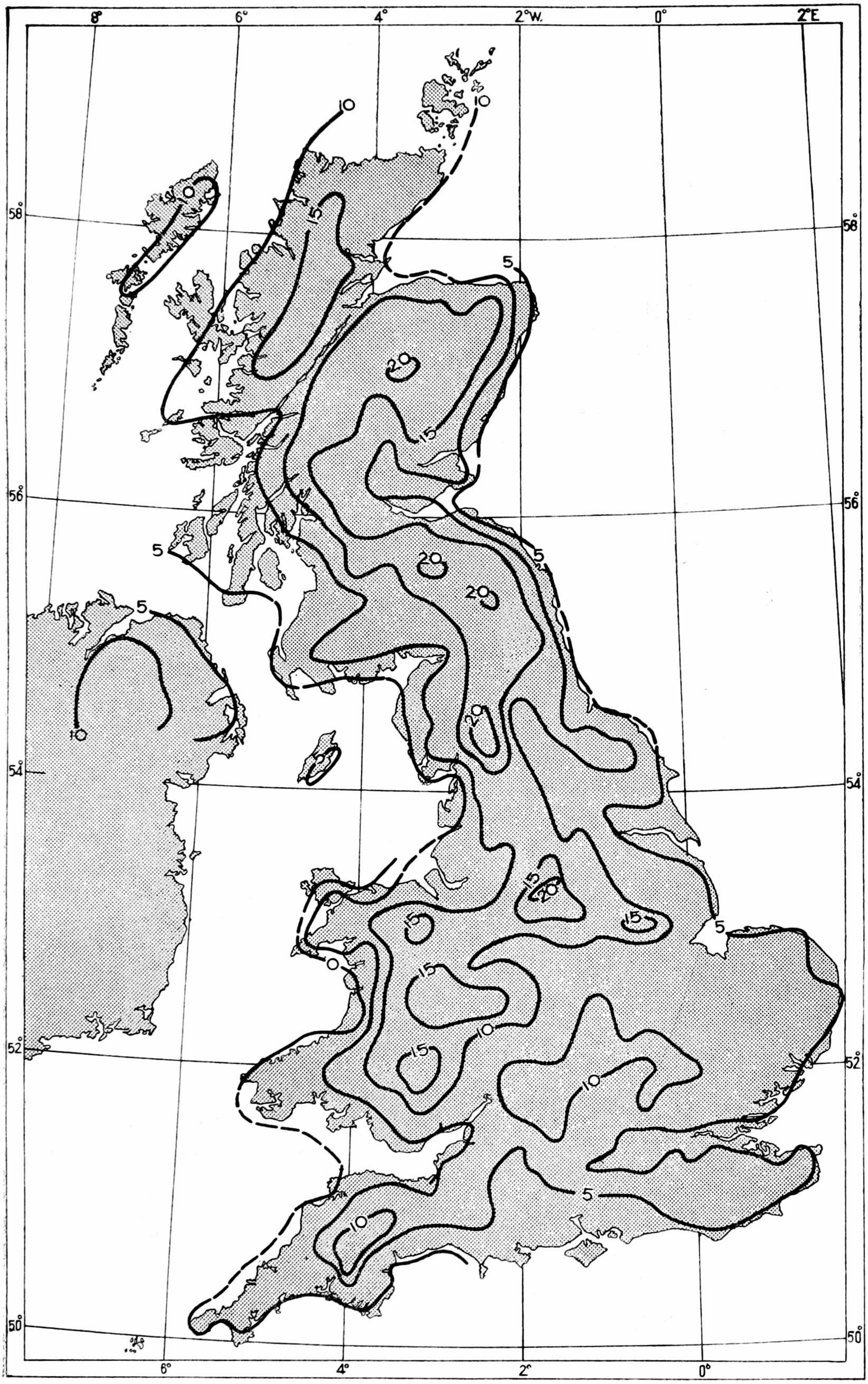


FIG. 2—NUMBER OF DAYS OF SNOW LYING, JANUARY 1955

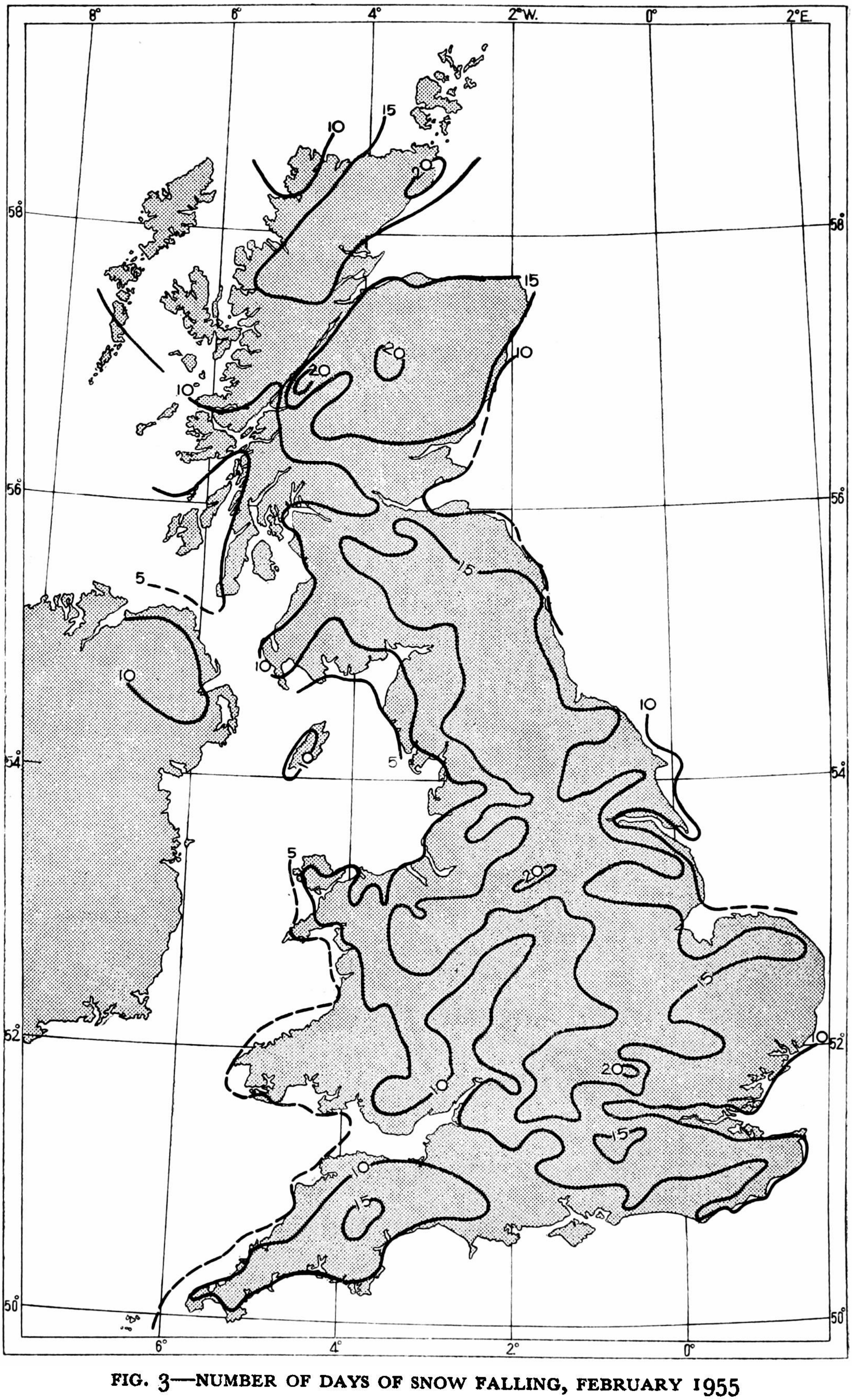


FIG. 3—NUMBER OF DAYS OF SNOW FALLING, FEBRUARY 1955

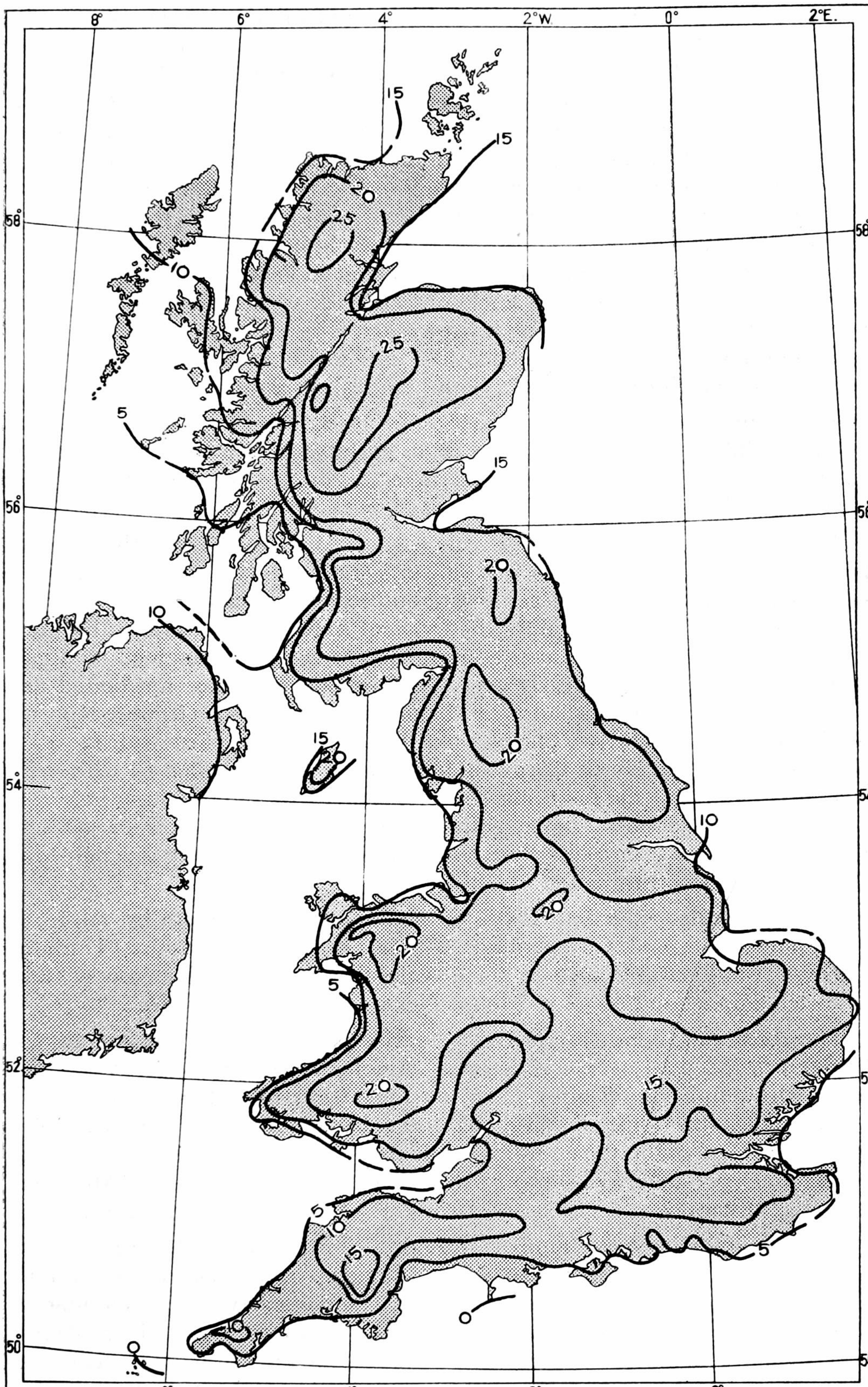


FIG. 4—NUMBER OF DAYS OF SNOW LYING, FEBRUARY 1955

snowstorms over Scotland (described locally as "the most severe of the century"), off the Lancashire coast and in Norfolk; drifts of 5 ft. were reported from Blackpool while Wells-on-Sea was temporarily isolated by drifts. Conditions were so bad in Scotland that the Royal Air Force recommenced "Operation Snowdrop", on similar lines to that flown in January, for the relief of snowbound communities. The operation continued for 11 days until the end of the month, and during this period aircraft from Kinloss flew 182 sorties, dropping 267 lb. of food and 105 tons of cattle fodder; Royal Naval helicopters from Wick flew 25 medical sorties and dropped 6½ tons of food and hay; 163 sheep were rescued from drifts by helicopter. The photographs taken on February 18, facing p. 152, show the meteorological office enclosure at Wick with a snowplough on the perimeter track, and an amusing picture taken a little further to the left which gives a graphic indication of the depth of the snow near the anemometer mast (the guys of which can be seen in both pictures) on the same day.

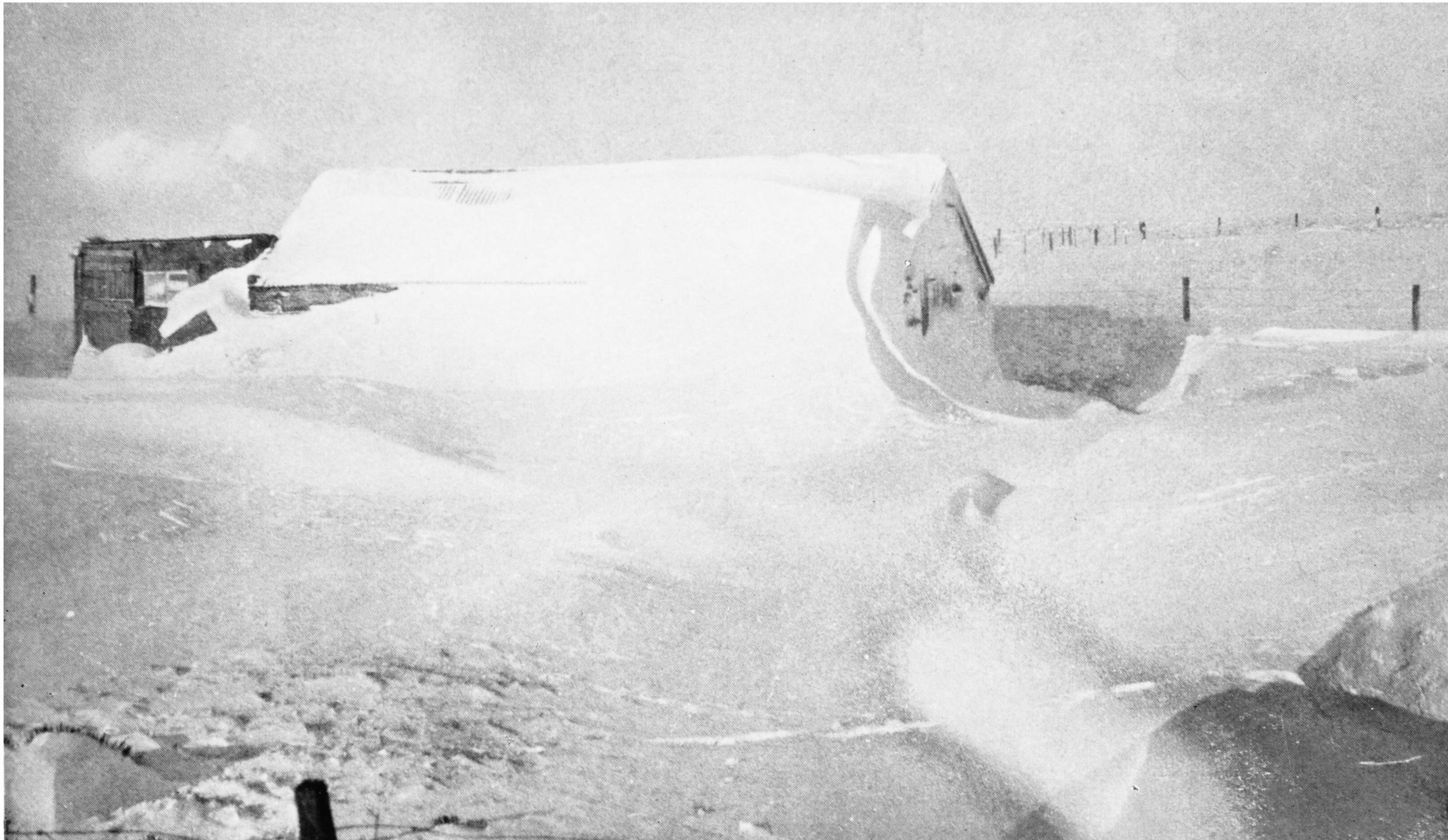
The accumulated depth of undrifted snow measured at 0900 on the 20th was 26 in. at Elphin, 18 in. at Glenrossal (both in Sutherland), 24 in. at Glenmore, 22 in. at Braemar (both in Inverness-shire), 24 in. at Glenlivet and 18 in. at Drummuir (both in Banffshire).

Throughout the last week of February winds were mainly easterly with low pressure over the Bay of Biscay and slow-moving fronts lying along the English Channel. Southern England had severe outbreaks of snow during this period, and on the 23rd the west country had violent snowstorms probably the worst since 1947. Snow fell continuously from 0400 to 2000 accompanied by a gale with gusts up to 60 kt. Nearly every road in Cornwall was snowbound and hundreds of motor vehicles had to be abandoned; drifts up to 5 ft. were reported on Bodmin Moor. The two photographs facing p. 153 are of snow drifts at the Filter Works of the North Cornwall Joint Water Board at 890 ft. with drifts 6–7 ft. Throughout the following day snow fell almost continously in Wales, the Midlands and East Anglia, with prolonged periods of snow in southern England. Reports from Derbyshire told of serious drifting during the night with drifts of 10 ft. near Ashbourne.

From the 20th to the 24th undrifted snow increased in depth by 7–9 in. in Northumberland and Cumberland, 6–8 in. in Nottinghamshire, Durham, Derbyshire and north Wales. In north Wales there were local increases of 18 in. at Bwlch Tunnel and 16 in. at Mount Pleasant (both in Flintshire).

The maximum depth attained by undrifted snow during the month was between 2 and 3 ft. over a wide area. Among the greatest depths reported were: Drummuir (Banffshire) 36 in. on the 21st; Bwlch Tunnel (Flintshire) 30 in. on the 25th–28th; Glenlivet (Banffshire) 28 in. on the 22nd–23rd; Elphin (Sutherland) 26 in. on the 20th–27th; Glenmore (Inverness-shire) 26 in. on the 22nd; Braemar (Inverness-shire) 24 in. on the 22nd; Derry Lodge (Aberdeenshire) 21 in. on the 24th; Buxton (Derbyshire) 20 in. on the 25th–28th.

Figs. 1 and 2 show the number of days of snow falling and the number of days of snow lying respectively during January, with isopleths drawn for multiples of five days. Snow fell on at least one day everywhere including the Scilly Islands, and on more than 10 days of the month over a considerable part of the country; and lay on the ground more than 20 days in parts of the Grampians, the Pennines and the Peak District (see Fig. 2). Fig. 3 shows that snow fell for 20 days or more during February in the Grampians, the Peak District

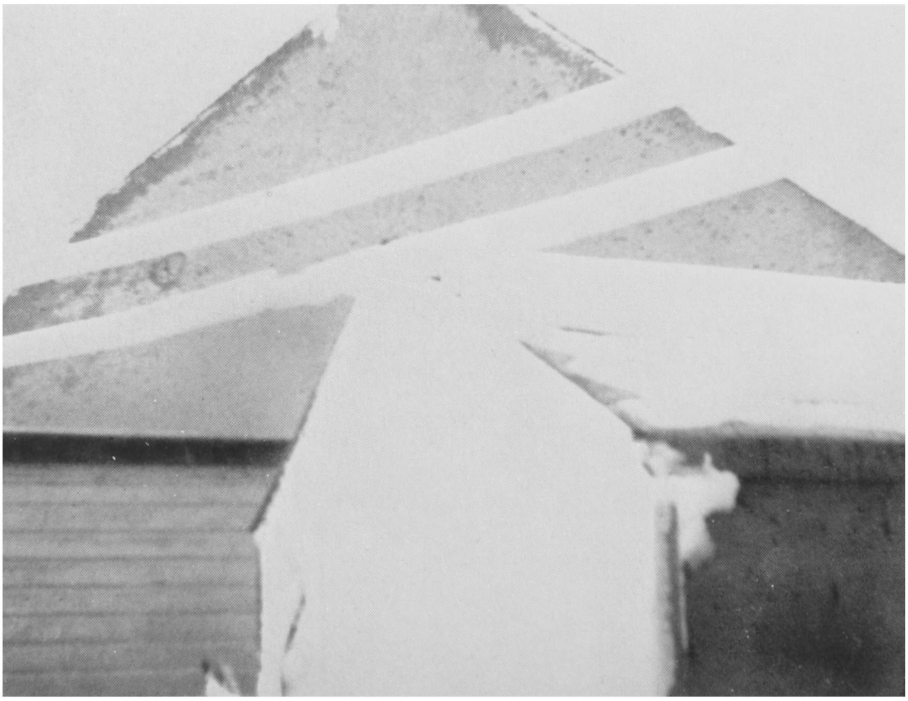


Reproduced by courtesy of J. McDonald, Wick

SNOW DRIFT COVERING A CROFT, MID CLYTH, CAITHNESS

Reproduced by courtesy of W. C. Glander

HELICOPTERS BEING LOADED AT WICK WITH FOOD FOR "OPERATION SNOWDROP"



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ICE FORMATION ON TELEPHONE WIRES NEAR THE METEOROLOGICAL OFFICE AT GRIMSETTER, NEAR KIRKWALL, AFTER THE SNOW OF FEBRUARY 17, 1955 and on the Dunstable Downs. The number of days of snow lying during February (Fig. 4) exceeded 25 on much of the higher ground in the north of Scotland, but a few stations such as Scilly and Portland Bill reported no days of snow lying.

The four maps reproduced and those mentioned earlier in the text are each based on several hundred observations.

COMPARISON OF WIND SPEEDS MEASURED SIMULTANEOUSLY BY A DINES ANEMOGRAPH AND A ROBINSON CUP ANEMOMETER IN FLUCTUATING WINDS

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In many papers attention has been paid to the lag of anemometers and to the errors that are caused by the fluctuation of winds in evaluating mean wind speeds from anemograms. The computations of Schrenk[1] on the lag errors of cup anemometers are well known. The over-estimation of the mean wind speed as indicated by cup anemometers in fluctuating winds may be considered as an established fact. The effect of wind fluctuation on the measurements of mean wind speed by anemometers of the pressure type was investigated by Noetzlin[2] and recently by Sanuki[3]. Again, over-estimation of mean wind speed measured by pressure-tube anemometers resulting from wind fluctuation must be accepted.

The question arises: how great is the over-estimation of mean wind speed under natural circumstances? The correct answer to this question cannot be given as it is impossible to obtain an exact value of mean wind speed. We must therefore confine ourselves to an investigation into the differences between the measurements of the two types of anemometers. As far as we know data demonstrating such differences have not yet been published.

Comparison of both anemometers at De Bilt.—We have made a comparison between the data from a Dines anemograph (Mk II) and a Robinson cup anemometer (conical cups of 10 cm. diameter, distance from middle of cup to axis 10 cm.) constructed by the Royal Netherlands Meteorological Institute. The anemometers are mounted about 40 m. above level country on the tower of the Royal Netherlands Meteorological Institute at De Bilt. The station is situated near the Utrecht–Amersfoort road and is surrounded by meadows and orchards; on the west side there are a few acres of wood (trees of 20-25 m.).

The comparison was carried out as follows:—

From the anemograms of the Dines anemograph estimates were made of the mean wind speed U_D together with the mean amplitude a for each clock hour. The determination of the wind fluctuations by means of eye reading of the mean amplitude is rather rough and has the disadvantage of being subjective, but no objective method was available. From the obtained amplitudes the "relative" fluctuation $b(=a/U_D)$ was computed, and in this way an expression almost independent of the mean wind speed was obtained*.

Each clock hour furnishes three data: U_D the mean wind speed from the Dines anemograph, b the mean "relative" fluctuations from the Dines anemograph,

* Relative fluctuation replaces the usual[4] mean fluctuation factor $(U_{max} - U_{min})/U$.

and c the number of contacts made by the Robinson cup anemometer. The material to be discussed consists of 1,274 hourly values obtained during the period February 23–May 1, 1953. Only observations from periods in which both instruments were exposed freely to the wind were used.

Regression lines were computed of the form $U_D = \alpha\, b + \beta$ indicating the relation between U_D and b for groups of c with mid-point values 3, 8, 13 . . . 58 and 68 contacts (representing the groups with 0–5, 6–10, 11–15, etc. contacts), and corresponding to wind-tunnel calibrations of 1·4, 2·3, 3·2, 4·2, 5·1, 6·1 . . . 12·2 and 14·3 m./sec.

The results are presented in Fig. 1. From this figure it is clear that there is a regular increase in the value of α with increasing c. It is obvious that there are not only differences in the measurements made by the Dines and Robinson anemographs, but that these differences change in a systematic manner. For mean wind speeds over 5 m./sec. U_D increases when b decreases; the opposite seems to hold for wind speeds under 5 m./sec. With higher wind speeds the over-estimation of the pressure-tube anemograph is greater than that of the Robinson cup anemometer; for lower wind speeds the fluctuations seem to have a greater influence on the cup anemometer. The latter effect is rather small however, and the question arises whether it is significant.

It is therefore clear that there is a fluctuation effect. It is possible, however, that this effect is partly caused by errors in the estimation by eye of the mean wind speed from the anemograms. The recording of wind structure on the diagram is rather compact. It may be that a great many low maxima are difficult to distinguish, so that the difference between lower and higher maxima is greater than that between lower and higher minima. If this is so the estimation by eye of the mean wind speed can easily be too high. The following experiment was performed in order to investigate this possibility.

During four different hours half-minute momentary readings were made of the height of the pen of the Dines anemograph. The mean of these readings was taken as the "true" mean of the Dines anemogram. Independently, estimations by eye of the mean wind speed for the same periods were made by six assistants of the Royal Netherlands Meteorological Institute. The results are given in Table I.

TABLE I—ESTIMATES OF THE MEAN WIND SPEED

Date	Mean wind speed U	Estimates by assistant A	B	C	D	E	F	Fluctuation b
1954		*metres per second*						
January 15 ...	9·8	9·8	9·9	9·9	10·4	9·9	10·2	1·2
January 21 ...	3·3	3·2	3·2	3·2	3·2	3·2	3·4	0·6
January 25 ...	7·3	7·6	7·5	7·3	7·4	7·5	7·6	0·6
February 8 ...	4·7	4·6	4·5	4·7	4·5	4·7	4·9	0·2

There is indeed some indication of a subjective error. Of course it is not possible to conclude from this small amount of material how great the subjective error really is; much more material would be needed.

Conclusion.—The wind speed obtained from anemograms of the Dines anemograph is highly influenced by the relative fluctuation. Especially for wind speeds above 5 m./sec. and fluctuations $b > 0·5$, over-estimation of the mean wind speed is considerable and amounts to as much as 10 per cent. as

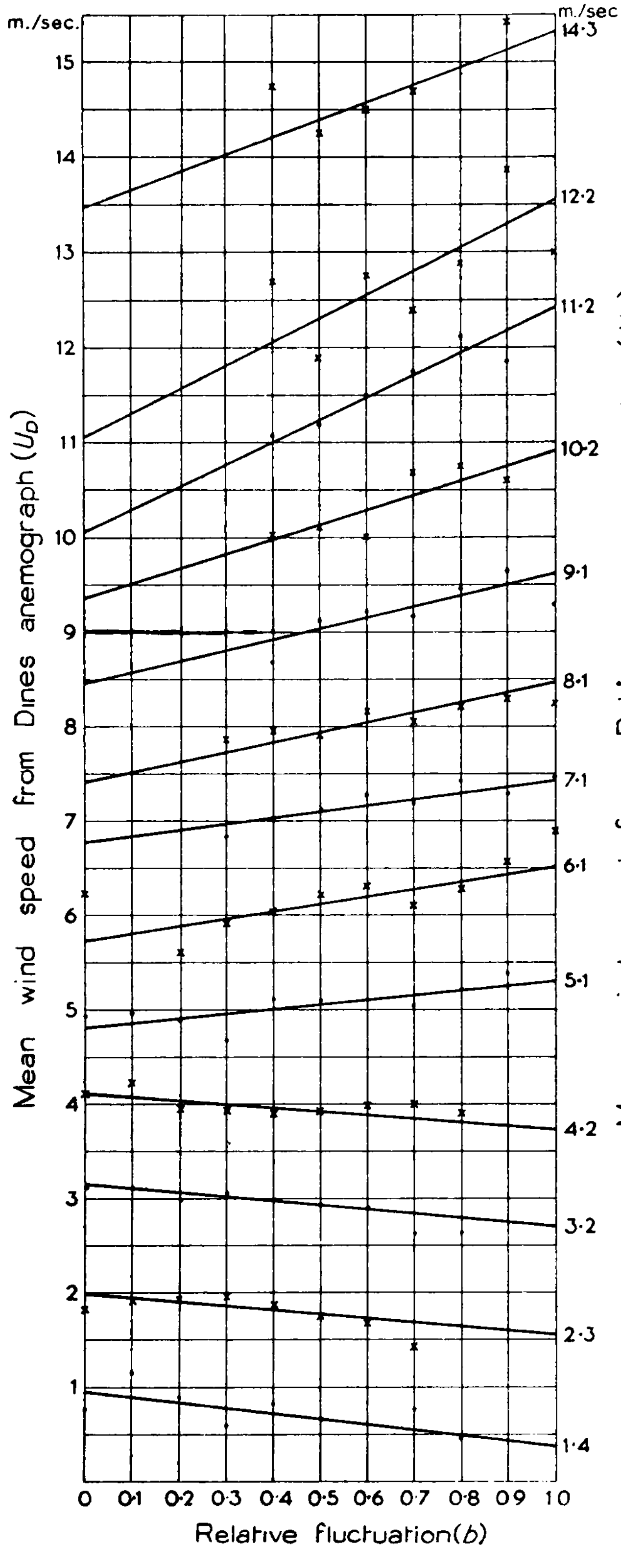

FIG. 1—REGRESSION LINES COMPUTED FOR EACH GROUP OF MEAN WIND SPEEDS, THE MID-POINT SPEED OF EACH GROUP AS MEASURED BY THE ROBINSON CUP ANEMOMETER BEING GIVEN ON THE RIGHT-HAND SIDE

compared with those indicated by a Robinson anemometer. This over-estimation is partly caused by the lag of the instrument and partly by subjective errors made when evaluating the anemograms.

Pressure-tube anemographs and Robinson cup anemometers are therefore not equivalent instruments.

The result of our comparison is another indication that the organization of a uniform network of anemometer stations is very necessary. Pressure-tube anemographs should not be used for this purpose[4].

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AVERAGE VECTOR WIND DISTRIBUTION OF THE UPPER AIR IN TEMPERATE AND TROPICAL LATITUDES

By A. F. JENKINSON, B.A.

Summary.—Charts have been drawn showing, for the months of January, April, July and October and for the area between the latitudes of 60°N. and 50°S., the stream-lines and isotachs of the average vector wind flow at the levels of 500, 300, 200 and 100 mb. They are based on the "surface" geostrophic vector wind with the addition of thermal vector winds in a succession of layers constructed from upper air temperature charts recently prepared in the Meteorological Office. A grid of 234 points was used, supplemented and checked by upper air wind data.

Data.—The basic data used were the preliminary charts, prepared in the Upper Air Climatology Branch of the Meteorological Office, of upper air temperatures over the world at the levels of 700, 500, 300, 200, 150 and 100 mb. for the months of January, April, July and October, with isotherms drawn at intervals of 2°C.

Theory.—The thermal wind between two pressure levels, that is the vector difference between the geostrophic winds at the upper and lower levels, is in the direction of the isotherms of the mean temperature (T plotted against log p) between the two levels and, for a given pair of pressure levels, proportional to the rate of increase of mean temperature at right angles to the isotherms.

In vectorial terms, the vector thermal wind $\mathbf{V}(p_1, p_2)$ between pressure levels p_1 and p_2 is given by

$$\mathbf{V}(p_1, p_2) = k(1, 2)\, \mathbf{n} \times \text{grad}\, T(1, 2) \qquad \ldots\ldots (1)$$

where T is the absolute temperature at pressure p, grad $T(1, 2)$ is the vector gradient of $T(1, 2)$ measured positively towards higher temperature, $\mathbf{n}$ is the unit vertical vector, $\times$ denotes vector multiplication,

$$T(1, 2) = \int_{p_1}^{p_2} \frac{T\,dp}{p},$$

and the constant

$$k(1, 2) = \frac{R}{gl} \log_e \left(\frac{p_1}{p_2}\right),$$

where l is the Coriolis constant for the latitude and R and g have their usual meanings.

If the average monthly temperature at various pressure levels p is plotted against $\log p$ the curve is essentially two straight lines, one for the troposphere and one for the stratosphere, with a discontinuity of lapse rate at the tropopause.

The layers chosen for the computation of thermal vector winds were 1000–500, 500–300, 300–200, 200–150, 150–100 mb. Apart from the layer including the tropopause the average curve of T plotted against $\log p$ differs most from a straight line in the layer 1000–500 mb.; but even in this layer the mean temperature $T(1000, 500)$ is very nearly $T(707)$, the temperature at 707 mb. ($\log 707 = \frac{1}{2}[\log 1000 + \log 500]$). At neighbouring places the way in which the average-temperature curve differs from a straight line is nearly identical, and the rate of change from place to place of the difference between $T(1000, 500)$ and $T(707)$ is of a much smaller order than the rate of change of $T(707)$, which is very nearly the rate of change of $T(700)$.

Hence, very approximately,

$$\mathbf{V}(1000, 500) = k(1000, 500)\, \mathbf{n} \times \text{grad } T(700) \qquad \ldots\ldots (2)$$

That is, the thermal wind of the layer 1000–500 mb. is in the direction of the 700-mb. isotherms with magnitude proportional to the gradient of temperature between the isotherms.

For the other layers above 500 mb. not including the tropopause, the mean temperature between any two levels is nearly half the sum of the temperatures at the two levels; and the gradient of the field of mean temperature is very approximately equal to half the vector sum of the gradients of the temperature fields of the two levels.

For the layer including the tropopause, the curve of T plotted against $\log p$ is two straight lines. Curves for neighbouring places are similar and the rate of change from place to place of the difference between $T(1,2)$ and $\frac{1}{2}[T(p_1) + T(p_2)]$ is very much less than the rate of change of $\frac{1}{2}[T(p_1) + T(p_2)]$. Hence, also for the layer including the tropopause, the gradient of the field of mean temperature is very approximately equal to half the vector sum of the gradients of the temperature fields of the two levels.

Thus the thermal wind of the layer 500–300 mb. is equal to half the sum of two vectors which are respectively directed along the isotherms of the 500-mb. and 300-mb. temperature fields and with magnitudes proportional to the gradients of temperature at those levels; and similarly for other layers.

In the notation of equation (2),

$$\left.\begin{array}{l}\mathbf{V}(500, 300) = \frac{1}{2}\, k(500, 300)\{\mathbf{n} \times \text{grad } T(500) + \mathbf{n} \times \text{grad } T(300)\} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \mathbf{V}(150, 100) = \frac{1}{2}\, k(150, 100)\{\mathbf{n} \times \text{grad } T(150) + \mathbf{n} \times \text{grad } T(100)\}\end{array}\right\} \ldots (3)$$

Method.—A fixed grid of 234 points was chosen being at the intersection of longitudes 160°W., 140°W., 120°W., ... 180°E. with latitudes 50°S., 40°S., 35°S., 30°S., 25°S., 20°S., 20°N., 25°N., 30°N., 35°N., 40°N., 50°N., 60°N.

For each of the months January, April, July and October, at each grid point, measurements were made of the vector quantities, for the levels of 700, 500,

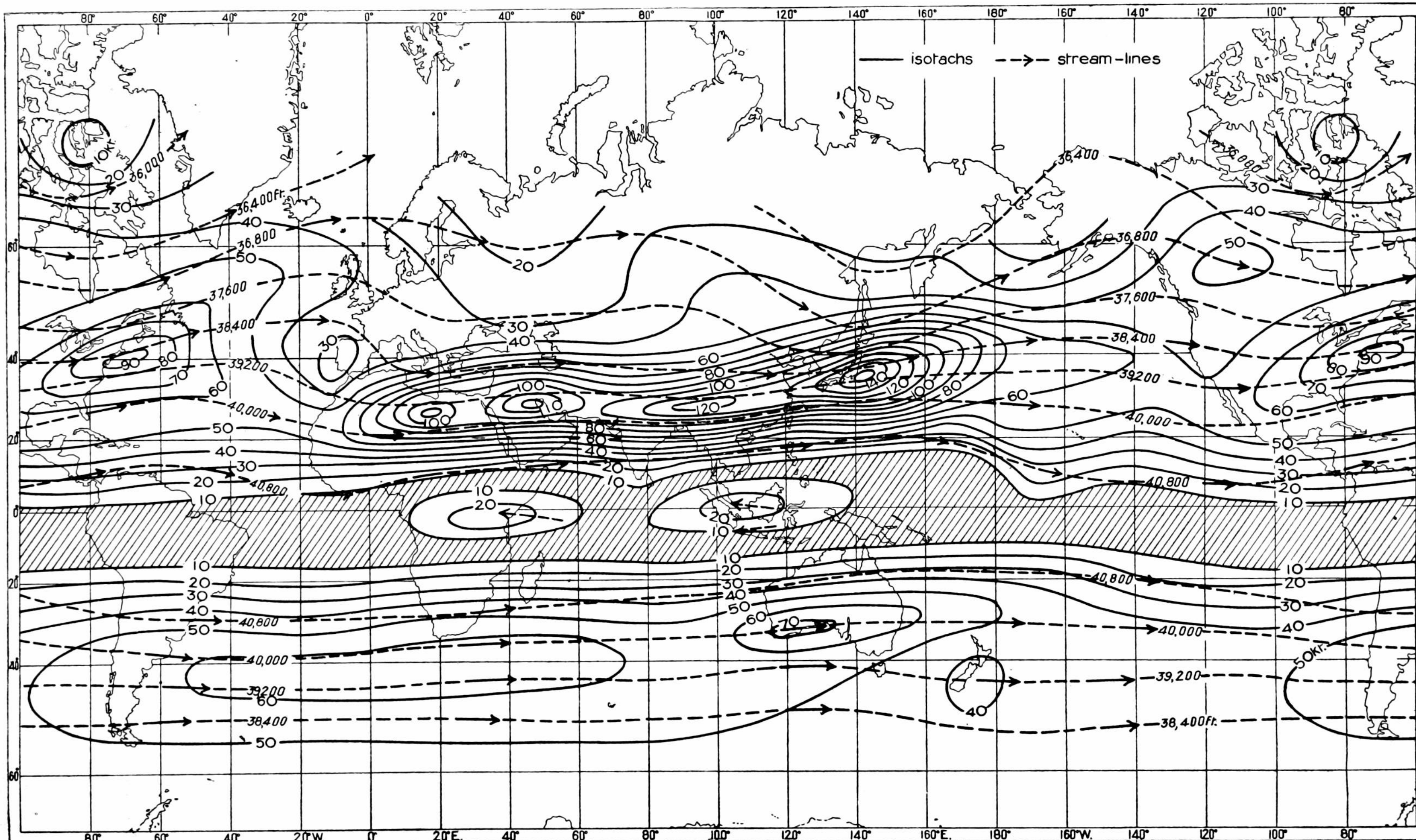

FIG. 1—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION AT 200 MB. IN JANUARY

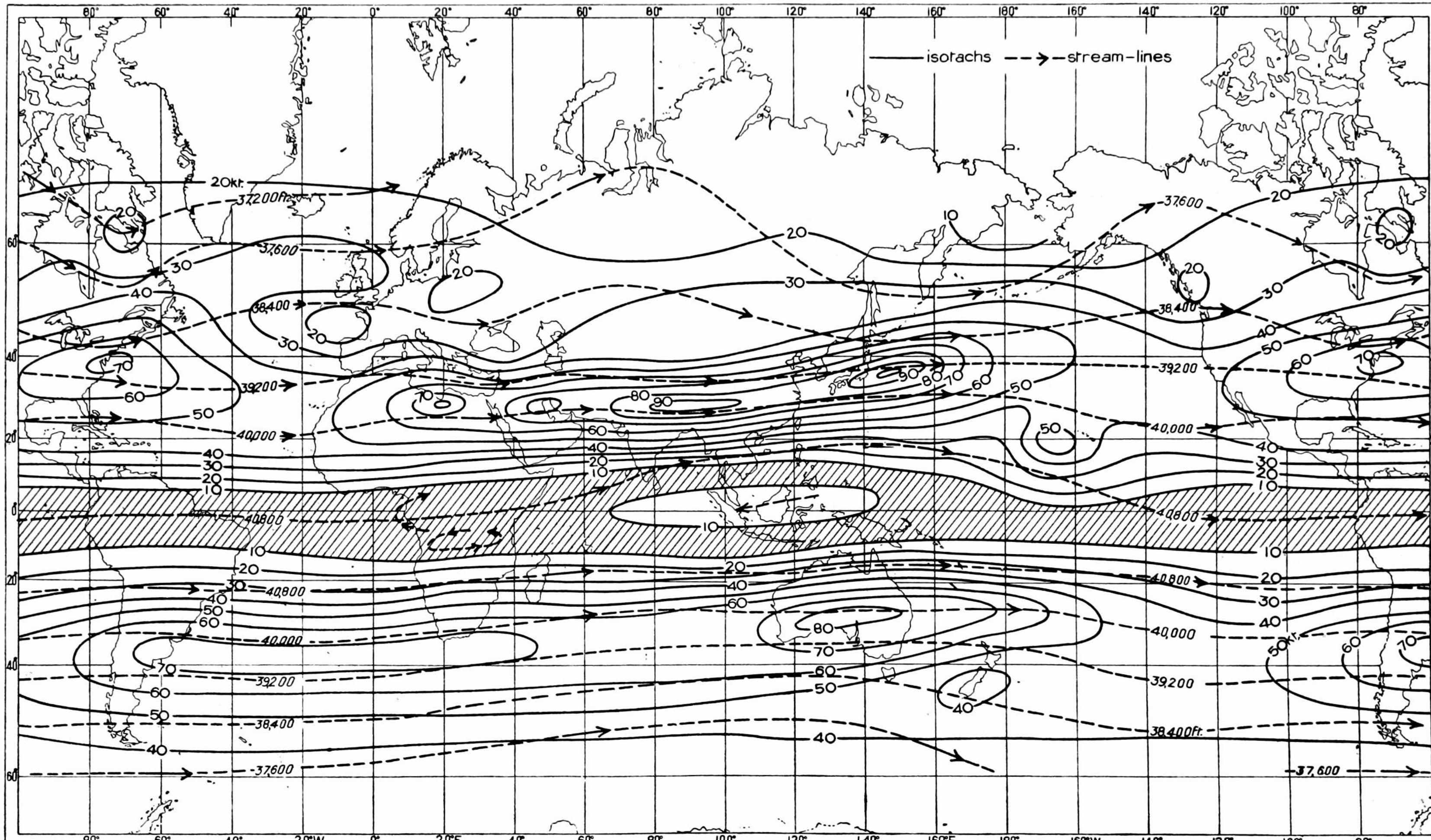

FIG. 2—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION AT 200 MB. IN APRIL

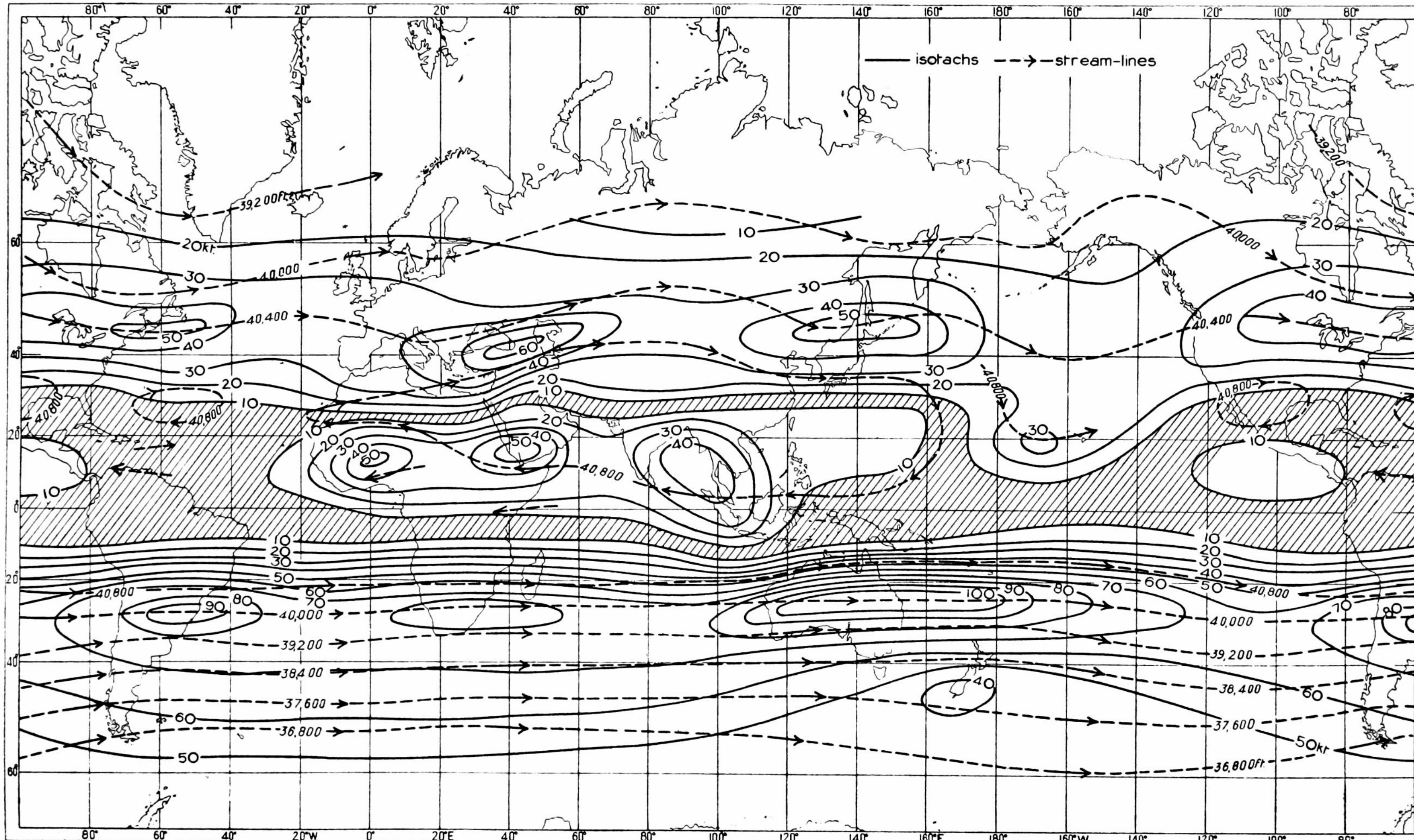

FIG. 3—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION AT 200 MB. IN JULY

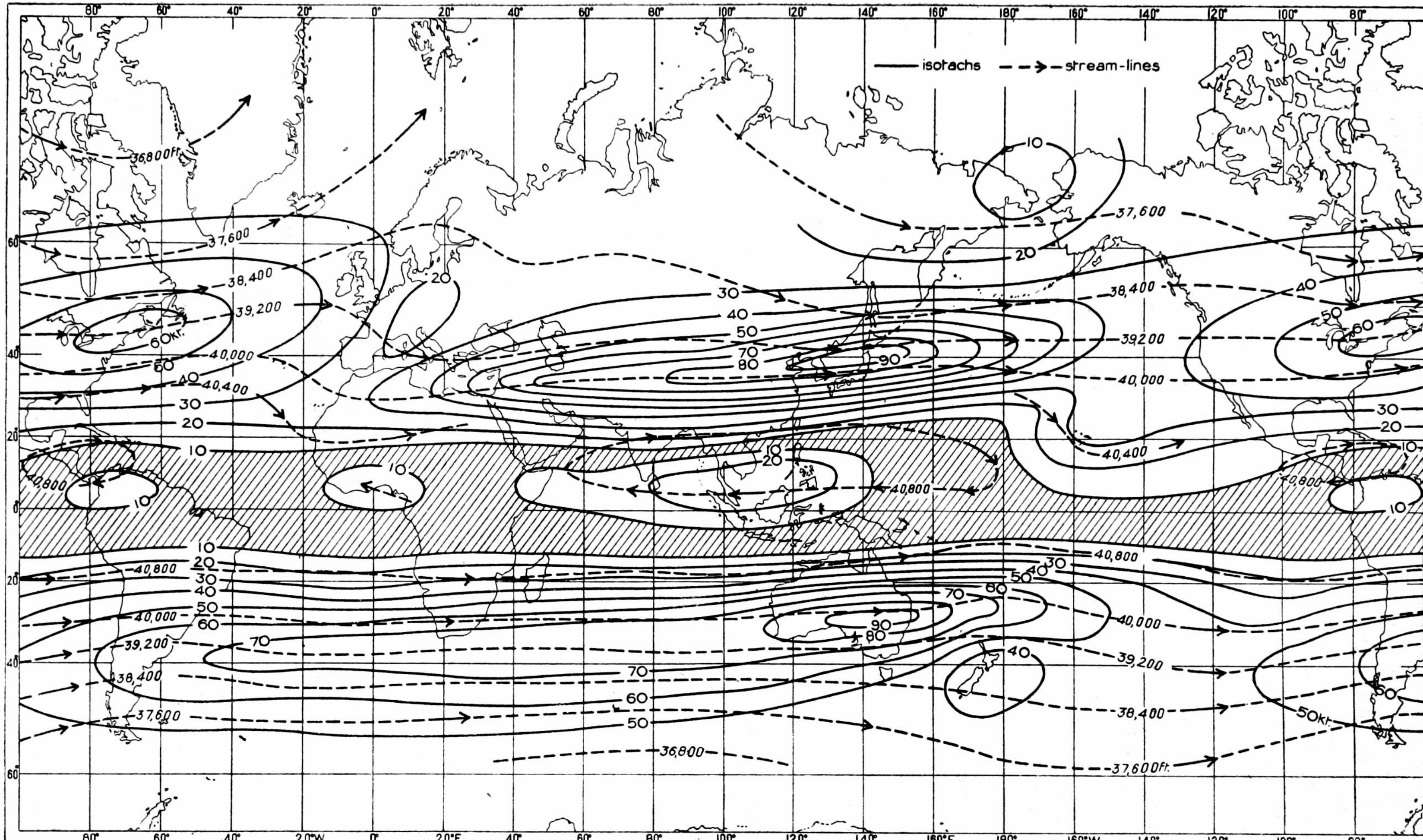

FIG. 4—STREAM-LINES AND ISOTACHS OF THE AVERAGE VECTOR WIND DISTRIBUTION AT 200 MB. IN OCTOBER

300, 200, 150 and 100 mb., whose directions were along the isotherms and of magnitudes equal to the gradients of the temperature field. From these, substituting the appropriate values of the constants k, the thermal winds were obtained for the layers 1000–500, 500–300, 300–200, 200–100 mb., with speeds measured to the nearest knot and directions to the nearest five degrees.

The "surface" geostrophic vector wind at each of the 234 grid points was measured from mean-sea-level pressure charts, with isobars drawn at 4-mb. intervals, prepared in the World Climatology Branch of the Meteorological Office. Over the oceans a check was obtained from the charts of average winds for five-degree squares prepared in the Marine Branch of the Meteorological Office[1–4], and for some doubtful points over the continents from available manuscript data in the Meteorological Office.

The vector winds at 500, 300, 200 and 100 mb. were obtained by successive vector addition of the "surface" and thermal vector winds. The vectors were plotted on 16 Mercator charts.

Geostrophic winds were not measured in the areas between 20°N. and 20°S. To help in drawing the charts wind data were worked up for a number of stations, chiefly for 3-yr. periods between 1949 and 1952; with the help of these data and other available data it was considered that the charts could be drawn up even in the tropical regions with considerable accuracy. Lists are given in the Appendix of data worked up, data recently published or made available, and also of older material examined.

Isotachs of the average vector wind speed in knots (full lines) and stream-lines (pecked lines with direction arrows) were drawn. Most of the stream-lines were drawn as isopleths of approximate contour height in hundreds of geopotential feet. The contour heights have been entered for the benefit of possible users, but it should be understood that they are not complete in themselves. Areas in the tropics with vector resultant wind speed less than 10 kt. were shown by hatching.

Of the 16 charts which were drawn, those for the level of 200 mb. for the months of January, April, July and October are reproduced as Figs. 1–4. A limited number of charts for all levels, approximately 28 in. × 17 in., are available for purchase on application to the Director, Meteorological Office, World Climatology Branch, Headstone Drive, Harrow, Middlesex.

Appendix

Vector mean winds for 3-yr. period

Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.
Athens	5, 6	Albrook		Lagos	...	Caribou*	9, 10	Gibraltar	27
Hanover	7	Field	6	Bismarck	9, 10	Oklahoma*	9, 10	Benina	27
Cairo	8	Marshall		Columbia*	9, 10	St. Cloud*	9, 10	Malta	27
San Juan	9, 10	Island	6	Greensboro*	9, 10	Big Spring*	9, 10	Nicosia	27
Canton		Guam	6	Little Rock*	9, 10	Brownsville*	9, 10	Nairobi	27
Island	6	Manila	6	Oakland*	9, 10	Charleston*	9, 10	Habbaniya	27
Honolulu	6	Wake		San Antonio*	9, 10	Miami*	9, 10	Bahrain	27
Midway		Island	6	Tatoosh*	9, 10	New Orleans*	9, 10	Aden	27
Island	6	Rome	6						

* July only.

Japanese stations[11], chiefly Wakkani, Tateno and Shionomisaki were worked up for 1950–51.

Vector mean winds recently published or made available

Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.	Station	Ref. No.
Larkhill	12	Singapore	13	Auckland	15	Poona (July 1949–50)	16	Falkland Islands	27
Lerwick	12	Hongkong	14	Nandi	15			Aldergrove	27

Older material examined

Station	Ref. No.	Station	Ref. No.	Miscellaneous data	Ref. No.
Lindenberg	17	Ghanzi	21	Observations from the German expedition "Meteor"	22
Batavia	18	Cuyaba	22	Cirrus cloud observations	23
Mauritius	19	Curityba	22	Pilot-balloon data for India	24, 25
Apia	20	Santiago	22	Vector winds computed from medium and cirrus cloud observations for the United States and the Caribbean	26

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METEOROLOGICAL OFFICE DISCUSSION

Prebaratics—their preparation and interpretation

The discussion on February 21, 1955, was opened by Mr. P. F. Illsley who largely confined himself to the methods employed at the Central Forecasting Office at Dunstable in producing "prebaratics" (forecast surface charts) for 24 hr. ahead covering the area from about 30°N. to 70°N. and 55°W. to 35°E. The main uses of these prebaratics are to give guidance to outstations, to assist in the preparation of forecasts issued from Dunstable, especially those for the B.B.C. and Press, and to meet international commitments. In his opening statement, of which a summary follows, Mr. Illsley referred to notable contributions to the literature on prebaratics by Sutcliffe[1] and Douglas.

Many aids and devices, e.g. isallobaric charts, hodographs, cross-section diagrams, frontal contour charts and isentropic analysis, have been developed to assist in the analysis of current charts and in the preparation of forecast charts but only a limited number of tools can be usefully employed in one office. At Dunstable these are surface charts, 1000–500-mb. thickness charts, 500-mb. contour charts and, to a less extent, those for 700 and 300 mb., and individual tephigrams and wind ascents. Lack of information from vital areas of the Atlantic sometimes makes a reliable analysis impossible, and even with adequate information frontal analysis presents difficulties. Fronts drawn are mainly those which are associated with an appreciable gradient in the 1000–500-mb. thickness field and those which, without having any obvious effect on the thermal field, nevertheless have a well marked surface discontinuity or well defined area of precipitation associated with them.

In producing prebaratics the main principles used at Dunstable are extrapolation, the use of synoptic models and analogues, and dynamical methods based on thickness and contour charts.

Extrapolation may be used on well marked features on both surface and upper charts to give first approximations to the future positions and intensities of anticyclones, depressions, ridges, troughs, etc. A slide was shown giving the tracks followed by the major surface features during the period November 8–17, 1954. This clearly illustrated that extrapolation for a few hours ahead would have given reasonably accurate positions for the centres of the anticyclones and depressions on most occasions, but for 24 hr. ahead extrapolation would have often resulted in large errors.

The tendency of the atmosphere to behave in a particular manner in recognizable circumstances enables systems to be introduced in certain areas, or to be developed in certain ways when the required conditions are realized or expected. The best known and probably the most important "model" in our region of the globe is the development of a frontal wave into a warm-sector depression which deepens and eventually occludes when it stops deepening, slows down and turns to the left. Much help in deciding whether a particular depression will follow this sequence can be obtained from considerations of the thickness field. A model peculiar to a particular area is the cyclogenesis in the Gulf of Lions when cold air penetrates into the western Mediterranean from France, and another is the breaking away of depressions from southern Greenland. In recent years study of the upper air has resulted in the formulation of additional models as, for example, a "block" which can roughly be defined as an area where there is a marked drop in the mean westerly flow throughout the troposphere. The prolonged blocking situation in January 1955 was illustrated by slides. The use of analogues is an extension of the use of models to a whole situation rather than a single feature. No situation is ever repeated in all details so that a complete analogue is not to be expected. However, knowledge of happenings in similar situations is valuable, and experience, so important in forecasting, is largely a matter of mental analoguing. Extremes of various kinds should be borne in mind and, to forecast an extreme, abnormal developments must be expected. A knowledge of singularities, such as those found by Lamb[2], is useful background knowledge since it gives some indication of the preferred circulations at any season.

The use of thickness charts in forecasting largely stems from Sutcliffe's theory of development. This theory, with various assumptions, links development with the surface isobars and thickness distribution in the formulae

for cyclogenesis $$V' \frac{\partial}{\partial s} (l + 2\zeta_0 + \zeta') < 0$$

for anticyclogenesis $$V' \frac{\partial}{\partial s} (l + 2\zeta_0 + \zeta') > 0$$

where V' is the thermal wind, $\partial/\partial s$ denotes change in the direction of the thermal wind, l is the Coriolis parameter $2\omega \sin \phi$, ζ_0 is the vorticity of the surface wind, and ζ' is the vorticity of the thermal wind. The 1000–500-mb. thermal wind field is usually used in applying the formula.

Complete evaluation of the thermal development over the whole of a chart is laborious, and in practice application of the Sutcliffe theory is restricted to a qualitative assessment of the development where vorticity changes in the thickness pattern are large, as near troughs and ridges, and where there is marked diffluence or confluence. The developments associated with these configurations have been discussed in various papers, the most exhaustive being that by Sutcliffe and Forsdyke[3].

Another dynamical approach, that of Rossby, is also made use of in the preparation of prebaratics. Rossby, postulating a barotropic atmosphere with no vertical motion, produced a formula for the movement of a train of small-amplitude waves as follows

$$C = U - \beta \frac{L^2}{4\pi^2},$$

where C is the speed of movement of the wave train towards the east, U is the mean westerly wind speed, L is the wave-length, and β is the latitudinal variation of the Coriolis parameter.

Checks at Dunstable have shown that, when applied to the large-amplitude waves of roughly sinusoidal form which appear in the 500-mb. flow pattern, the formula works in a qualitative sense, but much experience and care are needed in its application. Rossby's theory requires conservation of the absolute vorticity of the flow, and even if there is not a complete wave train some idea of the future pattern can be gained assuming constant-vorticity trajectories of the air from a region with a pronounced flow.

The movement of a front is largely controlled by the winds across it in the lower levels. Experience shows that cold fronts move roughly with the speed of the geostrophic wind at right angles to them though the development of a ridge behind a cold front may cause it to move more quickly. Warm fronts on the average move at some two thirds of the speed of the geostrophic wind at right angles to them but the ratio varies considerably. A warm front which shows little kink in the isobars will move at a speed near that of the geostrophic wind across it, while a large wind shift, a strong gradient ahead of the front and fast movement of the front all tend to produce a reduction in its speed below the geostrophic value. In extreme cases a warm front may be held stationary or its motion actually reversed while it still retains the characteristics of a warm front. The problem of occlusion largely resolves itself into forecasting the movements of the warm and cold fronts independently, and occluding the warm front to the point where the fronts cross. Fronts may be dropped on the prebaratic when frontolytic processes, especially subsidence, are expected. New ones are sometimes introduced usually in areas where substantial thermal gradients are expected to develop.

A prebaratic is most conveniently drawn on a light table with the prebaratic chart on top of the latest surface chart on which have been put the corresponding thickness lines. Before beginning the actual drawing a general study should be made of the broad-scale developments, including an assessment of the probable movements of any troughs and ridges in the 500-mb. pattern. The tracks of surface systems and upper air features should also be studied. The positions and intensities of the main surface-pressure centres, troughs and ridges are then put on the prebaratic chart using extrapolation, models and an application of development ideas. Fronts are sketched on roughly by extrapolation making allowance for expected changes in speed. A sketch of the isobars will then give a rough picture. Checks of the gradients will usually make adjustments necessary to some of the frontal positions to ensure consistency with the mean wind throughout the period. Thickness lines should then be estimated for the prebaratic time and the chart scrutinized to ensure consistency between surface and thickness features. A gridding of the surface and thickness fields to confirm that the 500-mb. pattern is in line with expectations is also advisable.

Slides were then shown illustrating developments during the period November 11–14, 1954; and the prebaratics prepared during this period, during which there was a rapid change from an unsettled westerly type of weather to an anticyclonic type over the British Isles, were discussed. It was noted that the change of type on November 13 fitted to the exact day the table of singularities given by Lamb[2].

Prebaratics have obvious advantages and drawbacks. Their production ensures that the forecaster gives thought to the various processes involved and tries to form the best balance. They force the forecaster to produce a definite solution, but herein lies one of the main drawbacks in that the prebaratic may be taken too literally and conclusions drawn which are not justified. A prebaratic should always be studied in conjunction with the corresponding "General synoptic review" in which possible alternative developments may be suggested. Even if normal confidence is indicated, the probable errors of prebaratics must be borne in mind. In the vicinity of the British Isles, the average error in the positions of pressure centres on 24-hr. prebaratics is some 240 miles and of fronts about 115 miles. This indicates a probable error of several hours in the timing of the passage of a front 24 hr. ahead, and the phraseology of forecasts for the latter part of a 24-hr. period should try to reflect this uncertainty. Forecasts of thicknesses and of 500-mb. contours should be studied in conjunction with the prebaratics. The forecast thicknesses will give some idea of the stability of the various air masses compared with their stability on the current charts. The statistical investigations by Murray[4] and Lamb[5] into the relationship of precipitation forms with thickness should be kept in mind during the winter months. In assessing the activity of fronts on a prebaratic it should be remembered that increased troughing at a front often leads to increased rainfall while the occlusion process frequently leads to greater rainfall near the point of occlusion. Winds increasing markedly with height over a warm sector are likely to spread rain well ahead of the warm front and reduce the activity of the cold front. Increased rainfall is likely near a wave or anywhere else where near-saturated air is subjected to convergence by falling pressure. Rising pressure and increasing anticyclonic curvature of the isobars will normally result in decreasing precipitation and thinning cloud. Modifications of the air masses due to cooling or heating by the underlying surface, by orographic or frontal uplift, or by subsidence should also be considered. Other factors to be borne in mind when interpreting a prebaratic are the season of the year, diurnal changes, and local effects such as sea-breezes and katabatic winds.

Mr. F. H. Bushby then presented the results of a computation of a 24-hr. prebaratic for 0300 on November 14, 1954, made with the aid of an electronic computer using the method described by Bushby and Hinds[6]. This was compared with the prebaratic for 0600 on the same day produced by orthodox methods and was clearly an improvement. Mr. Bushby pointed out that in producing the computed prebaratic the observed changes on the boundary had been used, and this point led to some discussion.

Mr. E. Gold commented on Mr. Illsley's clear and impartial exposition in which the shortcomings of present-day forecasting had been openly recognized. One of the older and well known forecasting "rules" which Mr. Illsley had omitted to mention is the tendency for mutual rotation of the centres of a dumb-bell-shaped depression. Mr. Gold also asked whether the term "blocking situation" was merely another name for a warm anticyclone. In reply Mr. Illsley said that the rotation of one depression round another is a special case of the more general rule that surface pressure features tend to move in the direction of the strongest flow in their circulations at low levels. A warm anticyclone certainly forms an important part of a "block", but some writers, at least, insist on a depression at a lower latitude to complete the block and the upper levels must also show marked diminution of the zonal flow.

Mr. H. T. D. Holgate pointed out that, on occasions, errors of several hundred miles occurred in the prebaratic positions of depression centres over the Atlantic. Such errors could have serious effects on transatlantic flights. Many differences between Dunstable and Prestwick forecasts could be traced to differences in the initial analysis caused mainly by insufficent data from the Atlantic. He asked if anything could be done to check doubtful ship reports. Mr. Illsley stated that no statistics are available on errors in prebaratics except for the vicinity of the British Isles. It is quite likely that the errors are larger in some areas, especially in the north-west Atlantic where information from ships is scanty. Everything possible is done at Dunstable to check doubtful reports. A continuous plot is kept of all British reporting ships on a wall-board and doubtful reports are referred back to the ships where possible. Many ships maintain a restricted radio watch, however.

Mr. H. H. Lamb considered that the singularities noticed in his own and other similar investigations are sufficiently pronounced to merit further investigation to discern the basic causes of the circulations producing the singularities.

Dr. J. M. Stagg, in a provocative contribution, asked whether the prebaratic is the best means of promulgating the considered views of forecasters at the Central Forecasting Office to outstations. To the man who prepares it a prebaratic is certainly useful in that it clears his mind but is there not the danger that the prebaratic is too specific? It is well known that there is a greater or less degree of uncertainty in a prebaratic, and this is taken account of by the originator when he frames his own related forecasts, but can this uncertainty be adequately represented to outstation forecasters by the present procedures even when the prebaratic is supplemented by the "General synoptic review"?

Mr. S. P. Peters said he would like to hear the views of outstation forecasters on the value they attached to receiving prebaratics and the accompanying "General synoptic reviews"; the construction of prebaratics is an essential process at Dunstable. There are often several possible solutions to the development problem and the prebaratic represents the one selected as the most probable. Outstation forecasters could always discuss their own ideas with the Central Forecasting Office by telephone.

Mr. E. G. Ward expressed the view that the Central Forecasting Office prebaratics are essential to the work of outstations. A forecaster at an average outstation has neither the time nor the facilities to produce 24-hr. prebaratics which are necessary to meet the very varied demands for forecasts made by the Services and the general public.

Mr. P. M. Shaw also considered that the Central Forecasting Office prebaratics were essential to outstations. He inquired about the use of the Sutcliffe theory in forecasting, and suggested that, in effect, a limited number of models, deduced somewhat empirically from the theory, are employed.

Dr. R. C. Sutcliffe recalled that long before the last war there were general ideas regarding the association of convergence and cyclogenesis, but no use was then made of three-dimensional dynamics in prediction, neither was development linked with the geometry of the surface and upper air pressure fields. Nowadays, however, these ideas are part and parcel of the forecaster's mode of thought. He agreed with Mr. Shaw that the present application of the Sutcliffe expression for development is largely qualitative in association with certain easily recognized configurations in the thickness field. For fuller use numerical methods and computational aids are necessary, and much progress is being made in these fields.

Mr. J. S. Sawyer was of the opinion that the almost universal adoption of prebaratics speaks for their advantages. He wondered whether isallobars could not be used more systematically in their preparation. To assist in the interpretation of prebaratics he suggested that precipitation areas should be indicated in some way.

Mr. B. Fox-Holmes considered that the Central Forecasting Office prebaratics are particularly valuable at outstations which are not manned continuously, and so cannot maintain a complete sequence of charts. He thought that the change from one prebaratic to the next is sometimes abrupt, and that in such circumstances some indication of the change of policy should be given earlier, say in

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VIEW FROM CONTROL TOWER OF METEOROLOGICAL ENCLOSURE, WICK, FEBRUARY 18, 1955

Excavation had begun inside the enclosure and a snow plough can be seen clearing the perimeter track. The depth of the drift in the foreground can be seen from the photograph below.

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SHOWING THE DEPTH OF THE DRIFT SNOW AT WICK, FEBRUARY 18, 1955

The guy lines on the right of the photograph extend from the anemometer pole and can also be seen in the top photograph.

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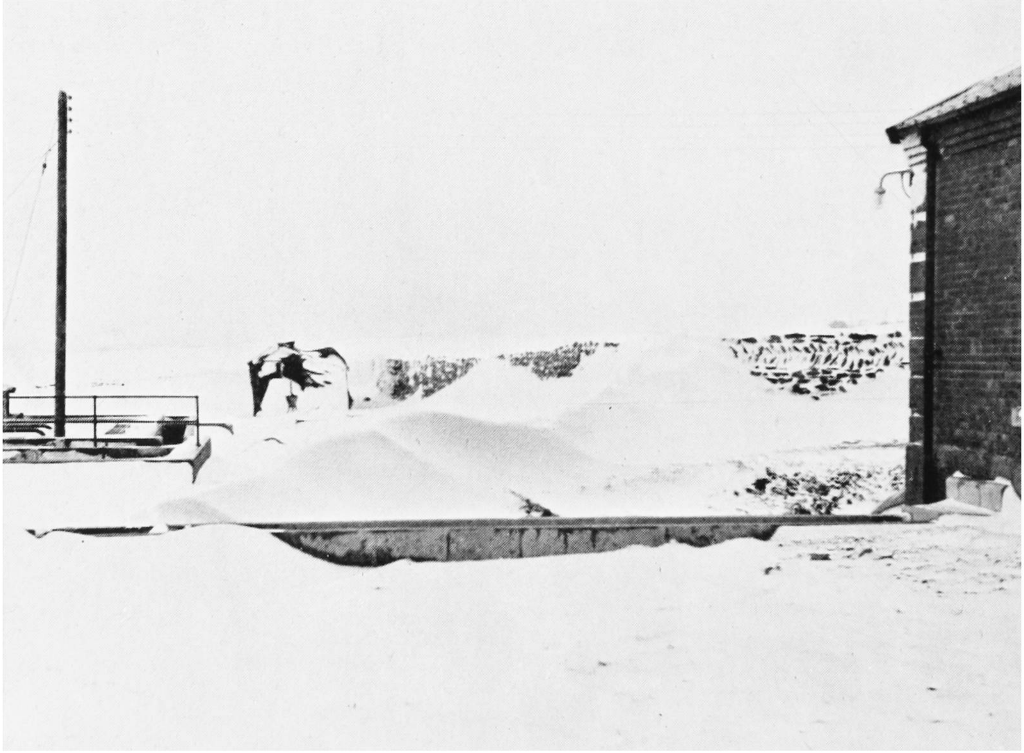
LOOKING AT THE GATES FROM INSIDE THE FILTER WORKS



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DRIFT INSIDE THE FILTER WORKS

DRIFTS UP TO 7 FT. DEEP AT THE FILTER WORKS OF THE NORTH CORNWALL JOINT WATER BOARD AT LOWERMOOR, NEAR CAMELFORD the "Supplementary general synoptic review". Mr. Illsley replied that any clear-cut indications that a prebaratic was going wrong would be so notified to the outstations, but one had to be sure that the line being followed was incorrect before making any radical alteration. An amended forecast which goes wrong is always liable to greater criticism, especially if the original forecast turns out to be correct after all.

The Director, in summing up, spoke of the comparisons that had been made during the discussion between "conventional" and "numerical" forecasts, and remarked that no forecaster could be more conventional than the computing machine. For success with numerical forecasting it would be necessary to obtain some forecast of the boundary conditions, perhaps by orthodox prebaratic methods.

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METEOROLOGICAL RESEARCH COMMITTEE

The 68th meeting of the Meteorological Research Committee was held on November 25, 1954. The Committee reviewed the progress which had been made on the more important research problems since the previous meeting and Dr. Scrase gave an account of the work being done under his control in developing meteorological instruments.

The 33rd meeting of the Synoptic and Dynamical Sub-Committee was held on December 9, 1954. The Sub-Committee discussed at length the provision of an electronic computer for Meteorological Office use and concluded that the time was now ripe for an intense effort in numerical forecasting using such a machine. A paper by Mr. J. G. Moore[1] on the average pressure and temperature of the tropopause was then considered. Two papers dealing with corrections which might be applied to radio-sonde temperatures were discussed. The first by Dr. F. J. Scrase[2] considered radiation and lag corrections and the second by Mr. D. H. Johnson[3] dealt with corrections which might be applied to take account of diurnal and interdiurnal variations.

The 31st meeting of the Physical Sub-Committee was held on December 16, 1954. There was some discussion on methods of measuring the stress of wind on water arising out of correspondence with the Ministry of Agriculture and Fisheries. The Sub-Committee then considered a paper by Dr. D. G. James[4] which dealt with observations of the fine-scale structure of the lowest 5,000 ft. of the atmosphere made from an aircraft of the Meteorological Research Flight. The observations referred primarily to days when convection was likely to occur. A further paper[5] relating to observations made by the Meteorological Research Flight discussed humidity measurements at heights up to 50,000 ft. over southern England. A paper[6] from Kew Observatory on the estimation of the reflection and absorption of solar radiation by a cloudless atmosphere was also considered.

ABSTRACTS

1. MOORE, J. G.; Average pressure and temperature of the tropopause. *Met. Res. Pap., London*, No. 874, S.C. II/176, 1954.

Using all available radio-sonde data, obtained by various methods, average pressures and temperatures at the tropopause (or 2 tropopauses) are plotted on Mercator world charts and polar charts for January, April, July and October, and isopleths drawn. Between latitudes 35° and 45°N., two tropopauses were found on 10–95 per cent. of occasions. The charts are discussed.

2. SCRASE, F. J.; The application of radiation and lag corrections to radio-sonde temperatures. *Met. Res. Pap., London*, No. 889, S.C. I/95, 1954.

Errors of a radio-sonde due to radiation (short and long waves) and corrections for solar altitude and lag are evaluated and set out in tables.

3. JOHNSON, D. H.; Diurnal and interdiurnal variations of the measured heights of pressure surfaces. *Met. Res. Pap., London*, No. 888, S.C. I/94, S.C. II/179, 1954.

Observed diurnal variations of 700, 500, 300, 200 and 100 mb. heights were computed for Malta and Nicosia (0300–1500–0300) and for Larkhill and Lerwick (0300–0900–1500–2100–0300). These are compared with radiation errors read from new graphs for Meteorological Office radio-sondes at solar altitudes 70° to −5° up to 20 Km. The observed and computed variations are mostly similar; differences are attributed to neglect of sky radiation. Smoothed "observed" curves are drawn for use in correcting 0600 and 1200 synoptic height tendencies for diurnal variation.

4. JAMES, D. G.; Fine-scale characteristics of the lowest 5,000 ft. of the atmosphere as observed from an aircraft. *Met. Res. Pap., London*, No. 875, S.C. III/172, 1954.

Flights were made on convective days between about 500 and 5,000 ft. to measure details of gustiness and bumpiness and fluctuations of temperature and dew point. The ultra-rapid instruments are described and the results tabulated in detail. Over land three layers were found: up to 800–1,200 ft., chaotic; from this layer to 200–300 ft. below cloud base, less frequent and better defined fluctuations; sub-cloud layer, increased stability. Over sea these layers are not found; bumpiness is less and there is often an inversion. It is inferred that during the morning bubbles of heated air rise from the ground and, if moist enough, form cloud. Further ascent warms and deepens the sub-cloud layer and cloud formation proceeds by bubbles from this layer, continuing long after surface temperature has passed its maximum.

5. MURGATROYD, R. J., GOLDSMITH, P. and HOLLINGS, W. E. H.; An interim report on measurements of humidity from aircraft to heights of about 50,000 ft. over southern England. *Met. Res. Pap., London*, No. 877, S.C. III/174, 1954.

Regular observations with the Dobson-Brewer pressurized hygrometer in a Canberra up to 50,000 ft. over southern England are described. Observations at 5,000–50,000 ft. are tabulated and discussed for 21 flights. At the tropopause the frost point ranged from −65° to −96°F. lower for high than low tropopause. About 50,000 ft. (100 mb. above tropopause) values cluster round −120°F. (relative humidity over ice at −60°F. 0·7 per cent.). There may be a "humidity tropopause" a few thousand feet above temperature tropopause.

6. BLACKWELL, M. J., ELDRIDGE, R. H. and ROBINSON, G. D.; Estimation of the reflection and absorption of solar radiation by a cloudless atmosphere from recordings at the ground, with results for Kew Observatory. *Met. Res. Pap., London*, No. 894, S.C. III/178, 1954.

Records on cloudless occasions at Kew in 1947–51 of total, direct and diffuse radiation (total and two spectral regions) and illumination on a horizontal surface are discussed, including effect of London smoke with E. winds. Attenuation of radiation by Rayleigh scattering and "Fowle" (particulate) scattering and by water absorption, and diffuse radiation, are computed by several methods for a model atmosphere. Results are compared with those given by the extra-terrestrial distribution of solar radiation proposed by Nicolet and known attenuation of an unpolluted atmosphere. The results are consistent if the measured illumination is reduced by 5 per cent. Absorption is estimated as rather less than 10 per cent. with another 10 per cent. for "grey" multiple scattering. Albedo of cloudless atmosphere (total and various wave-lengths) is plotted against sine of solar altitude.

ROYAL METEOROLOGICAL SOCIETY

Meteorology in a large water engineering project

At a meeting of the Royal Meteorological Society on Wednesday, February 16, 1955, with the President, Sir Graham Sutton, in the Chair, Dr. E. B. Kraus gave a talk on meteorology in a large water engineering project.

Dr. Kraus has been the meteorological officer attached to the Snowy Mountains Hydro-Electric Authority, Cooma, New South Wales, and he described, partly with the aid of a film of the construction work in progress, the plan to build a large reservoir on the eastern side of the Snowy Mountains and drain the water through a tunnel to the western side where it was needed for irrigation. During flood time the flow of water in the tunnel was to be from west to east, thus filling the reservoir; during drought the flow was to be from east to west. The fall of water was to be used for hydro-electric power, and it was this that made the scheme commercially possible.

Meteorological advice was necessary to make the best use of the rainfall, for out of an average annual rainfall of 16 in. the total run-off was only 1½ in. The annual rainfall at the peak of the Snowy Mountains (Mount Kosciusko) was about 150 in. A large reservoir could only be placed on the eastern side of the mountains where, unfortunately, because of föhn effects the evaporation was greatest; subsidiary feeder reservoirs were available at higher levels but their storage capacity was insufficient for commercial use.

The meteorological aid could be summarized under the headings of expected yield from the reservoir, protection against floods, duration of droughts, effect on soil conservation, observations, forecasting and miscellaneous matters. The dearth of previous observations made it difficult to estimate the normal rainfall yield and very difficult to estimate the maximum storm yield. Various methods had been tried including the "transplanting" of storms, observed in detail in similar climatic areas, to the Snowy Mountains area; the spring yield was estimated by means of a snow survey correlated with stream gauges during the spring run-off, but this would need at least ten years of observations. New stations had been set up, including 14 climatological, 150 rainfall and 98 storage stations; these last often consisted merely of an ordinary milk can chained in position. Such forecasting as was requested during the constructional period was comparatively easy, since all that was required was the likelihood of rain, and it had been observed that every front crossing the Australian continent gave rain on reaching the Snowy Mountains. When the project was fully operational—from 1960 onwards—much more detail would be required, in particular the rainfall amounts during the next 48 hr., for the demand for power would be greatest if it could be supplied in accurately predicted amounts.

Dr. Penman asked for details of the effect of tree destruction on the soil and the amount of water available for irrigation (this was conserved in lower reservoirs on the western side). Dr. Glasspoole asked about compensation water; there was little difficulty in the Australian scheme because the whole area was nationally owned and only used under leases for grazing. Mr. Craddock asked about the marked decrease in seasonal rainfall at the turn of the century; Mr. Gold thought it might be due to faulty measurement, but Dr. Kraus assured him that the same decrease occurred simultaneously in many parts of the world between 30°N. and 30°S. Furthermore the period used for normal averages in Australia, 1911–40, was chosen because of the loss of records in the first decade of the century when many farmers went bankrupt; 1902–48 was used for stream-gauges. Mr. Ludlam asked what progress there was on large-scale treatment of water surfaces with a film of cetyl alcohol to prevent evaporation; Dr. Kraus replied that Deacon and Priestley had developed a method of renewing the film from anchored floats over a disturbed sizeable water surface but it was still experimental.

LETTERS TO THE EDITOR

Confluence and diffluence

The term confluence is widely used in synoptic meteorology to imply a flowing together without necessarily implying "convergence" as defined in hydrodynamics. The distinction is very important, and corresponding with "divergence" I have been guilty in certain papers of writing "difluence" and of pronouncing it with a long i.

My attention has been drawn to this error and as the word is a handy one which is being rather widely adopted I would like to commend the correct form for future use.

R. C. SUTCLIFFE

March 22, 1955

Precipitation with clear sky

In the typescript *Meteorological Magazines* for 1944 and 1945 there was considerable discussion of this phenomenon, and a conclusion which emerged was that, at a place like Wrexham lying to the east of the mountains, low cloud can lie over the mountains in a strong W. wind and precipitate fine rain which comes to earth some miles to eastward. The cloud is invisible from where the observation is made and it does not itself advance down into the lowlands owing to adiabatic warming. However, observations in Wrexham in February 1955 seem to show that other processes must operate at times. On February 5 there was a period of light rain from 2130 to 2230 G.M.T. The cloud then suffered a complete and rapid dispersal, and from 2235 to 2255 light rain continued to fall from the cloudless sky. Not a trace of cloud could be seen and the stars were as bright as they can be with a nearly full moon, and it was calm at the surface. The rain was not heavy enough to be registered on the autographic rain-gauge, but was sufficient to wet clothing.

Again, on February 15 at 0920 there was a light fall of snow in the absence of low cloud and with 4 oktas of hazy cirrus only. The dry bulb was 32°F. and the wind NNW. 6 kt. The rest of the day was fine; a little low cloud occurred about an hour later, but even then there was only thin high stratocumulus above.

One or two other similar cases have been reported in the *Meteorological Magazine**.

S. E. ASHMORE

11 Percy Road, Wrexham, February 20, 1955

NOTES AND NEWS

Heavy rainfall at Changi, Singapore

During a rainy spell which affected Singapore on December 8–11, 1954 the rainfall amounts at the airfields on the island for the standard 24-hr. period ending at 0730 local time (0000 G.M.T.) on December 10 were as follows:—

	in.
Changi (at eastern end of Singapore Island)	9·29
Seletar (on north coast, 7½ miles west-north-west of Changi)	7·58
Kallang (on south coast, 9 miles south-west of Changi) ...	9·06
Tengah (inland, near west of island, 19 miles west of Changi)	7·09

However, this is not the whole story; for in the 24-hr. period ending 2230 local time on December 9, a total fall of 12·90 in. was measured at Changi. The rate of fall during this period is given in the three-hourly records below:—

Local time	Rainfall in.	Local time	Rainfall in.
2230–0130	0·48	1030–1330	1·65
0130–0430	1·93	1330–1630	3·22
0430–0730	1·42	1630–1930	1·53
0730–1030	2·10	1930–2230	0·57

The rate of fall is not exceptional for Singapore, as on many occasions this rate is greatly exceeded in thunderstorms (e.g. 4·28 in. fell in a thunderstorm

* DINES, J. S.; Drizzle falling from a clear sky. *Met. Mag., London*, **70**, 1935, p. 16.
ASHMORE, S. E.; Drizzle falling from a clear sky. *Met. Mag., London*, **70**, 1935, p. 116.

at Changi between 1430 and 1530 local time on April 20, 1953*). However, the persistence of the heavy rainfall can be assessed when the actual fall is compared with the average rainfall for December—just over 10 in. The maximum intensity of rainfall occurred on December 9 when 0·4 in. fell in 9 min., i.e. at a rate of 2·67 in./hr.

The rainfall at Changi for the standard period ending 0730 local time on the 10th—9·29 in.—is the highest 24-hr. fall since records were begun here in 1947. The previous highest was 6·66 in. in January 1947. Also, it approaches the highest 24-hr. fall ever recorded in Singapore which was 9·62 in. in December 1892.

The weather was associated with a surge in the NE. monsoon which, it is thought, was converging aloft over Singapore Island and south Malaya with Indian Ocean westerlies, the latter having been strengthened by a depression in the Bay of Bengal. But as most of the upper air information in this area is derived from pilot-balloon ascents, it will be realized that during the rain spell little or no data were available. Unfortunately, too, the Singapore radar-wind equipment was unserviceable most of the month.

It is notable that during the period there was no report of thunder from any station in Singapore or south Malaya. The cloud structure, as reported by aircrews and by inference from the Singapore radio-sonde ascents, was 8 oktas nimbostratus continuous from about 5,000 ft. to over 30,000 ft. with strato-cumulus and stratus below.

Besides the spell December 8–11, the rainfall generally throughout the month was abnormally heavy, and the previous highest 24-hr. rainfall at Changi—6·66 in. in January 1949—was exceeded again when a fall of 7·29 in. was measured in the 24-hr. period ending 0730 local time, December 17.

The total rainfall measured at Changi during December was 35·91 in. which is more than double the previous highest December rainfall, 17·17 in. in 1947. It is also much higher than the greatest December rainfall ever measured in Singapore which was 22·01 in. in 1942. And, as far as can be ascertained, the rainfall at Changi in December 1954 is the highest fall ever recorded for any month in Singapore, the previous highest being 32·3 in. in January 1893.

When one considers that the fall of 12·9 in. in 24 hr. is more than the average six-month fall in London and that the month's rainfall of 35·9 in. is approximately the average fall over eighteen months in London, the reader may be able to imagine just how much rain did fall at Changi during December 1954.

F. BOTHWELL

Meteorological Office album of historical photographs

An ornamental album containing photographs of historical interest related to the Meteorological Office, and suitable for exhibition, is being prepared in collaboration with Her Majesty's Stationery Office. The photographs are mostly of international meteorological conferences and other important meetings. The album has spare leaves to facilitate the addition of photographs to the collection. Any readers knowing of photographs which might be suitable for adding to the album are invited to communicate with the Editor.

* PALMER, W. G.; Heavy storm at Changi. *Met. Mag., London*, **82**, 1953, p. 341.

NEWS IN BRIEF

Information has been received from Stockholm that Dr. Anders Ångström retired from the post of Director-in-Chief, Meteorological and Hydrological Institute of Sweden on December 31, 1954. Dr. Ångström is succeeded by Dr. Alf Nyberg.

METEOROLOGICAL OFFICE NEWS

Academic successes.—*University degrees.*—We offer our congratulations to Mr. G. B. Tucker, Scientific Officer, who has been admitted to the degree of Ph.D. in Meteorology in the University of London, and to Mr. J. MacDowall, Scientific Officer, who has been admitted to the degree of M.A. in the University of Cambridge.

Fellowship.—Mr. D. H. McIntosh, Senior Scientific Officer, has been elected a Fellow of the Royal Society of Edinburgh.

General Certificate of Education.—Information has reached us that Mr. J. H. Rawlinson, Scientific Assistant, has passed the General Certificate of Education at the Advanced Level in Pure Mathematics.

Ocean weather ships.—The following extracts from reports by the Meteorological-Officers-in-Charge aboard two ocean weather ships emphasize the contrast in weather which can be experienced in the North Atlantic.

O.W.S. *Weather Recorder.*—Voyage 57 (December 7–January 3, 1955) at station I.

A white Christmas indeed! But white with spray and spume for gale force winds and storms were the notable features of this voyage. Gales were recorded on 15 days and reached storm force on 6 occasions.

O.W.S. *Weather Explorer.*—Voyage 57 (December 24–January 22, 1955) at station A.

Apart from a severe gale on the outward passage the weather was very good indeed. In fact, no one can recall a better voyage at any season. The wind rarely exceeded force six and we enjoyed quiet anticyclonic weather for almost the entire trip.

Sports activities.—The Air Ministry Chess Championship of 1955 has been won by Mr. P. B. Sarson; second was Dr. J. Pepper. Of the nine contests held since 1946 the Meteorological Office has provided the winner six times and the runner-up six times.

WEATHER OF MARCH 1955

The pressure pattern departed widely from normal over most of the Atlantic and Europe, on account of the frequency and persistence of blocking anticyclones; the highest monthly mean pressure in this sector was 1020–1021 mb. over Ireland and the Hebrides. The subtropical anticyclone was represented by a 1020 mb. centre near the Bahamas. Pressure was relatively low in three areas—1004–1005 mb. off Labrador, 1006 mb. off north Norway and 1010 mb. between the Azores and Spain. In other parts of the hemisphere the patterns seem to have been closer to normal. Pressure had been notably high all winter over north Greenland and the Canadian archipelago, but whereas this was abnormal in December, January and February it is usual in March; the March 1955 pressure values were close to normal in these northern areas, but a southward extension of the anticyclone, which was noticeable in the second half of the month, produced the maximum pressure anomaly of +14 mb. in Iceland.

The temperature and rainfall patterns over Europe reflected the anomalies in the pressure and wind distribution. Prevalent northerly and easterly winds brought below-normal temperature all over Europe, culminating in departures of −4°C. in central Europe and locally in England. Rainfall exceeded twice the average over the mountains of north Norway and locally in Denmark, the eastern Alps, Sardinia, southern Italy and the Balkans.

In the British Isles the weather during the first two weeks was anticyclonic, with wintry showers and long sunny periods. High pressure in the neighbourhood of Greenland maintained a cold arctic air stream over the major part of the country for about another week, until an influx of maritime air from the south-west, from the 23rd to the 26th brought a change to mild wet weather. During the remainder of the month, as an anticyclone moved southwards from Iceland, a polar air stream was re-established over the country with a return to fine cold weather.

During the first three days of the month an anticyclone centred over Germany maintained a cold easterly air stream with dry sunny weather over the southern part of the country, but in the north-west and north the passage of an active trough on the 1st was associated with fresh to strong south-westerly winds and considerable rain in Ireland, Wales and Scotland; heavy rain coupled with melting snows caused widespread floods in the Renfrewshire-Clyde area. Areas of fog, dense in the north-east, formed in the moister air behind the trough during the early hours of the 2nd and 3rd, but otherwise the weather was fine though rather cold. By the 4th, an anticyclone of over 1040 mb. had crossed the Atlantic and settled west of Ireland, and fresh northerly winds associated with the system brought frequent snow showers to eastern England. These showers were particularly prolonged in East Anglia and Kent on the 6th where snow lay in places up to a depth of 6 in. On the same day there was a general veer of wind to north-easterly, and slight snow showers spread westward across the whole country. There was a return to fine cold weather on the 10th, as an anticyclone developed over the British Isles, until a temporary incursion of maritime air from the north-west during the 14th and 15th brought day temperatures to their seasonal normal for the first time this month; 54°F. was registered in a few places. Rain and drizzle occurred in Scotland, but some places in the extreme south continued to enjoy more than 10 hr. of sunshine daily. High pressure developed over Greenland on the 16th and for nearly a week afterwards the British Isles was under the influence of an associated northerly air stream of arctic origin. Showers of sleet or snow occurred in all areas, and temperatures everywhere again fell below normal. Bournemouth (Hurn) recorded a grass minimum temperature of 10°F. during the early hours of the 18th and again on the 20th, Kew recorded 12°F. on the grass on the 20th and 21st. A polar depression crossed Scotland on the 20th, and during that evening and the following day parts of southern Scotland and the Lake District had heavy falls of snow, depths of undrifted snow from 6 to 9 in. being reported. A pronounced change occurred on the 22nd when warm moist air spread from the south-west as far north as the Scottish border. A small but vigorous depression moved up the Irish Sea and across northern England on the 23rd, accompanied by gales in the south-west and locally heavy rain. A gust of 85 kt. was reported from Cornwall, and there was considerable damage to shipping in the path of the gales; the Norwegian ship *Venus* was blown on to the rocks in Plymouth Sound, and there were reports of several other vessels breaking adrift. The following day another though less vigorous depression followed a similar track, again with outbreaks of heavy rain, but this too turned east towards the North Sea before reaching Scotland. A big contrast of temperature was thus established between the south of England where temperatures were generally about 60°F. (63°F. was reached at Kew and London Airport and 66°F. on the Air Ministry roof, Kingsway, on the 25th) and Scotland where the temperature was still generally below 40°F. In 48 hr. during the passage of these two depressions ¾ in. of rain fell in many places in Wales, northern England and southern Scotland, but still heavier falls were measured on the 25th and 26th when thunderstorms and thundery rain broke out over a wide area in England and Wales. In the 24 hr. up to the evening of the 26th many places had more than 1 in. while there were falls of 2 in. or more in parts of south Wales and the Midlands. It was reported to have been the wettest week in Birmingham since November 1951. The four days of abnormally wet weather resulted in serious floods in the Midlands; the River Severn was reported to be 6 ft. above its normal level at Worcester on the 27th. On the 26th an anticyclone began to move southwards from Iceland and brighter colder weather with northerly winds spread over the whole country by the 27th. The closing days of the month were dry and sunny with some stations in the west reporting more than 11½ hr. of sunshine on the 31st. In spite of the number of sunny days, with sunshine totals 50 per cent. above normal in parts of south-west England and Wales, it was a cold month for most of the country. Birmingham and Ross-on-Wye had their coldest March since 1916 and Kew since 1917.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	65	10	−4·9	83	−5	134
Scotland	57	9	−3·0	50	−5	116
Northern Ireland ...	57	18	−3·9	36	−11	139

RAINFALL OF MARCH 1955

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square	1·14	62	*Glam.*	Cardiff, Penylan	1·41	45
Kent	Dover	2·06	99	*Pemb.*	Tenby	3·42	110
,,	Edenbridge, Falconhurst	1·50	60	*Radnor*	Tyrmynydd	4·49	84
Sussex	Compton, Compton Ho.	1·66	60	*Mont.*	Lake Vyrnwy	3·54	79
,,	Worthing, Beach Ho. Pk.	0·92	48	*Mer.*	Blaenau Festiniog	2·55	30
Hants.	St. Catherine's L'thouse	1·04	53	,,	Aberdovey	2·48	74
,,	Southampton (East Pk.)	1·18	52	*Carn.*	Llandudno	1·48	73
,,	South Farnborough	0·96	48	*Angl.*	Llanerchymedd	1·86	63
Herts.	Harpenden, Rothamstead	1·34	65	*I. Man*	Douglas, Borough Cem.	2·47	83
Bucks.	Slough, Upton	0·99	56	*Wigtown*	Newton Stewart	2·21	64
Oxford	Oxford, Radcliffe	1·43	87	*Dumf.*	Dumfries, Crichton R.I.	2·10	70
N'hants.	Wellingboro' Swanspool	2·18	122	,,	Eskdalemuir Obsy.	3·42	70
Essex	Southend, W. W.	1·03	67	*Roxb.*	Crailing	1·23	57
,,	Felixstowe	1·45	97	*Peebles*	Stobo Castle	1·64	57
Suffolk	Lowestoft Sec. School	1·54	96	*Berwick*	Marchmont House	1·62	61
,,	Bury St. Ed., Westley H.	1·67	88	*E. Loth.*	North Berwick Gas Wks.	1·24	67
Norfolk	Sandringham Ho. Gdns.	2·07	109	*Midl'n.*	Edinburgh, Blackf'd. H.	1·51	77
Wilts.	Aldbourne	1·66	70	*Lanark*	Hamilton W. W., T'nhill	1·90	68
Dorset	Creech Grange	1·36	48	*Ayr*	Colmonell, Knockdolian	...	...
,,	Beaminster, East St.	1·63	56	,,	Glen Afton, Ayr San.	1·81	43
Devon	Teignmouth, Den Gdns.	2·13	82	*Renfrew*	Greenock, Prospect Hill	2·11	45
,,	Ilfracombe	1·39	48	*Bute*	Rothesay, Ardencraig	1·47	41
,,	Princetown	3·31	48	*Argyll*	Morven, Drimnin	1·32	27
Cornwall	Bude, School House	1·03	42	,,	Poltalloch	...	...
,,	Penzance	1·95	61	,,	Inveraray Castle	1·51	24
,,	St. Austell	1·44	42	,,	Islay, Eallabus	...	...
,,	Scilly, Tresco Abbey	2·19	84	,,	Tiree	0·88	26
Somerset	Taunton	1·14	55	*Kinross*	Loch Leven Sluice	2·31	77
Glos.	Cirencester	1·72	74	*Fife*	Leuchars Airfield	1·58	81
Salop	Church Stretton	3·58	149	*Perth*	Loch Dhu	2·60	39
,,	Shrewsbury, Monkmore	2·57	154	,,	Crieff, Strathearn Hyd.	2·17	68
Worcs.	Malvern, Free Library	2·36	122	,,	Pitlochry, Fincastle	0·62	22
Warwick	Birmingham, Edgbaston	3·45	164	*Angus*	Montrose, Sunnyside	1·56	75
Leics.	Thornton Reservoir	2·75	149	*Aberd.*	Braemar	2·03	68
Lincs.	Boston, Skirbeck	2·05	131	,,	Dyce, Craibstone	1·78	67
,,	Skegness, Marine Gdns.	2·24	135	,,	New Deer School House	2·11	82
Notts.	Mansfield, Carr Bank	2·99	143	*Moray*	Gordon Castle	1·44	62
Derby	Buxton, Terrace Slopes	3·68	89	*Nairn*	Nairn, Achareidh	0·79	43
Ches.	Bidston Observatory	1·78	94	*Inverness*	Loch Ness, Garthbeg	...	...
,,	Manchester, Ringway	1·82	83	,,	Glenquoich	2·21	23
Lancs.	Stonyhurst College	1·49	40	,,	Fort William, Teviot	1·00	15
,,	Squires Gate	1·37	61	,,	Skye, Broadford	1·87	31
Yorks.	Wakefield, Clarence Pk.	2·29	127	,,	Skye, Duntuilm	1·80	41
,,	Hull, Pearson Park	2·37	130	*R. & C.*	Tain, Mayfield	1·26	56
,,	Felixkirk, Mt. St. John	2·03	103	,,	Inverbroom, Glackour	1·98	40
,,	York Museum	1·93	115	,,	Achnashellach	2·31	34
,,	Scarborough	2·15	119	*Suth.*	Lochinver, Bank Ho.	1·28	34
,,	Middlesbrough	1·18	75	*Caith.*	Wick Airfield	1·64	72
,,	Baldersdale, Hury Res.	1·99	69	*Shetland*	Lerwick Observatory	1·56	49
Norl'd.	Newcastle, Leazes Pk.	1·91	93	*Ferm.*	Crom Castle	0·78	25
,,	Bellingham, High Green	1·75	60	*Armagh*	Armagh Observatory	1·08	46
,,	Lilburn Tower Gdns.	1·77	67	*Down*	Seaforde	1·73	59
Cumb.	Geltsdale	0·95	34	*Antrim*	Aldergrove Airfield	0·87	35
,,	Keswick, High Hill	1·38	31	,,	Ballymena, Harryville	0·75	24
,,	Ravenglass, The Grove	2·29	74	*L'derry*	Garvagh, Moneydig	0·81	26
Mon.	A'gavenny, Plâs Derwen	3·13	94	,,	Londonderry, Creggan	1·36	42
Glam.	Ystalyfera, Wern House	3·86	72	*Tyrone*	Omagh, Edenfel	1·03	32

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