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## RAINFALL VARIATIONS OVER A SMALL AREA

By J. OLIVER, B.A.

**Introduction.**—In order to examine the variation of rainfall over a small area and to test the use of a single rain-gauge to represent the rainfall of a locality, a grid of six standard eight-inch diameter, non-recording gauges was set up. A self-recording gauge was also established to give the duration, time of fall and character of the rain. Figure I shows the details of the site. Gauges 1 and 4 were 55·5 feet apart, gauges 2 and 5, 3 and 6 were 28·3 feet apart and all other intervals were 20 feet. The site exposure was considered satisfactory. The surface sloped gently from gauge 1 (the highest gauge), from which gauges 2 to 6 differed by 0·47, 1·13, 1·12, 1·52 and 0·34 feet respectively. There was no reason to suspect that the gauges or other site factors would cause unusual wind eddies. The site was about 400 yards from high water in Swansea Bay and therefore contrasted with that for the rather similar investigation by L. H. Watkins at the Road Research Laboratory.[1]

At 0930 G.M.T. 104 readings were made between 25 April and 13 December 1956 after which building operations altered the site. The rainfall recorder was in action until October when a fault developed. A wide variety of weather and rainfall conditions was experienced during the investigation period.

In the inner can of each gauge a measuring cylinder, graduated to 0·01 in. and checked for accuracy of graduations, was placed. Readings up to 0·500 in. were obtained therefore without any loss of water. In the 13 falls of over 0·500 in. the final reading was derived from the cylinder reading, up to 0·500 in., plus the amount subsequently poured from the inner can. In the latter circumstances slightly greater recording errors are likely but every care was taken to minimize these. The cylinders were dried out after each reading. It was felt that moisture left in the can after emptying did not exceed the equivalent of 0·001 in. of rain. When rain was falling at the observation time all gauges were covered at the same time immediately before reading. This made it possible to ignore the slight differences in time of reading when comparing daily totals.

The cylinder graduations were approximately 6/32 in. apart and, by ensuring that the cylinders were vertical and the meniscus uniformly illuminated, readings to within 0·001 in. were considered possible. In reading distant gauges to 0·001 in. the effects of temperature variations on the diameter of the gauge rims and the water volume are significant. With closely spaced gauges this problem and that of differential evaporation loss do not arise. No snow was recorded. Mean falls under 0·010 in. were not used.

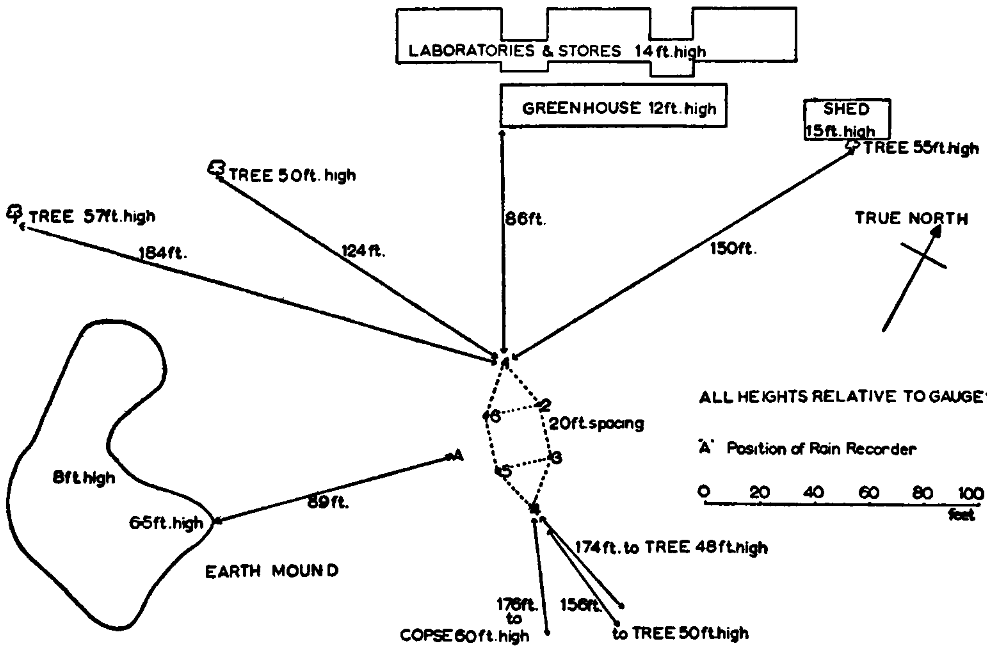


FIGURE I—SITING OF GRID OF RAIN-GAUGES

The site is level apart from a gradual drop of 15 feet below gauge 4 over a distance of 230 feet to the south-east.

**The nature of the differences.**—The distribution of the highest and lowest readings between the gauges shown in Table I was sufficiently balanced to justify the assumption that there were no major differences in their exposure. Where two or more gauges had the same highest or lowest value they were all included in the totals. Although they were only 20 feet apart, gauge 4 had the most maximum values and gauge 5 the most minimum readings.

TABLE I—FREQUENCY OF HIGHEST AND LOWEST READINGS FOR THE GAUGES

| | Gauge number 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| | *number of occasions* | | | | | |
| Highest reading | 11 | 30 | 21 | 44 | 13 | 19 |
| Lowest reading | 30 | 10 | 16 | 11 | 42 | 21 |

For each daily set of six readings the mean fall, standard deviation and coefficient of variation (expressed as a percentage) were calculated. For the 104 observations the mean standard deviation was 0·0024 in. and the mean coefficient of variation 2·7 per cent. The maximum standard deviation of 0·0132 in. was associated with a steady five-hour period of frontal rain with strong, gusting winds.

The mean difference between the highest and lowest readings in each set of six readings was 0·0068 in. The largest difference was 0·0340 in. Expressing for each day the maximum difference as a percentage of the mean for the day a mean variation of 8·3 per cent was obtained. This figure was weighted by the high percentage variations for small mean values, but a number of small variations with small totals and moderately large variations with large totals occurred. For a total over 0·500 in. the highest variation was 5·8 per cent.

Normally rainfall is recorded to the nearest 0·01 in. In this investigation on this basis the highest reading exceeded the lowest by 0·01 in. on 59 days, by 0·02 in. on 9 days and by 0·03 in. on 3 days. The daily differences in gauge readings cancel out over longer periods. The totals for the whole period from readings to the nearest 0·001 in. and 0·01 in. respectively are given in Table II. The relative order of the gauges is altered by the different accuracy of reading only in the case of gauges 1 and 3. Readings to 0·01 in. gave totals about one per cent higher. The highest-reading gauge exceeded the lowest by 0·97 per cent with readings to 0·001 in. and 1·02 per cent for readings to 0·01 in.

TABLE II—RAINFALL TOTALS

| | Gauge number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | *total in inches* | | | | | |
| To 0·001 in. | 21·529 | 21·622 | 21·583 | 21·614 | 21·462 | 21·415 |
| To 0·01 in. | 21·77 | 21·85 | 21·75 | 21·79 | 21·68 | 21·62 |
| | *excess percentage of readings to 0·01 in. over those to 0·001 in.* | | | | | |
| | 1·12 | 1·05 | 0·77 | 0·81 | 1·02 | 1·00 |

**Causes of variation.**—The relationship between the variations in gauge readings on different days was examined in the hope that a correlation with one or more causal factors could be found. Correlation coefficients between sets of readings were determined. Although some strong positive and negative correlations appeared the associated characteristics of rainfall totals, duration and intensity, and of wind strength and direction were so variable that no precise causes could be discovered. Space does not permit the discussion of specific examples.

**Rainfall amount and duration.**—The relationship to duration and total of fall is indicated by the following details. Thirty out of the forty-nine cases with standard deviations of 0·0020 in. or more registered falls of 0·200 in. or above. Thirty-nine falls of 0·200 in. or over were recorded. Seven of the nine cases with a standard deviation under 0·0020 in. were falls of short duration. Twenty-six of the thirty-nine falls of over four hours' duration had standard deviations of 0·0020 in. or more. Seven of the thirteen exceptions had falls below 0·200 in. Only three cases of long duration (eight hours or more) and a standard deviation under 0·0020 in. were found. The largest fall recorded, 0·904 in., gave a standard deviation of 0·0030 in. A steady fall, which occurred within two observing periods, gave durations of five-and-a-half and five hours for which the mean falls were respectively 0·530 in. and 0·582 in. with standard deviations of 0·0045 in. and 0·0132 in. Tables III and IV illustrate the relationship of rainfall totals to variability of readings.

TABLE III—RELATIONSHIP OF STANDARD DEVIATIONS TO RAINFALL TOTALS

| Rainfall in inches | Total number of cases | Cases with standard deviation under 0·0020 in. | Cases with standard deviation over 0·0030 in. | Mean standard deviation in inches |
|---|---|---|---|---|
| 0·00–0·09 | 46 | 39 | 1 | 0·00142 |
| 0·10–0·19 | 19 | 14 | 3 | 0·00188 |
| 0·20–0·29 | 17 | 5 | 6 | 0·00328 |
| 0·30–1·00 | 22 | 3 | 14 | 0·00437 |

TABLE IV—RELATIONSHIP OF COEFFICIENTS OF VARIATION TO RAINFALL TOTALS

| Rainfall in inches | Total number of cases | Cases of coefficient of variation 0–0·9% | Cases of coefficient of variation 1·0–1·9% | Cases of coefficient of variation over 2·0% | Mean coefficient of variation % |
|---|---|---|---|---|---|
| 0·00–0·09 | 46 | 1 | 6 | 39 | 5·01 |
| 0·10–0·19 | 19 | 8 | 8 | 3 | 1·27 |
| 0·20–0·29 | 17 | 6 | 9 | 2 | 1·33 |
| 0·30–1·00 | 22 | 18 | 3 | 1 | 0·79 |

**Rainfall intensity.**—The expectation that heavy showers would give the largest reading differences was not borne out. Twenty-nine cases of showery rain and twenty of drizzle were compared. 72 per cent of the showers and 55 per cent of the drizzle gave standard deviations of 0·0020 in. or less. This was not due to heavier falls of drizzle. Twelve of the shower totals exceeded 0·200 in. but only five of the drizzle falls did so.

**Wind force and direction.**—Data was limited to visual observations at the time of recording and to information obtained from the *Daily Weather Report.*[2] There were no gales during the period but the few moderate to strong breezes generally gave high standard deviations. Since the total falls in these cases were also high no conclusive link with wind force was apparent. No relationship to wind direction was revealed. It is convenient to explain the differences between gauges as being due primarily to the vagaries, especially near the ground, of wind eddies around the gauges, but it is impossible to substantiate this view. More precise local knowledge on the gustiness of the wind and the factors encouraging or limiting turbulence would help considerably. Longer durations of fall would permit eddies to have a greater effect, yet at the same time allow more chance for the variations they cause to cancel out. It is probable that there are rainfall variations over short distances which are explained not by minor eddies immediately around the gauge but by varying dispersal of the raindrops as they fall from the cloud base.

## Conclusions

(i) In relation to rainfall totals, daily periods showed larger differences between gauges than means for longer periods.

(ii) The greatest deviations occurred with falls which were heavy and usually, but not always, of long duration. Showers did not show a high degree of variation.

(iii) The differences between the totals of the six gauges for the whole period of observation were so small that they would not invalidate the practice of basing regional rainfall contrasts upon single representative gauges.

## Comments by A. Bleasdale

Both the present paper by J. Oliver and the earlier paper by L. H. Watkins,[1] discuss useful and interesting studies from which precise statistical estimates may be made of the accuracy of point rainfall measurements using standard rain-gauges *on satisfactory sites.* It may not be generally realized, however, that these studies are not breaking completely new ground, and that the routine collection of rainfall data, for very nearly a century, has resulted in the accumulation of a large amount of material leading to conclusions which are broadly equivalent to those reached in these two papers. In particular, there have been, during various periods and in various places throughout the country, pairs of gauges, one of any pair usually regarded as the standard and the other as a check gauge. There are a number of pairs at present in use. From the data from such pairs it has long been known that with the attainable accuracy of rainfall measurement it is both practicable and desirable to make *routine* daily measurements of rainfall to the second place of decimals in inches, but that there is no point in attempting to estimate the third place. It is arithmetically convenient to retain the two places of decimals for monthly and annual totals and even for averages, but the standard errors applicable to monthly and annual totals, areal averages and long-period averages require separate and fuller consideration. In this field, particularly with regard to averages, there are outstanding statistical problems which have not been completely solved. Returning to individual point measurements, a matter of overwhelming importance is that the use of unsatisfactory rain-gauges or unsuitable sites, or both, can completely vitiate the seeming accuracy of rainfall measurements indicated by studies with pairs or groups of gauges. Inaccuracies can be of the order of ten or even twenty per cent, far more often than not in the sense of deficiencies of catch on over-exposed sites, especially in hilly country. It is errors of this nature which are most troublesome in regional rainfall studies as referred to in the third conclusion of Mr. Oliver's paper.

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## AVERAGE HEIGHT OF THE STANDARD ISOBARIC SURFACES OVER THE TEMPERATE AND TROPICAL REGIONS IN JANUARY AND JULY

By H. HEASTIE, M.Sc.

**Introduction.**—The revision of *Upper winds over the world*[1] was started by constructing circumpolar charts of the height of the standard isobaric surfaces, as explained in a previous article,[2] where some of the charts for January were shown. Two further papers presented some of the corresponding charts for July[3] and for April and October.[4] In the course of this revision the mapping of the contours of the standard isobaric surfaces has been extended to 60°S. on a Mercator projection and some of these charts for January and July are presented here with a brief description. The complete sets of charts are given elsewhere.[5,6]

**Data.**—As for the circumpolar charts, data for the period 1949–53 were used. The main sources were manuscript data, CLIMAT TEMP[7] reports and the data tabulations from United States Weather Bureau *Daily Series Synoptic Weather Maps*, together with daily, monthly and annual publications of various countries. Further details are given in the appendix to *Meteorological Research Papers*, No. 1045.[5] Whenever available, data from ascents made in darkness were used in order to minimize errors due to solar radiation. Where daylight ascents had to be used no attempt was made to apply radiation corrections systematically because of the variety of types of radio-sonde in use. It proved possible, however, to apply corrections to data from stations using either the British or the Canadian type of radio-sonde. Wind data which were readily available for British overseas stations and Hong Kong were used. The period of these data was 1948–53, in general, though shorter periods only were available for some stations. All available data, irrespective of period, from stations in Antarctica were consulted as a guide to the drawing of the charts at the southern boundary.

**Method of constructing the charts.**—In constructing the circumpolar charts it was found necessary to draw a separate set of charts for each year. South of 55°N., however, variability from year to year is much less and it proved possible to work directly from data meaned over the five-year period. A set of temperature charts for each isobaric surface and of temperature lapse between adjacent isobaric surfaces were plotted. These charts together with the contour and thickness charts made four sets which were drawn so as to be mutually consistent. The 700-millibar temperature and contour charts were drawn first and the corresponding charts at 500 millibars were constructed by adding on the 700–500-millibar temperature lapse and thickness respectively. The addition was performed by using values at a set of grid points and consistency maintained by ensuring that the thickness agreed with the mean temperature of the layer determined as the mean of the 700 and 500-millibar temperatures. The charts at higher levels were built up by a repetition of this process, allowance being made for the effect of the tropopause in the relevant layer.

**Charts.**—Six only of the charts are illustrated here. North of 55°N. the charts are merely a redrawing of the circumpolar charts on a Mercator projection apart from some very minor amendments along the 55°N. parallel. The isopleth interval—100 geopotential metres—is double that shown on the circumpolar charts.[2, 3, 4]

For January the 500-millibar contour chart (Figure 1) represents the flow pattern in the troposphere in extratropical regions. A mainly westerly flow is shown in both hemispheres, with much greater meridional components in the northern hemisphere. There the main troughs occur at 80°W. and 140°E. in association with the cold lows over northern Canada and Siberia. The main ridges are at 160°W. and 0° with a weak trough–ridge pattern over eastern Europe and Russia. In the southern hemisphere troughs and ridges are much less pronounced; the main trough appears to be at about 40°E. with a subsidiary trough at 40°W. These features are also distinguishable on the 200-millibar (Figure 2) and 100-millibar chart (Figure 3).

Average contour charts tend to smooth out the jet streams which appear on the daily charts, but at 200 millibars (Figure 2) two strong wind belts can be noted over the North Atlantic. These are associated with the polar and subtropical jet streams. The more southerly one can be seen to link up across the Sahara with the strong wind belt of the Middle East which in turn extends across India to form part of the very strong belt over and south of Japan. A more rigorous analysis, using meridional cross-sections and streamline–isotach technique, suggests that the strong wind belt over India and China is not continuous with the one to the east of Japan. The more northerly strong wind belt over the North Atlantic becomes diffuse towards Europe and it is not possible to identify two separate streams elsewhere on the chart. These wind belts can be seen also on the 300-millibar chart (not reproduced here) and the 100-millibar chart (Figure 3), though at these levels the winds are less strong than at 200 millibars. In the southern hemisphere the data are too sparse to provide much detail. The strongest wind belt appears to lie between 45° and 50°S., with maximum winds occurring about 40°E. in association with the main trough. As in the northern hemisphere the axis of the strong wind belt lies at or near the 200-millibar surface (Figure 2). In the New Zealand sector there is a further wind maximum at 30° to 35°S. apparent on the 200-millibar and 150-millibar charts.

The seasonal contrast between summer and winter is much more marked in the northern than in the southern hemisphere. The very strong wind belts of the northern hemisphere described above have disappeared in July except over the eastern Mediterranean and northern United States where they appear on the 200-millibar chart (Figure 5) with wind speeds much reduced A belt of high contour height extends round the hemisphere at about 30°N. (Figures 5 and 6) except over India and China in the lower levels (Figure 4) where the monsoonal surface low is reflected by troughs in the 700-millibar (not reproduced here) and 500-millibar contours. At high levels (Figure 6) this belt, which is most marked over the Eurasian land mass leads to an easterly flow pattern over a large area south of 25°N. in eastern longitudes. This area is too near the equator for the winds to be deduced directly from the contours, but subsequent analysis using wind data indicates a belt of strong easterly winds with a maximum of over 60 knots.

In extratropical regions of the southern hemisphere there is mainly westerly flow, with little meridional motion, in July as in January. At 500 millibars (Figure 4) the main trough appears at about 80°E., while the main flow extends rather further northward than in January (Figure 1). The strength of the flow at this level shows little change between January and July, but at 200 millibars (Figure 5) the July flow is stronger and at 100 millibars (Figure 6) very much stronger than in January. The highest wind speeds occur at 200 millibars in January (Figure 2), while in July, south of 45°S., speeds are increasing with height up to and above 100 millibars. It seems probable that there are two strong wind belts, one corresponding to the subtropical jet stream with an axis at about 200 millibars and the other corresponding to the jet stream of temperate latitudes in the troposphere but merging in the stratosphere with the strong wind belt associated with the winter stratospheric jet.

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2. HEASTIE, H.; Average height of the standard isobaric surfaces over the north polar regions in January. *Met. Mag., London,* **85,** 1956, p. 368.

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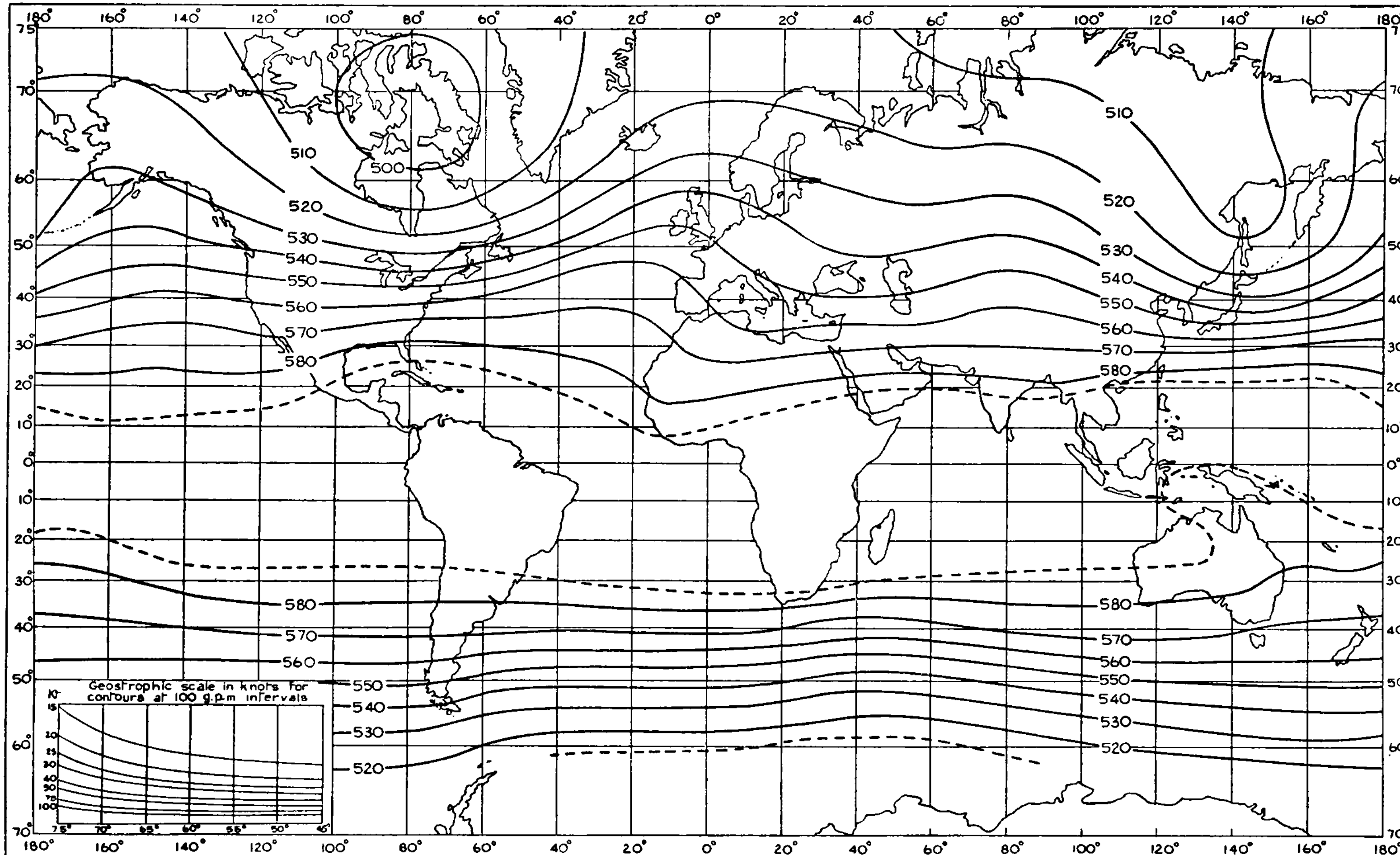



FIGURE I—AVERAGE 500-MILLIBAR CONTOURS FOR JANUARY 1949–53
Isopleths are drawn at intervals of one hundred geopotential metres.
(see p. 294)

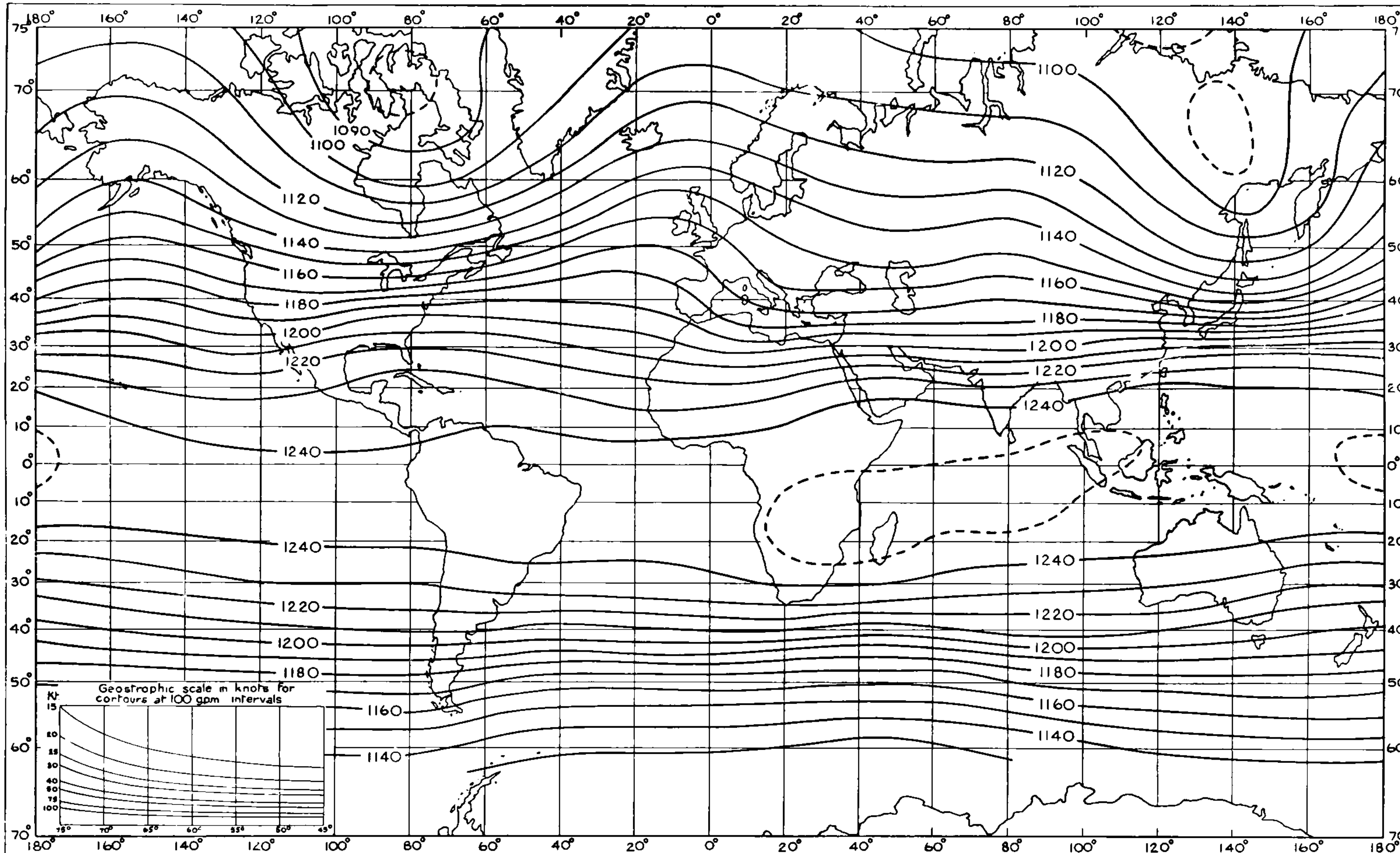



FIGURE 2—AVERAGE 200-MILLIBAR CONTOURS FOR JANUARY 1949–53

Isopleths are drawn at intervals of one hundred geopotential metres.

(see p. 294)

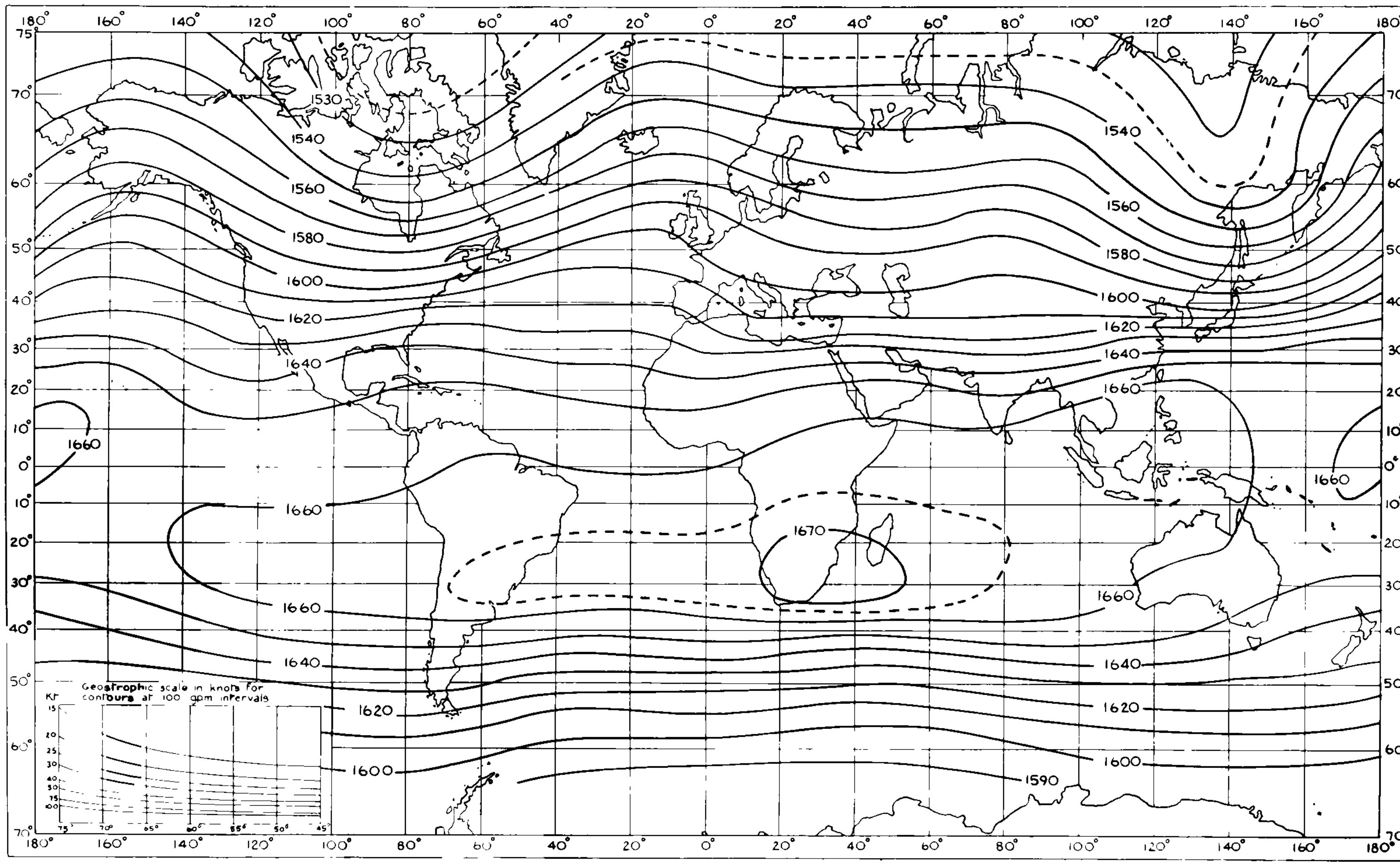



FIGURE 3—AVERAGE 100-MILLIBAR CONTOURS FOR JANUARY 1949–53

Isopleths are drawn at intervals of one hundred geopotential metres.

(see p. 294)

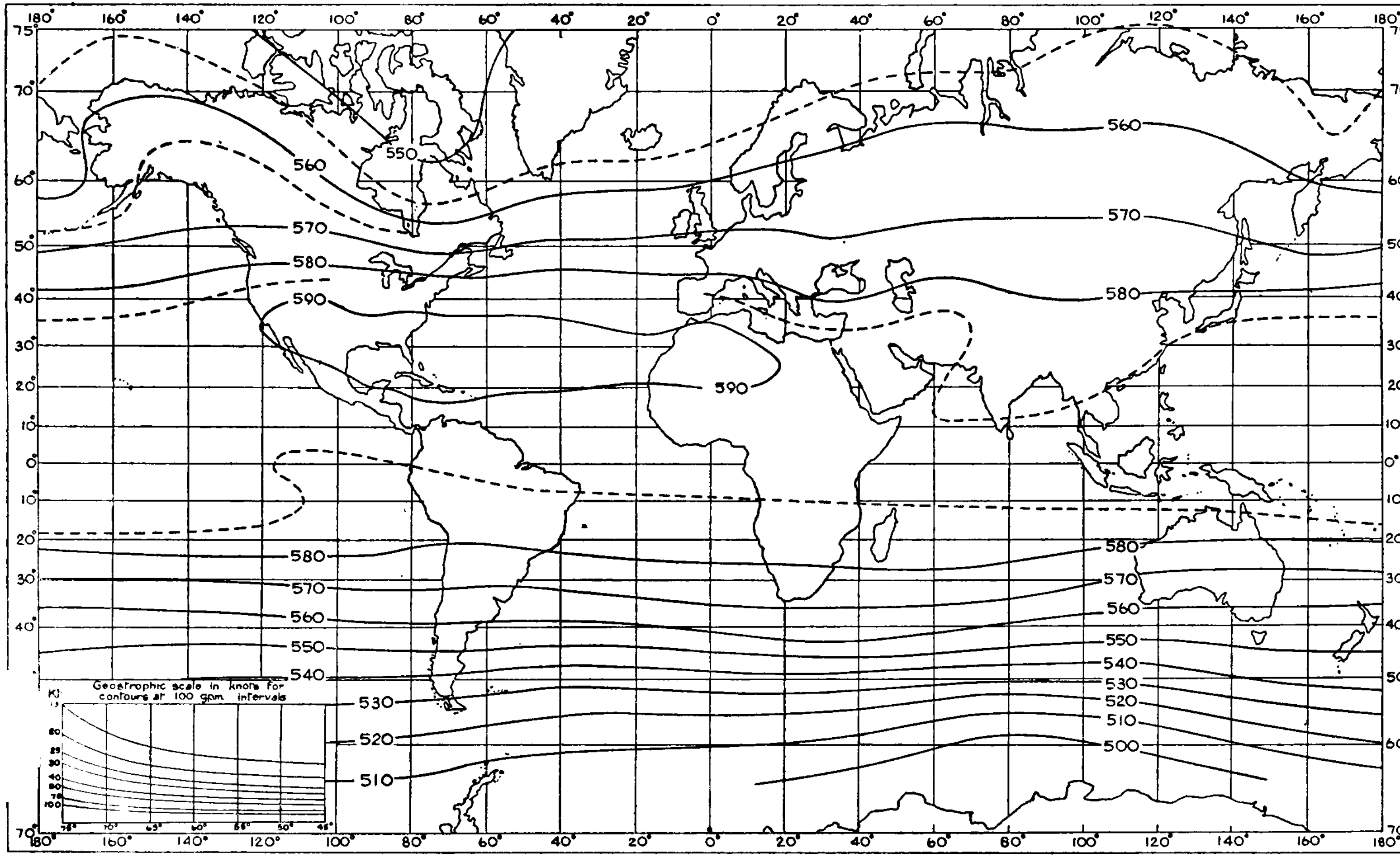



FIGURE 4—AVERAGE 500-MILLIBAR CONTOURS FOR JULY 1949–53

Isopleths are drawn at intervals of one hundred geopotential metres.

(see p. 295)

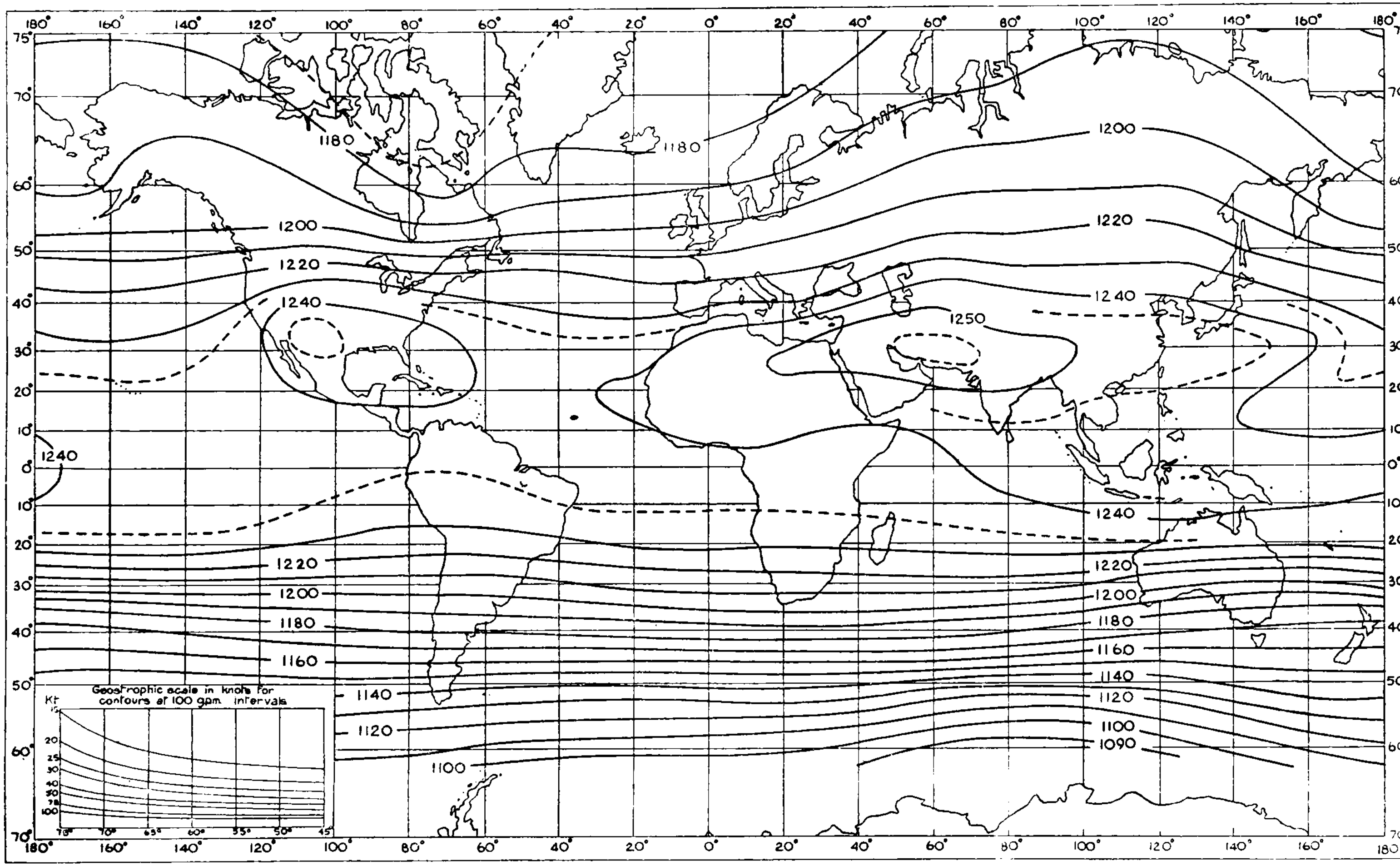



FIGURE 5—AVERAGE 200-MILLIBAR CONTOURS FOR JULY 1949–53

Isopleths are drawn at intervals of one hundred geopotential metres.

(see p. 295)

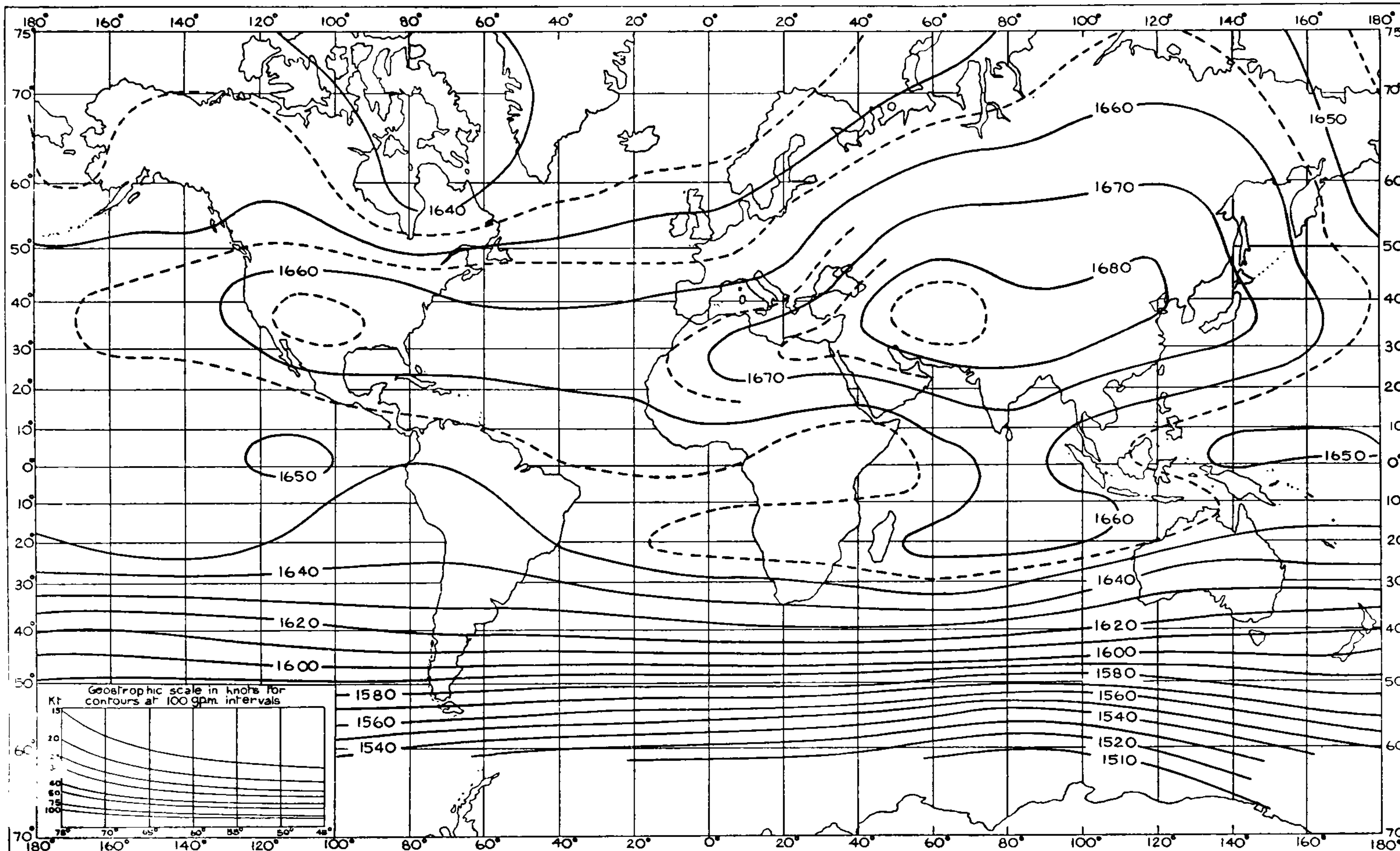



FIGURE 6—AVERAGE 100-MILLIBAR CONTOURS FOR JULY 1949–53

Isopleths are drawn at intervals of one hundred geopotential metres.

(see p. 295)

# BLOCKING ANTICYCLONES IN THE ATLANTIC–EUROPEAN SECTOR OF THE NORTHERN HEMISPHERE

By E. J. SUMNER, B.A.

Northern hemisphere circulation patterns are predominantly zonal in character, particularly in the middle and upper troposphere, with a general west-to-east mobility (progression) of both surface and upper features. But from time to time, in limited sectors, the strength of the zonal component of the flow decreases sharply, usually because of excessive meandering of the upper current often accompanied by a fanning out or bifurcation of the jet stream. In these circumstances the progression, of the larger features at least, diminishes and may even be replaced by an effective east-to-west displacement (retrogression). Simultaneously a complete "inversion" of the normal latitudinal distribution of surface pressure occurs, with a depression in the subtropics and an anticyclone in middle or high latitudes which hold up (or block) the eastward progress of oncoming systems.

This, in barest outline, is blocking. (For a fuller discussion of the subject, the reader is referred to a previous paper by the present writer.[1]) There are two main synoptic types which for convenience may be called "diffluent" and "meridional" blocks, respectively. The first type, which is also the commonest, is illustrated in Figure 1. As will be seen, the jet stream separates into two distinct streams, one going to the north-east around a large warm anticyclone (usually known as the blocking high) while the other circumnavigates the cold low to the south. The second type, shown in Figure 2, is essentially a single upper ridge of very large amplitude, the anticyclonic circulation associated with it extending throughout the whole troposphere and beyond, as it does in type one. Changes from one type to the other frequently occur within the same spell of blocking.

**Blocking 1949–56.**—The following study, which is a continuation of an earlier one,[1] is of the seasonal and geographical distribution of blocking in the eight-year period 1949–56. Only patterns reasonably resembling those of Figures 1 and 2 were selected, the catalogue being based on a series of miniature circumpolar charts (0300 G.M.T. surface, 1000–500-millibar thickness and 500-millibar contour) prepared in the Research Section at Dunstable. However, these were not available for the first two months of 1949 and from June 1955 to the end of the period; for these nine months the *Synoptic Weather Maps* (sea level and 500 millibars) of the United States Weather Bureau were used.

Undoubtedly the most important single feature of blocking, in forecasting for the latitudes of the British Isles, is the blocking high. Thus in the present selection both the surface and the upper (500-millibar) high-pressure cells had to be fairly well developed, although a particularly strong upper circulation was sometimes deemed to compensate for a poor or almost non-existent surface feature, and conversely. The position of the anticyclone at 500 millibars (or if absent, that of the surface high) was taken to define the position of the blockage, and measurements of its latitude and longitude, to the nearest five degrees, were made at appropriate intervals.

The area considered lay from 100°W eastwards to 60°E, and north of 50°N. Spells of blocking were begun with the first and ended with the last 0300 G.M.T. charts showing the appropriate patterns. If a blocking anticyclone moved from the east or west into or out of the area at some time during its lifetime, it was

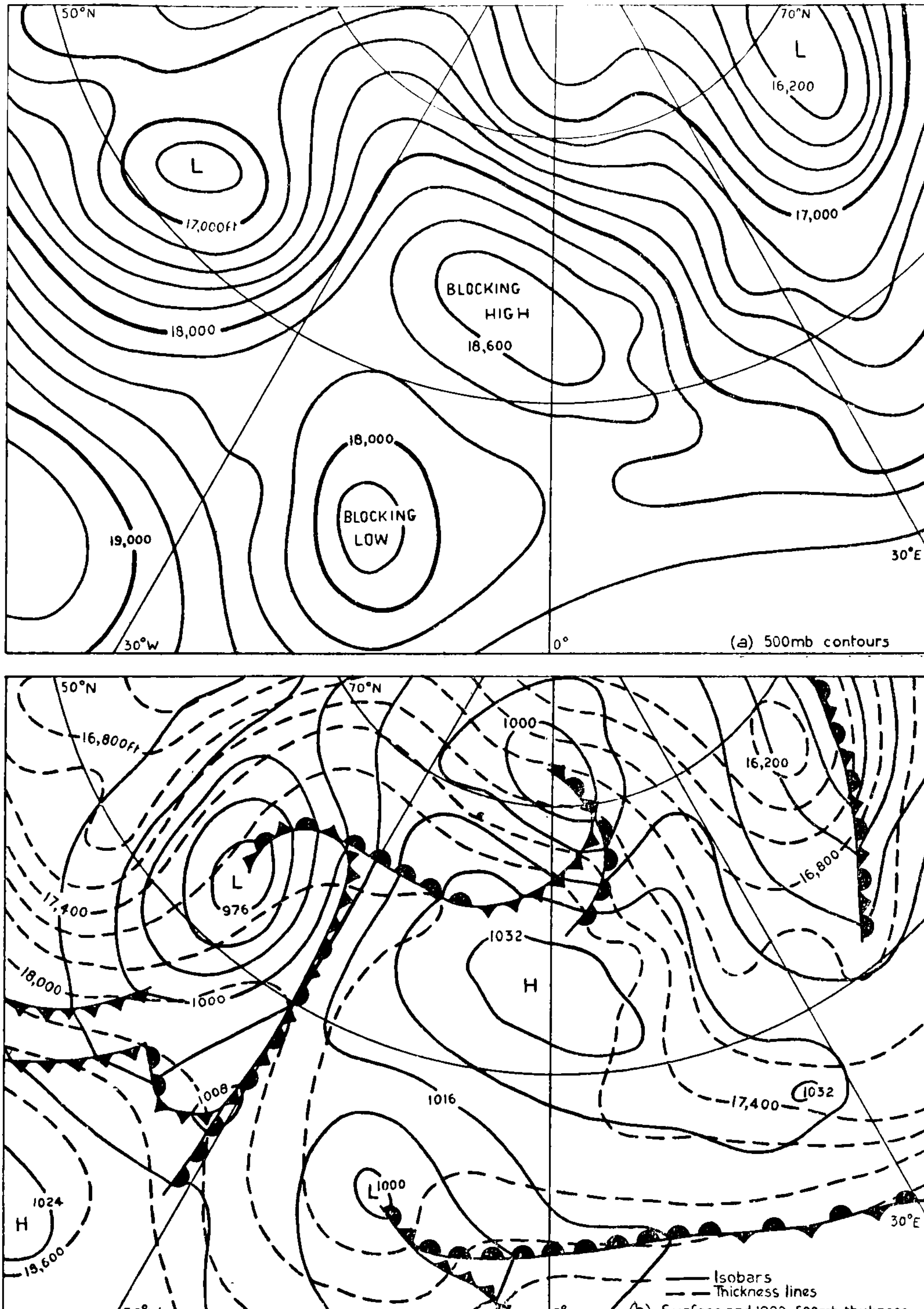



FIGURE 1—EXAMPLE OF A "DIFFLUENT" BLOCK, 0300 G.M.T., 22 DECEMBER 1948

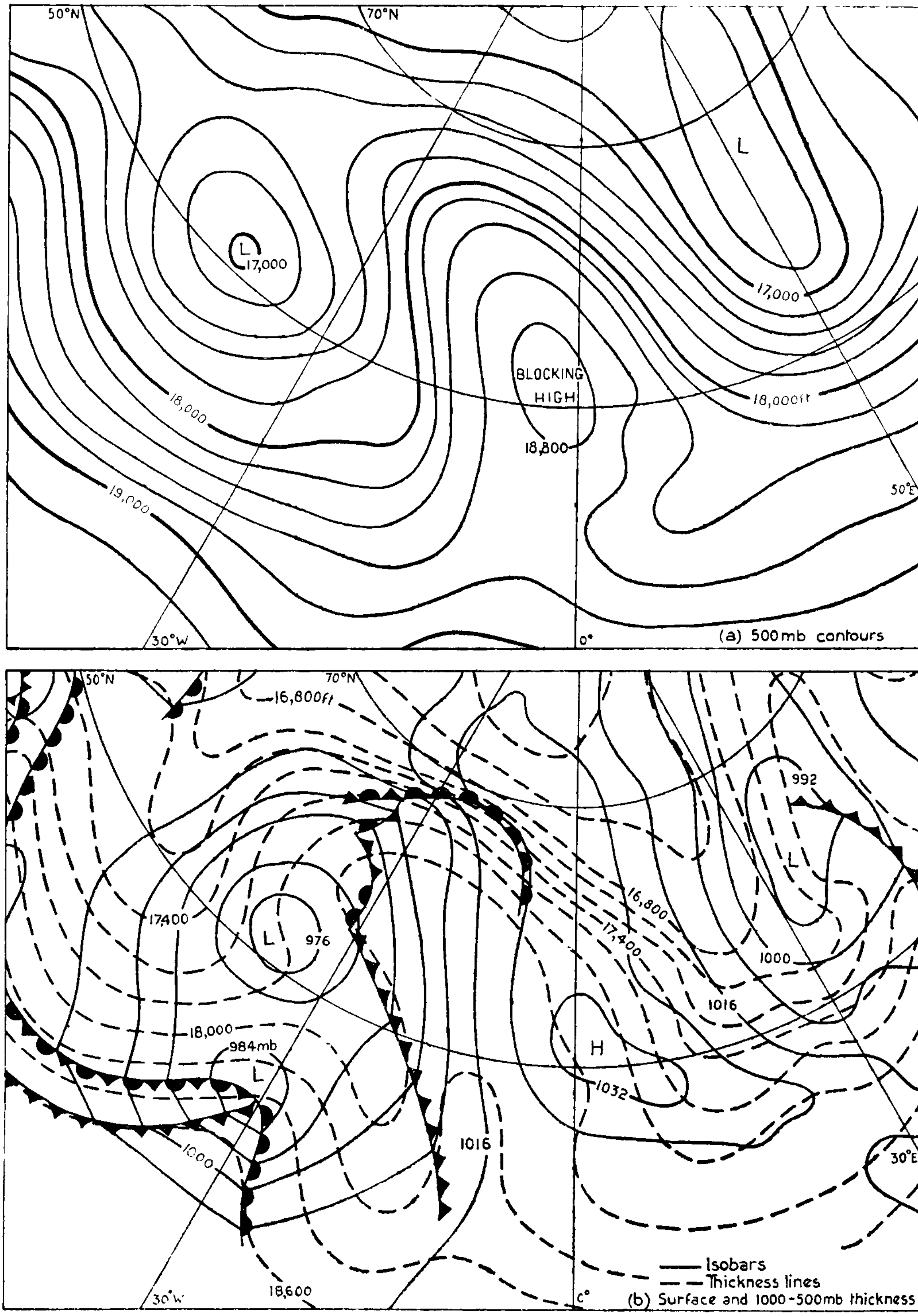



FIGURE 2—EXAMPLE OF A "MERIDIONAL" BLOCK, 0300 G.M.T., 23 NOVEMBER 1948

"followed" in order to complete the statistics relating to spell duration. Blocking highs south of 50°N were excluded mainly because there is effectively little difference between them and the normal subtropical highs. Highs which formed south of 50°N and subsequently moved northwards were included from the time they crossed the 50th parallel, and a spell of blocking was discontinued if and when it finally sank below 50°N.

The longitudinal movements of the blocks were classified into periods when they were eastward-moving or progressive (P), quasi-stationary (Q) and westward-moving or retrogressive (R), respectively. The measurements of position, referred to above, were recorded only at the beginning and end of such periods, unless changes of latitude occurred within them.

In the earlier study[1] cases for the first half of the period only (that is 1949–52) were analysed and compared with the results of two other papers, by Rex[2] and Bretzowsky *et alii*,[3] working from dissimilar points of view and with earlier data. The data compiled for the second half of the period (that is 1953–56) thus provided an opportunity for further comparison and verification. However, as the results for the two four-year periods were broadly confirmatory, they are here lumped together and only the main differences will be explicitly remarked on.

**General statistics.**—During the eight years in question there were 115 distinct spells of blocking of average duration 14·5 days. These comprised 1,670 days of blocking (that is occurrences on 0300 G.M.T. charts) of which 1,593 were within the area and period considered. (The final case, commencing on 20 December 1956, continued to 7 January 1957, and there were 70 days of blocking east of 60°E.) Two blocking patterns occurred simultaneously within the area on 67 occasions (about 4½ per cent of the time); for ease of working, these few overlaps were usually treated as two separate days of blocking.

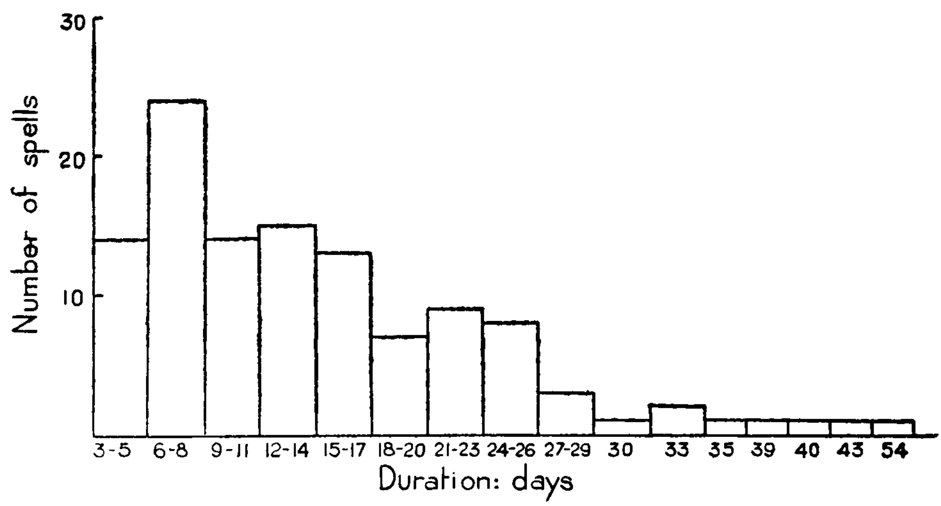



FIGURE 3—FREQUENCY DISTRIBUTION OF SPELL DURATION

115 spells: 1,664 days of blocking, average duration 14·5 days.

The frequency distribution of spell duration is shown in Figure 3; they range from three to 54 days with a mode at seven days and a median duration of about 12 days. It is evident from these figures that a medium-range forecaster would be well advised to preserve a recently formed block on his charts for the whole of the forecast period (four or five days, that is). It may of course be forecast to vary in intensity and position; in fact, blocking anticyclones were progressive about one third of the time and retrogressive about one quarter (see Table I).

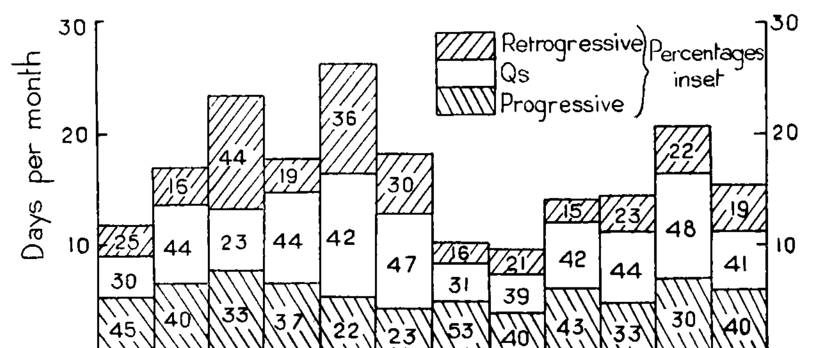
**Secular variation.**—The variations from year to year of days of blocking within the area and of the percentages of progressive, quasi-stationary and retrogressive cases, are shown in Table I. The number of overlapping cases is given in brackets after each yearly total.

TABLE I—YEARLY DISTRIBUTION OF BLOCKING

| Year | Percentage occurrence P | Q | R | Total number of days | Number of spells | Average duration in days |
|---|---|---|---|---|---|---|
| 1949 | 39 | 40 | 21 | 184 (1) | 13 | 15·0 |
| 1950 | 32 | 33 | 35 | 205 (6) | 13 | 15·5 |
| 1951 | 32 | 49 | 19 | 207 (12) | 11 | 19·0 |
| 1952 | 31 | 41 | 28 | 233 (25) | 16 | 16·5 |
| 1953 | 33 | 44 | 23 | 182 | 13 | 14·5 |
| 1954 | 28 | 44 | 28 | 195 (19) | 12 | 17·0 |
| 1955 | 35 | 38 | 27 | 201 | 21 | 9·5 |
| 1956 | 43 | 34 | 23 | 186 (4) | 16 | 12·0 |
| 1949–56 | 34 | 40 | 26 | 1593 (67) | 115 | 14·5 |

The secular variation is remarkably small, especially if overlaps are ignored. Each year one or more blocking anticyclones were present for about half the time. However, some years had few spells of long duration whereas others had many of short duration. There was a little more variation in the proportions of P, Q and R, but not systematically.

It should be stated that both Rex[2] (14 years' upper air data for a similar sector, from the end of 1932 to 1940 and from 1945 to the beginning of 1950) and Bretzowsky[3] (70 years' surface data, 1881–1950, for the sector 20°W–50°E) find considerably more secular change for their periods.




| Spells centred within the month | J | F | M | A | M | J | J | A | S | O | N | D | Total spells |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | 6 | 9 | 12 | 11 | 15 | 9 | 5 | 4 | 9 | 11 | 14 | 10 | 115 |
| Average duration: days | 12 5 | 23 0 | 16·5 | 10·5 | 16·5 | 15·5 | 12 0 | 18·0 | 14·0 | 12·5 | 13·0 | 11·5 | 14·5 |
| Standard deviation of monthly values: days | 6·5 | 9·0 | 4 0 | 6 0 | 7·0 | 6 5 | 9·5 | 8·0 | 9·5 | 7·5 | 6·0 | 10·0 | |

FIGURE 4—AVERAGE MONTHLY DISTRIBUTION OF BLOCKING, 1949–56

**Monthly distribution.**—The average monthly distribution is shown in Figure 4. The general profile, with its spring maximum, late summer minimum and secondary maximum in autumn, is in close agreement with Bretzowsky's figures, even to the temporary slump in April. A similar annual distribution occurs in the number of spells per month (also shown in Figure 4) but with the autumn maximum almost equal to that in spring. The longevity of blocking in February is in sharp contrast to the shortest average duration in April. It is also interesting to note how persistent blocking can be in August on the few occasions that it becomes established.

Five out of the eight years had fairly similar annual profiles, although the scatter in some months was quite large (see the figures for the standard deviations of monthly amounts, Figure 4). There was a decrease in the amount of blocking in spring from the first to the second half of the eight-year period, and a compensating increase in the summer.

The high proportions of retrogression in March and May and of progression in July and September are noteworthy; these are partly associated with the general shift of blocking anticyclones from Europe to the Atlantic in spring and back again in late summer and autumn, as will be seen in the next section. The comparative absence of progression in May and June and of retrogression in July and September (particularly) point to the same effect. All of these proportions were consistently above or below average, as the case might be, in both halves of the period, most of them 25 per cent or more above their average percentages (Table I).

Other categories of significance, on the same criterion of consistency and size of departure from average, are: the high proportion of progression in January at the expense of the quasi-stationary class, and the smallness of the Q-class in March and the R-class in December.

**Distribution with latitude and longitude.**—The latitudinal distribution (Figure 5) shows a peak frequency between 55° and 60°N, although cases within the next higher five-degree range are almost as common. Broadly, the percentage of progression decreases with increasing latitude and vice versa for retrogression. The former variation was, however, almost entirely confined to those cases situated west of the Greenwich Meridian.

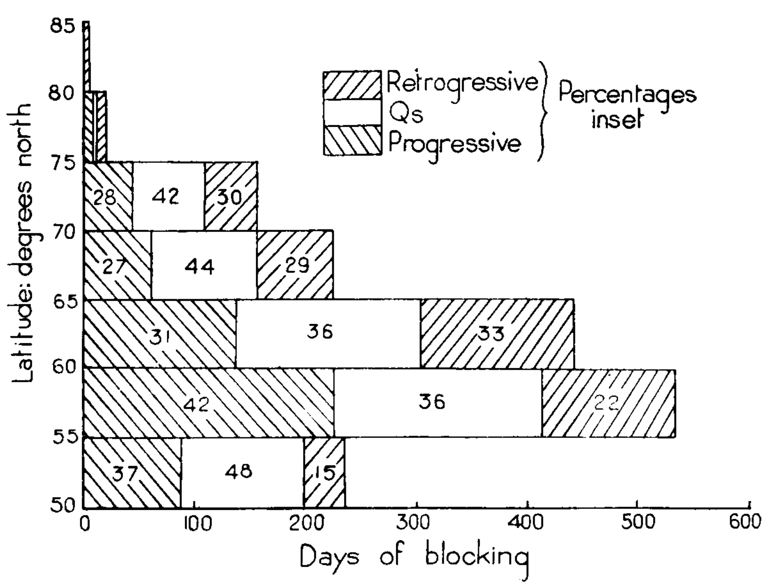



FIGURE 5—DISTRIBUTION OF BLOCKING WITH LATITUDE

The longitudinal profile (Figure 6) has a peak just west of Greenwich falling more quickly to the west than the east. Rex,[2] using the split in the jet stream to define the position of blocking, found a similar but sharper peak, with the skewness to the west instead of the east as in our data. Retrogression is relatively more frequent over the Atlantic than over Europe, whereas progression increases eastwards. Well developed blocks are almost non-existent over North America.

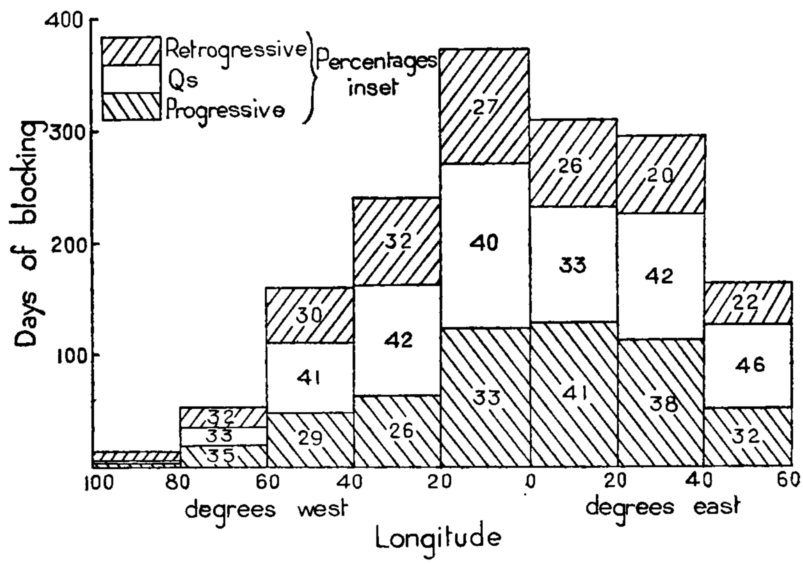



FIGURE 6—DISTRIBUTION OF BLOCKING WITH LONGITUDE

Tables II and III give the latitudinal and longitudinal distributions by months. With respect to the former, some "lifting" to higher latitudes is apparent in the summer, with a pronounced slump in mean latitude in April; apart from this systematic effect the meridional profile is similar to that of Figure 5 for nearly every month.

TABLE II—MONTHLY DISTRIBUTION OF BLOCKING ANTICYCLONES WITH RESPECT TO LATITUDE, FOR THE PERIOD 1949–56 AND THE AREA 100°W–60°E

| Latitude range | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *degree.* | | | | | | | *number of days* | | | | | | |
| 50–54 | 18 (1) | 22 | 27 (1) | 44 | 32 | 13 | 5 | 18 | 14 | 7 | 19 | 15 | 234 (2) |
| 55–59 | 17 (1) | 47 | 73 (1) | 67 | 52 | 36 | 10 | 19 | 59 | 51 | 58 | 41 | 530 (2) |
| 60–64 | 30 | 29 (14) | 61 (3) | 24 | 67 | 39 | 45 (4) | 14 | 28 | 32 | 42 | 28 (3) | 439 (24) |
| 65–69 | 24 | 18 (9) | 19 (4) | 5 | 32 | 23 | 15 (4) | 14 | 10 | 16 | 20 | 24 (1) | 220 (18) |
| 70–74 | 5 | 22 (8) | 9 (4) | 2 | 27 | 29 | 6 | 9 (7) | 2 (1) | 9 | 19 (2) | 14 | 153 (23) |
| 75–79 | | | | | 1 | 6 | | 2 | | | 5 (2) | 1 | 15 (2) |
| 80–84 | | | | | | | | | | | 2 | | 2 |
| Total | 94 (2) | 138 (31) | 189 (13) | 142 | 211 | 146 | 81 (8) | 76 (7) | 113 (1) | 115 | 165 (4) | 123 (4) | 1593 (70) |
| Average latitude | | | | | | | *degrees* | | | | | | |
| | 61·5 | 61·5 | 60·0 | 57·5 | 62·0 | 64·5 | 63·0 | 61·5 | 59·5 | 61·0 | 61·0 | 62·0 | 61·5 |

Figures in brackets give the (additional) number of days of blocking east of 60°E.

Table III shows a striking westward shift of blocking from February to May, and a return eastwards in late summer and autumn. (This return occurred in June in the second four years' data but was delayed until August in the first.) This gives rise to a marked dissimilarity in the annual distributions over the Atlantic and over Europe, as is evident from the last two columns of Table III in which the monthly totals in the 60-degree sectors west and east of Greenwich, respectively, are given. These distributions are similar to these given by Bretzowsky.[3]

TABLE III—MONTHLY DISTRIBUTION WITH RESPECT TO LONGITUDE

| Month | Longitude: °W 99–80 | 79–60 | 59–40 | 39–20 | 19–0 | Longitude: °E 1–20 | 21–40 | 41–60 | 61–80 | Totals in 60° sectors 0–59°W | 1–60°E | Grand total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | number of days | | | | | | | | | | | |
| Jan. | | 1 | 13 | 15 | 18 | 33 | 12 | 2 | 2 | 46 | 47 | 96 |
| Feb. | | 1 | 2 | 42 | 26 | 25 | 23 | 19 | 31 | 70 | 67 | 169 |
| March | | 5 | 14 | 25 | 59 | 40 | 34 | 12 | 13 | 98 | 86 | 202 |
| April | | 6 | 20 | 28 | 34 | 26 | 20 | 8 | | 82 | 54 | 142 |
| May | 2 | 9 | 43 | 48 | 57 | 35 | 11 | 6 | | 148 | 52 | 211 |
| June | 5 | 4 | 24 | 23 | 33 | 12 | 43 | 2 | | 80 | 57 | 146 |
| July | 1 | 5 | 3 | 8 | 14 | 18 | 12 | 20 | 8 | 25 | 50 | 89 |
| Aug. | | | | 1 | 15 | 10 | 29 | 21 | 7 | 16 | 60 | 83 |
| Sept. | | | 2 | 14 | 25 | 31 | 30 | 11 | 1 | 41 | 72 | 114 |
| Oct. | | 9 | 5 | 3 | 28 | 43 | 24 | 3 | | 36 | 70 | 115 |
| Nov. | | 1 | 21 | 13 | 35 | 15 | 35 | 45 | 4 | 69 | 95 | 169 |
| Dec. | 6 | 8 | 15 | 18 | 20 | 16 | 23 | 17 | 4 | 53 | 56 | 127 |
| Total | 14 | 49 | 162 | 238 | 364 | 304 | 296 | 166 | 70 | 764 | 766 | 1663 |

It does not follow of course that these seasonal drifts are entirely accomplished by the migration of individual blocking highs, even though the monthly proportions of progression and retrogression, as discussed in the previous section, are in the required sense. In fact, on investigation, it seemed that the increased tendency for blocks to form and to stay over the Atlantic in spring and over Europe in autumn was about of equal importance.

**Constitution of spells.**—An analysis of the duration of individual periods of progressive, quasi-stationary and retrogressive blocking is given in Table IV. Periods of retrogression are much less frequent than either of the other two classes, but on average last slightly longer than periods of progression. The model frequency is, however, three days for each class of movement.

TABLE IV—FREQUENCY DISTRIBUTION OF DURATION OF PROGRESSIVE, QUASI-STATIONARY AND RETROGRESSIVE PERIODS

| Type of movement | Duration of periods in days 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | More than 12 days | Total number of periods | Total days | Average duration days | Average speed °longitude per day |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | number of periods | | | | | | | | | | | | | | | | |
| P | 12 | 29 | 33 | 31 | 12 | 17 | 9 | 4 | 2 | 1 | – | – | — | 150 | 579 | 3·9 | 6·0 |
| Q | 13 | 22 | 33 | 25 | 19 | 13 | 3 | 3 | 3 | 2 | 1 | 1 | 13, 13, 13, 14, 14, 17, 18, 23 | 146 | 669 | 4·6 | — |
| R | 4 | 20 | 22 | 21 | 11 | 12 | 3 | 2 | 1 | 1 | 2 | 2 | — | 101 | 422 | 4·2 | 7·5 |
| Total cases | 29 | 71 | 88 | 77 | 42 | 42 | 15 | 9 | 6 | 4 | 3 | 3 | 8 | 397 | 1,670 | 4·2 | |

One would expect from these figures that the longer spells would almost certainly contain more than one of the ingredients P, Q or R. Indeed, about 40 per cent of the 115 cases were composed of all three constituents, some of them more than once (average duration 21 days), and 25 per cent any two combined (average duration about 13 days). The remaining 35 per cent were "pure" spells, lasting on average about eight days, but less than one tenth of these were retrogressive throughout.

This deficiency of the R-class in the shorter spells suggested that there might be a systematic variation in the proportions of P, Q and R with spell duration. Accordingly the spells were segregated into five approximately equal groups of increasing duration and the percentage of days of each class of movement worked out for each group (see Table V). The average duration in days of individual sub-periods is given in the second column for each group.

There is a steady decrease in the amount of progression with increasing spell duration, and an equally marked, though not so steady, increase in the amount of retrogression. Although the quasi-stationary sub-periods lengthen a little in the longer spells, there is no significant variation in the average duration of periods of P and R.

In interpreting these results, it is possibly significant that retrogression is frequently accompanied by the development of new anticyclonic cells somewhere on the western flank of the original blocking high, which merge with it or take over from it so as to effect a net westwards displacement. This merger

TABLE V—PERCENTAGES OF DAYS OF P, Q AND R FOR VARYING SPELL DURATION

| Type of movement | Spell duration in days: 3–6 | | 7–11 | | 12–16 | | 17–22 | | More than 22 | | All the spells | | Number of cell renewals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *per cent* | *days* | *per cent* | *days* | *per cent* | *days* | *per cent* | *days* | *per cent* | *days* | *per cent* | *days* | |
| P | 52 | 4·5 | 38 | 3·5 | 35 | 3·4 | 31 | 4·4 | 30 | 4·0 | 34 | 3·9 | 22 |
| Q | 36 | 3·5 | 49 | 4·2 | 37 | 4·2 | 45 | 5·5 | 39 | 5·0 | 40 | 4·6 | 80 |
| R | 12 | 4·2 | 13 | 2·7 | 28 | 4·3 | 24 | 4·0 | 31 | 4·5 | 26 | 4·2 | 102 |
| Total number of cases | 25 | | 26 | | 24 | | 19 | | 21 | | 115 | | 204 |

process goes on to a less extent in quasi-stationary blocking, but very rarely with progression (the total number of renewals in each class is given in the last column of Table V). It has been suggested by various authors that such cell renewals are necessary for the continued existence of anticyclones, and the above data are in keeping with this hypothesis.

In Table IV the average speeds of progression and retrogression are given: these varied little from month to month. It is surprising at first sight that the latter exceeds the former (7·5 degrees longitude per day as compared with 6·0). Here again the clue probably lies in the cell replacement process, which in about 20 per cent of the cases of retrogression resulted in the formation of a completely new surface cell some 30–40° to the west of the declining original high, the continuity being maintained more in the upper flow pattern. In general, these rapid discontinuous displacements were immediately followed by a slow progression as the still developing surface high moved towards the axis of the asymmetric upper ridge. The same was true but in less degree in the larger proportion of cases of more continuous retrogression involving cell renewals. If all these more erratic movements were smoothed out, the mean speeds would probably both be between five and six degrees longitude per day.

**Formation, decline and general character.**—A synoptic study was made of the formation and ultimate decline of each case catalogued. A complete account with the necessary illustrations is beyond the compass of the present article, but the following notes and references may serve as an introduction to the subject.

Two of the commoner evolutions in the formative stage were: (*a*) a so-called instability development in which a progressive upper ridge, in association with a developing surface ridge or anticyclone, increased in amplitude (sometimes quite slowly) usually decelerating as it did so; (*b*) a simple anticyclonic disruption of an existing long wave as the axis of an upper ridge, rotating clockwise, became more and more inclined to the meridians ultimately resulting in a partial cutting off of anticyclonic and cyclonic circulations in the high-latitude part of the ridge and the low-latitude part of the succeeding trough, respectively. These two evolutions have been well illustrated by Sutcliffe.[4] Instability developments usually led to the formation of meridional blocks (Figure 2) and long-wave disruptions to diffluent blocks (Figure 1), but the former process often followed through to the latter without first forming or settling down as a meridional type.

Of the 115 spells, 14 formed along the lines of (*a*) above and eight as in (*b*), with a further 19 resulting from a combination of both processes. In another 26, a pre-existing low-latitude block moved to north of 50°N often in association with an instability development to the north. It was not so easy to classify the remaining 48 cases, although most of them showed minor instability or disruptive characteristics. In general the mean zonal flow in the sector in which the fully developed blocking subsequently appeared was already lower than elsewhere, possibly days before, and the pressure gradually built up in the region of weak thermal contrast and semi-stagnant upper flow.

Initially 71 of the cases were of the diffluent type and the other 44 meridional, but subsequent alternations of type—usually because of longitudinal movement of the blocking high—were common, especially in the longer spells. Of those diffluent to start with, 39 remained so throughout their lifetime, 12 turned to the meridional type before dying out and 20 subsequently alternated between the two. Only 12 of the meridional type remained so; 14 changed to the diffluent type and 18 alternated.

The decline of blocking was easier to classify. A large proportion of cases (58 out of the 115) ended as the high sank into lower latitudes (where it usually persisted as a subtropical cell) with a simultaneous decrease in the amplitude of the upper ridge and a resumption of a more zonal type of flow. At this stage most cases were progressive, only 14 being quasi-stationary and five retrogressive.

The breakdown of a further 40 cases was rather more complicated, the main features being a preliminary narrowing of the upper ridge with a northwards withdrawal of the secluded portion while the remnants of the ridge farther south sank into lower latitudes allowing the westerlies to advance in middle latitudes. (At this end stage, the blocking highs, or what were the largest surviving portions, were equally likely to be quasi-stationary as moving to the west or the east.) In the remaining 17 cases, the cellular features of the pattern simply weakened and faded away.

The longitude at which the highs were sufficiently well formed to be included and at which they were finally lost are classified in Table VI, together with the movement behaviour at the time. Most of the spells, the mobile ones especially, formed over the Atlantic, the peak frequency being just west of the British Isles. By the end of their existence, however, they had spread east and west. The scarcity of retrogression initially is a reflection of the fact that at quite a late stage of their growth the highs were usually moving towards their maximum latitude and were still under the influence of the zonal westerlies.

TABLE VI—LONGITUDE AND MOVEMENT BEHAVIOUR, INITIALLY AND FINALLY

| Type of movement | | Longitude: °W 99–80 | 79–60 | 59–40 | 39–20 | 19–0 | Longitude: °E 1–20 | 21–40 | 41–60 | 61–80 | Total | Net displacement | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *number of cases* | | | | | | | | | | | |
| Beginning of spell | P | 3 | 2 | 5 | 11 | 18 | 9 | 6 | 2 | | 56 | 55 | First half of spell |
| | Q | | 2 | 5 | 12 | 11 | 8 | 7 | 7 | 1 | 53 | 33 | |
| | R | | | | 2 | 2 | 1 | 1 | | | 6 | 27 | |
| Total | | 3 | 4 | 10 | 25 | 31 | 18 | 14 | 9 | 1 | 115 | | |
| End of spell | P | | 1 | 5 | 12 | 9 | 9 | 14 | 6 | 6 | 62 | 51 | Second half of spell |
| | Q | 2 | | 10 | 2 | 7 | 4 | 2 | 4 | 1 | 32 | 23 | |
| | R | 1 | 4 | 2 | 6 | 4 | | 2 | 1 | 1 | 21 | 41 | |
| Total | | 3 | 5 | 17 | 20 | 20 | 13 | 18 | 11 | 8 | 115 | | |

Later on in a spell retrogression, which is more a high-latitude phenomenon, comes increasingly into its own, but largely at the expense of the quasi-stationary class. This will be more evident from the figures given in the last column for the net displacement within the first and second halves of the spells (in this connexion Q represents a net displacement of five degrees of longitude or less, P and R a greater net displacement, east and west, respectively).

**Discussion.**—Climatological statistics are largely a record of a period; they may have little application in forecasting for later periods, indeed, they may be worse than useless. Those especially which give rise to preconceived ideas about what is the most likely synoptic evolution or pressure type at a particular calendar date may not only be a snare but, some forecasters think, a singular delusion. To be of any practical use, statistical relationships must be demonstrably stable over a lengthy period; and the more widely relevant they are to forecasting problems the better.

The present sample of data, although it covers a sizeable portion of the modern era (during which upper air charts have been regularly available in forecasting), represents only a small slice of climatic history. Fortunately, as we have seen, the broad picture appears to survive the test of time. The same monthly and longitudinal distributions, for example, may reasonably be expected to recur in future. The monthly totals may of course be expected to vary considerably from year to year; also there is some evidence of an appreciable variation in yearly amounts, in spite of the lack in recent years.

There can be little doubt that blocking is of major importance in forecasting the weather of the British Isles for periods up to several weeks ahead because of its large area of influence, long persistence and dominating position near to the country. The emphasis we have placed on the high-pressure cell of the blocking complex and the choice of its centre to locate blocking is perhaps questionable, but for our latitudes at least this is the most important pivotal system. Given the dates of formation and decay of these anticyclones and their central positions throughout a whole season, say, much could be deduced not only about the general character of the weather over a wide area but also the more localized sequences of weather type. For lower latitudes the position of the blocking low, if one exists, would be more indicative.

Several attempts have been made to explain the preferred seasonal and geographical distributions of blocking. Elliott and Smith,[5] for example, regard it as a sort of safety valve which releases the surplus heat accumulated in low latitudes—presumably mainly in the latent form and reaching a maximum in spring. Certainly the growth of a proportion of blocks from instabilities is consistent with this idea, in that most of these cases appear to be initiated by a rapid cyclogenesis on the western flank of the main subtropical high on the Atlantic. A greater distortion of the thickness lines and the upper flow would be produced if the air brought up from the south ahead of this low were moister than usual and therefore subject to less cooling as it was lifted.

However, since instabilities do not always lead to blocking, other factors must be contributory. Berggren *et alii*[6] have emphasized the importance of an initial general diffluence in the upper flow in ensuring the maximum meridional growth (and deceleration) of an incipient long wave, and this too seems to be borne out in synoptic experience. Another feature, noticed in the formative stage of blocking, was the frequency with which cells broke away from a pre-existing anticyclone in polar regions to join with the high-pressure surge from lower latitudes, thereby facilitating a break in the westerlies. This may be another but rather indirect link with the seasonal warming, the main effect of which is the eviction from the warming continents in spring of air, part of which accumulates in the polar basin. This process presumably must go on irrespective of the synoptic régime in middle latitudes.

But however cogent such speculations are, it is unlikely that any further advance will be made in understanding blocking phenomena without more study of the dynamics of individual cases on a quantitative basis. The necessary tools are slowly being provided to research workers and there are signs that this important problem will receive the attention it merits. In the meantime it is hoped that some of the information and ideas summarized here will be of some interest and use in forecasting practice.

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## BANNER CLOUD OVER THE MATTERHORN

By G. J. JEFFERSON, M.Sc.

Two accompanying photographs illustrate the formation of a banner cloud on the Matterhorn. This well known wedge-shaped peak of over 14,000 feet in southern Switzerland is situated far enough away from other nearby mountains of similar height for the effects of airflow over it to be clearly evident. The uplift of air flowing over it becomes visible when the relative humidity is large enough to allow condensation to take place. The appearance of the banner cloud and its subsequent changes in size and form make changes in humidity in the middle troposphere (12,000–14,000 feet) very evident.

Plate I (facing p. 312) was taken on a day when the cloud had first appeared in the early morning after a spell of some days of almost cloudless weather. It persisted as shown in this photograph for most of the day. The wind appeared to be from approximately a westerly direction and cloud could be seen forming on the windward side of the peak. It seemed to be an intermittent process, separate cloud elements forming about every half minute or so and not taking more than five seconds to form. Each one then moved up and over or behind the peak to merge with the general cloud mass. The cloud was streaming out on the east side with the top of the east face of the peak obscured by cloud carried in by the lee-side eddy. This can be seen in Plate I which also shows a cloud element actually in process of formation on the right side of the peak. At this time the only other clouds were a few wisps of cirrus and a few patches over some of the other high peaks in the area.

On the following day (see Plate II, facing p. 313) the cloud had become noticeably more extensive, being both of greater vertical extent and also extending further downwind before dispersing. By this time, too, there were other patches of cloud moving across the sky at about the same height but not associated with any particular mountain and not of a standing-wave type. The conclusion was inescapable that the relative humidity in the middle troposphere had increased. Locally this phenomenon is treated as an omen of bad weather. In this case it duly followed. The sky became overcast during the evening of the 21st and about two inches of snow fell during the early morning of the 22nd in Zermatt at the foot of the Matterhorn. It remained overcast with medium cloud during the 22nd but the following day (23 February) was fine and the banner cloud had disappeared.

An examination of the synoptic situation for this time shows that an anticyclone which had been centred over France for some days was transferred to the Bay of Biscay on the 20th, leaving a west-north-west surface flow over north-west Europe while a cold front was moving south across England. Winds over Switzerland at 1200 G.M.T. on 20 February 1959 at 700 millibars were about 280 degrees 15 knots with a high centre over south-west France. At 500 millibars they were a little stronger (260 degrees 20 knots at Payerne) with a high centre approximately over the Gulf of Lions. By midday on the 21st the cold front was nearing the Alps and a wave on the returning warm front had formed over Scotland and was moving rapidly south-south-east. By 0600 G.M.T. on the 22nd this had developed a marked warm- and cold-front structure and was giving precipitation over central and eastern France, south-west Germany and Switzerland. By midday on the 23rd the anticyclone had returned eastward and was centred near Munich.

Payerne is the nearest radio-sonde station and an examination of the soundings shows that the relative humidity at 600 millibars (about 13,500 feet) was approximately as follows:

1200 G.M.T., 19 February 1959: 13 per cent; no cloud.
1200 G.M.T., 20 February 1959: 29 per cent; Plate I.
1200 G.M.T., 21 February 1959: 100 per cent; Plate II.
1200 G.M.T., 22 February 1959: 100 per cent; overcast.
1200 G.M.T., 23 February 1959: 14 per cent; no cloud.

The increase in relative humidity during the period of appearance and increasing size of the banner cloud and the decrease accompanying its disappearance is evident.

Closer inspection of the Payerne sounding for 1200 G.M.T., 20 February, approximately the time of the first photograph, reveals that the layer of air between 590 and 690 millibars would need to be raised by over 5,000 feet to attain saturation. Since this is roughly the height of the main pyramid of the mountain it would mean that air would have to be lifted up through its entire height to attain saturation. This was obviously not taking place. It is probable, however, that the air over the Alps had undergone some more general uplift on reaching the main mountain ranges and that at the time of its impact with the Matterhorn it already had a relative humidity well above that shown by the Payerne sounding. As a rough estimate a figure of 2,000 feet would not appear to be unlikely as the maximum amount of uplift. With the air temperatures prevailing in the 700–600-millibar layer at Payerne, this would require a relative humidity of about 66 per cent to cause condensation. It is probable that at the time of the second photograph the saturated air at Payerne (which lies about 80 miles to the north-west) had not yet reached the Matterhorn and that the relative humidity while still well short of 100 per cent had risen well above 66 per cent.

*Photograph by G. J. Jefferson*

PLATE I—BANNER CLOUD ON THE MATTERHORN, 1330 G.M.T., 20 FEBRUARY 1959

The photograph was taken from a height of 8,000 feet in the mountains above Zermatt, Switzerland, looking south-west.

(see p. 311)

To face p. 313]

*Photograph by G. J. Jefferson*

PLATE II—BANNER CLOUD ON THE MATTERHORN, 1415 G.M.T., 21 FEBRUARY 1959

The photograph was taken from a height of 6,000 feet near Zermatt, Switzerland, looking south-south-west.

(see p. 311)

## LETTERS TO THE EDITOR

### Low temperatures and cold Easters in England

Probably more than one reader of this Magazine will have been expecting to see corrected the statement by Mr. J. G. Gallagher on p. 15 of the January 1959 issue that the lowest air temperature ever recorded at a low-level station in England was equalled by the reading of −5°F. in a frost-hollow some 200 feet above mean sea level near Shawbury early on 24 January 1958. The *Monthly Weather Report* cites the occurrence of a minimum of −6°F. in the screen at Bodiam, Sussex (71 feet above mean sea level), on 20 January 1940 and again at Elmstone, Wingham, East Kent (28 feet above mean sea level), on 30 January 1947.

On p. 66 in the March 1959 number of the Magazine Mr. R. E. Booth includes "the coldest Easter on record" among the misdemeanours of the year 1958. Mr. Booth may have evidence from one or another part of Britain to support his assertion, but for the neighbourhood of London it certainly does not hold good. Since annual public holidays were regularized by Act of Parliament on 25 May 1871 the coldest Eastertide at Kew Observatory has been that of 1883. Data published in the *Meteorological Record* of the Royal Meteorological Society show the Kew mean temperature over the period Good Friday to Easter Monday (23–26 March) that year to have been 34·7°F. Eastertide in 1958 (4–7 April) gave a corresponding value of about 40°F. there. Furthermore, the 1879 Eastertide was both later and colder than that of 1958 in the London area, with a mean temperature at Greenwich Observatory of 37°F. over the four days beginning Good Friday, 11 April.

E. L. HAWKE

*Culverkeys, Wilstone, Tring, Herts.*

*Reply by R. E. Booth*

I should like to thank Mr. Hawke for pointing out that there have been colder Easters in the London area than that of 1958. The rather loose phrase Mr. Hawke refers to, "the coldest Easter on record", should have read "the coldest Easter on record this century at Kew".

### Unusual phenomena during a foggy period with temperatures below freezing

Between 14 January and 13 February 1959, Jever had several spells of fog with temperatures below 32°F., while the area was under the influence of the large continental anticyclone.

In this period 49 observations were made in which the wet-bulb thermometer read higher than the dry bulb. After the first occurrence, the observers were carefully briefed on the correct painting and seeding procedures, and the thermometers checked both above and below 32°F. In all, 46 cases were accepted, with negative depressions varying from 0·1 to 1·1 degrees. Thirty-six of the readings were made in fog, and the remainder with visibilities less than 2,200 yards. The temperature range was from 4°F. to 28°F.

The average relative humidity with respect to water in the fog was 97½ per cent, but the true value could well be lower, taking into account the light winds (average four knots from an 85-foot anemometer) and any lag effect on the wet bulb associated with falling temperature. Thermograms for the period showed sharp falls in temperature associated with negative depressions greater than 0·3 degrees. Results obtained on several occasions using a whirling psychrometer also gave lower values.

On 16 January, between 0150 hours and 0250 hours, the temperature fell from 18·3°F. to 4·0°F., with fog forming from 10 to 30 feet thick, but with a base four to six feet above the snow-covered ground. From 0500–0600 hours, the fog had a base one to three feet above the ground, and consisted of several thin horizontal layers, with alternate fog and clear strata. The density of the fog varied, but the visibility was generally 300 yards, with lights 800 yards away clearly visible at times between the layers. The only suggestions of wind at the time were gentle undulations moving through the strata from east to west. The effect was similar to the behaviour of cigarette smoke in a still, cold room. At this time, a beautiful and extremely delicate deposition of ice crystals became noticeable on the enclosure fence. This was in the form of starlike crystals and plates, approximately a quarter of an inch long and very close together.

The temperature, $-15\frac{1}{2}$°C. to $-13$°C., is within the range given for this form of crystal by B. J. Mason[1]. It is also approximately that at which the difference between the saturation vapour pressures over ice and water is a maximum, and where the snow surface would have a maximum counter-effect on the formation of water fog. From the tenuous nature of the fog, and the low humidity figures, it would appear to consist largely of ice crystals. Petterssen[2] states that few water fogs can exist at temperatures below $-15$°C. (Another case of fog with base above the ground occurred on 29 January, this time over a rime-covered surface.)

The runway at Jever is orientated east to west, with forests on either side 500 yards apart at the eastern end for half its length. On the southern side the trees continue for almost the full length, but further from the runway. On 2 February a large bank of fog lay to the east of the station and aircraft reports showed its movement to be $2\frac{1}{2}$ miles per hour towards the airfield. The temperature was 36°F. ahead of the fog and 29°F. in it, with tops 600 feet. On reaching the eastern end of the woods it developed extremely rapidly westwards along the trees, almost like a chain reaction. In five minutes the visibility fell from 1,700 yards to 100 yards on the airfield, with the forests completely covered. However, on reaching the end of the trees the fog slowed to its former rate of progress, leaving the western end of the runway clear, and the last aircraft home was able to land there safely.

The abundance of available moisture over these forests is also shown up, under other conditions, by the formation or persistence of very low stratus, base 100–200 feet over the trees.

Next day the fog was still 600 feet thick and the upper air ascent from Emden showed the temperature to be 25°F. from base to top. An Anson aircraft, overshooting during a practice Ground Controlled Approach, passed through the fog, and a fall of ice needles occurred. The length of the needles was 3–4 millimetres, and the fall died away after 20 minutes.

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2. PETTERSSEN, S.; Weather analysis and forecasting. Vol. II, New York, 1956, p. 125.


*Meteorological Office, R.A.F. Jever, Germany* S. M. ROSS

[The *Observer's Handbook*[1] states that negative depressions of up to half a degree Fahrenheit are possible. This is based on a theory due to E. G. Bilham[2] which depends on writing the psychrometric equation in the form

$$e = E - \frac{dEi}{dt} \cdot \delta t - A \cdot \delta t,$$

where $E_i$ is the saturation vapour pressure over ice in millibars at the temperature of the dry bulb and $\delta t$°F. is dry-bulb temperature minus wet-bulb temperature, $\delta t$ being small. $\delta t$ is negative in sign in the conditions considered. $A$ has the value 0·4 for screen observations. Inserting values for $dE_i/dt$ and supposing that $e$, the vapour pressure, is equal to the saturation vapour pressure over supercooled water at the temperature of the dry bulb, it is readily found that the maximum negative value of $\delta t$ has the following values at the temperatures stated:

| Temperature (°F.) . . . | 30 | 25 | 20 | 15 | 10 | 5 | 0 |
|---|---|---|---|---|---|---|---|
| $\delta t$ (°F.) . . . | 0·07 | 0·27 | 0·40 | 0·50 | 0·54 | 0·54 | 0·51 |

Nevertheless, it seems certain that negative depressions much exceeding these values can occur. E. Gold has reported observations of negative depressions of 2° and 1·5°.[3,4] Mr. Gold's observations were at temperatures only just below freezing point and his admittedly tentative explanations could hardly apply at the much lower temperatures reported by Mr. Ross. The higher value cannot be due to the air in the screen being calm because $A$ then has a higher value than 0·4. It is also difficult to explain the large differences with falling temperatures by lag because the lag of the wet bulb is less than that of the dry bulb.[5] Mr. Ross has verified the accuracy of his thermometers against an inspector's thermometer.

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2. BILHAM, E. G.; Negative depressions of the wet-bulb. *Met. Mag., London*, 1941. (Typescript available in Meteorological Office Library.)
3. GOLD, E.; Unusual wet-bulb reading. *Met. Mag., London*, **76**, 1947, p. 62.
4. GOLD, E.; Unusual wet-bulb readings. *Met. Mag., London*, **82**, 1953, p. 54.
5. London, Meteorological Office; Handbook of meteorological instruments. London, 1956, pp. 161, 162.

Ed. M. M.]

## REVIEW

*The upper atmosphere*. By H. S. W. Massey and R. L. F. Boyd. 9 in. × 6 in., pp. xii + 333, *illus.*, Hutchinson & Co. Ltd., 178–202 Gt. Portland Street, London, W.1, 1958. Price: 63*s*.

This book might almost have been written especially for those only too numerous meteorologists who have always been meaning to learn something about the upper atmosphere but somehow have never been able to find the time. It is not quite a popular book—the reader is assumed to have a matriculation-plus knowledge of physics and mathematics, and to be accustomed to thinking in scientific terms. But for anyone who has these qualifications it is an outstandingly readable account of the subject, lucid, entertaining and fluent—one is never forced to refer back, or checked by difficult steps in the reasoning. That it should have this easy quality is a little surprising, for the style is not, by literary standards, good. There is a great deal of jargon, and the English is often, it seems, wilfully casual. One does not need to be a purist to shudder at such sentences as "a high temperature tends to blow out the air so it extends to greater heights". However, the reader always knows what the authors mean, even when a grammarian might be in doubt.

The book begins with two introductory chapters, "The relevant physics" and "The atmosphere"—mere bread and butter before the cake. Then come three chapters on methods of observation—"Research by balloons and rockets", "Probing with sound waves" and "Probing with radio waves". The state of the upper atmosphere is next discussed in four chapters entitled "The ozonosphere and ionosphere", "Lights in the night sky", "Aerial tides and magnetic effects" and "Solar, magnetic and ionospheric disturbances". Meteors and cosmic rays each have a chapter to themselves, and the book ends with chapters on "Artificial satellites" and "Future possibilities".

The chapters on instruments and methods of observation, especially those concerned with rockets and satellites, are the best and liveliest part of the book. One gets an impression that this is where the authors' hearts lie. Oddly enough, optical instruments are not thought worth a special chapter and indeed receive rather cursory attention throughout. The chapters on the state of the upper atmosphere are clear and interesting, but from the meteorologist's point of view it is a little unfortunate that the subjects which interest him most seem to interest the authors least. The treatment of, for example, variations in the amount of ozone, or the distribution of winds, temperature and density in the stratosphere, strikes one as rather hasty and lifeless, and so important a subject as the radiation balance is scarcely mentioned. But perhaps this is only another way of saying that the book does not attempt to give more than an outline of the subject—and one notices this most on one's own ground.

The volume is neatly though modestly bound, and well printed. No misprints were noticed. It is very generously illustrated with line drawings in addition to 27 photographic plates, six of which are in rather unlikely-looking colour. Both the bibliography and the index are a little skimpy. Taken as a whole, this is a book every meteorologist should read and, at three guineas, it is very sound value.

B. C. V. ODDIE

## METEOROLOGICAL OFFICE NEWS

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

*Mr. T. R. S. Starkey-Smith,* Senior Assistant (Scientific), who retired on 11 September 1959, having joined the Office in August 1925 as a Grade III Clerk. He was promoted Assistant II in 1941 and in the Barlow re-organization he was graded Assistant Experimental Officer and later became a Senior Assistant. Mr. Starkey-Smith has accepted a temporary appointment in the Meteorological Office.

**Sports Activities.**—*Athletics.* The Air Ministry Annual Sports Meeting was held at the White City Stadium on 16 September 1959. Mr. C. W. Fairbrother, Renfrew, increased his record of last year to 6 feet 7 inches in winning the High Jump. The Tug-of-War team from Dunstable retained the Halahan Shield. The Bishop Shield was won yet again by the Meteorological Office, but only by 1½ points margin over the Department of the Air Member for Supply and Organization.

**Royal Air Force Volunteer Reserve (Meteorological Section).** — *Awards.* It was announced in Air Ministry Orders dated 19 August 1959 that Flight Lieutenants R. H. Medhurst and T. Seeley had been granted the Air Efficiency Award.

## OFFICIAL PUBLICATION

*Handbook of weather messages, third edition*

The *Handbook of weather messages* is designed to serve as a concise book of reference to international and regional approved practices for reporting coding and plotting meteorological observations, forecasts and analyses, both on the surface and in the upper air. It is in loose leaf form to facilitate the entry of amendments.

Part I contains particulars of meteorological reports, forecasts, warnings, etc., which are issued by radio from Dunstable in Great Britain and from certain centres abroad. It also contains a list of station index numbers for those stations which are normally included in these broadcasts. A new edition is being printed.

Part II contains details of the various codes and specifications which are used in the compilation of weather messages. This third edition incorporates some additions and modifications chiefly in coded forecasts, analyses and upper air reports which were adopted by the World Meteorological Organization based on the recommendations of the Commission for Synoptic Meteorology (New Delhi in January–February 1958) and which come into force in most cases on 1 January 1960. It contains 35 forms of code messages, over 140 code specifications and some 250 or so different combinations of letters to describe the various elements dealt with in the codes.

Part III gives detailed information concerning the entry of the readings into the daily and monthly registers, the coding of information for transmission, the decoding of messages received from other sources and finally the plotting of the information on synoptic charts.

## WEATHER OF JULY 1959

### Northern Hemisphere

For the fourth successive month pressure anomalies over the hemisphere were small, nowhere exceeding 5 millibars. Over the Atlantic and North America mean pressures were below normal north of approximately 55°N. (with anomalies of −5 millibars just north of Hudson Bay and −4 millibars south of Iceland), and above normal south of this latitude. A strong mean westerly flow across the Atlantic in the latitudes of Britain was associated with this distribution of anomalies. The north-eastward extension of the Azores high was stronger than usual and although anomalies were only +1 or +2 millibars over much of western and central Europe, they rose to +5 millibars around the Baltic. Further anomalies of +5 millibars occurred over a small area east of the Kamchatka peninsula.

As a consequence of the prolonged anticyclonic conditions during the month, mean temperatures were above average almost everywhere in Europe. Anomalies reached +4°C. in western Germany and also north of the Black Sea but over the greater part of the region they were +1°C. or +2°C. Negative anomalies of up to −4°C. occurred along the east coast of Greenland and north coast of Iceland where it was reported that the ice had been much slower than usual in breaking up.

Much of the North American continent experienced warmer weather than usual, anomalies reaching +3°C. in California, but it was cooler than usual in the Mississippi basin and northern Canada.

The distribution of rainfall over Europe was very variable. The driest places were mainly in central France and around the southern Baltic where amounts were only 10 or 20 per cent of normal, but some stations in Spain, Germany and northern Norway received twice their average. As a result of thunderstorms, floods covered wide areas of Austria on the 22nd. It was a dry month over the western half of North America, while in the eastern half totals were near or above normal. A hurricane from the Gulf of Mexico (the fourth of the season), moved across Texas on the 26th. Gusts of up to 105 miles per hour and rainfall totals of up to 15 inches were reported along the coast and considerable damage was done in the Galveston area. The south-west monsoon gave abnormally heavy rains in western and central districts of India and at places in west Pakistan totals exceeded three times the average. Flooding of the River Indus was reported during the middle of the month.

## WEATHER OF AUGUST 1959

### Great Britain and Northern Ireland

Weather over the British Isles during August was warm, sunny and very dry apart from local outbreaks of thundery rain. The situation was mainly anticyclonic except during the second week when shallow depressions gave thundery outbreaks and when a very deep depression off Ireland gave some heavy and more continuous rain on the 13th and 14th.

The first three days of the month were rather cool and showery with north-westerly winds, but on the 4th a ridge of high pressure spread from the west over the country and weather became fine and sunny in southern and central districts, although weak troughs gave some rain or drizzle in the north. The ridge spread slowly northward during the next few days and by the 8th the fine warm weather had extended to the whole of the British Isles and afternoon temperatures at many places in the south exceeded 80°F.

On the 9th the ridge of high pressure covered northern districts while shallow depressions drifted slowly northward from France. Thunderstorms developed in Wales and southern England and were exceptionally severe in south-west England on the 10th. Rainfall exceeded four inches in 24 hours at several places, while at Newquay over 2½ inches fell in 75 minutes and St. Mawgan had a fall of nearly 1¾ inches in two hours during the afternoon and a similar amount in two hours during the evening. Thundery outbreaks continued on the 11th—Newquay had another 2¼ inches, making nearly five inches of rain there in two days—but on the 12th there was fairly general rain in southern England associated with a small depression in the English Channel.

An exceptionally deep depression for the time of year developed off south-west Ireland on the 13th and moved northward. Winds increased to gale force in many western districts and rain was widespread and locally heavy but gave place to quieter showery but brighter weather the following day. Showers were mostly confined to the west on the 15th, and on the 16th an anticyclone moved northward to the English Channel and weather became fine and warm over most of the country for about a week. The anticyclone was centred over northern Germany on the 19th but an associated warm airstream from the continent still affected the British Isles and temperature rose to 88°F. in Yorkshire on the 20th and to 83°F. in many places in Scotland on the 21st. However, on the 20th a shallow area of low pressure spread into southern England from France and that night thunderstorms broke out in south-west England and the Channel Islands and became widespread the following day. Rainfall was very heavy in Kent and widespread flooding occurred.

On the 23rd an anticyclone became situated off the south-west of the British Isles and weather was fine and warm in central and eastern districts but cloudy with rain and drizzle in Scotland and north-west England. On the 26th the anticyclone moved northward to western Scotland and during the remainder of the month weather was fine but cooler over most of the country with light northerly winds and scattered showers.

This month, like May, June and July, was warm, sunny and dry over most of the country. The mean temperature was about 3°F. above average in eastern England and eastern Scotland, the maximum temperature being over 4°F. above average in north-east England. In many areas it was the sunniest August since 1947. Fifteen days or more without measurable rain occurred from the 14th in Central Wales and over most of England except the West Midlands and the south-west. Less than 10 per cent of average rainfall was measured in the Fylde and the lower valleys of the Yorkshire Ouse, Tees and Tyne.

Growers were generally feeling the effect of the prolonged dry, warm weather. The tomato crop was outstandingly good and flowers abundant but prices were low. Lettuces, although in great demand, were a poor crop in many areas. Germination of spring cabbage was generally bad, and strawberry runners were slow in rooting, owing to the dry soil, although in some districts the thundery outbreaks helped. Cucumbers promised to be good and in some districts sprouts had already been picked.

## WEATHER OF SEPTEMBER 1959

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

| | AIR TEMPERATURE | | | RAINFALL | | SUNSHINE |
|---|---|---|---|---|---|---|
| | Highest | Lowest | Difference from average daily mean† | Percentage of average* | No. of days difference from average* | Percentage of average† |
| | °F. | °F. | °F. | % | | % |
| England and Wales ... | 86 | 23 | +2·5 | 9 | −11 | 146 |
| Scotland ... ... | 80 | 28 | +2·4 | 36 | −11 | 134 |
| Northern Ireland ... | 80 | 36 | +2·2 | 47 | −12 | 131 |

# RAINFALL OF SEPTEMBER 1959

## Great Britain and Northern Ireland

| County | Station | In. | *Per cent of Av. | County | Station | In. | *Per cent of Av. |
|---|---|---|---|---|---|---|---|
| *London* | Camden Square Gdns. | ·08 | 4 | *Pemb.* | Maenclochog, Ddolwen B. | ·41 | 8 |
| *Kent* | Dover ... ... ... | ·09 | 4 | *Cards.* | Aberporth ... ... | ·35 | 10 |
| " | Edenbridge, Falconhurst | ·11 | 5 | *Radnor* | Llandrindod Wells ... | ·20 | 6 |
| *Sussex* | Compton, Compton Ho. | ·15 | 5 | *Mont.* | Lake Vyrnwy ... ... | ·41 | 8 |
| " | Worthing, Beach Ho. Pk. | ·10 | 5 | *Mer.* | Blaenau Festiniog ... | 1·50 | 15 |
| *Hants.* | St. Catherine's L'thouse | ·17 | 7 | " | Aberdovey ... ... | ·43 | 10 |
| " | Southampton, East Pk. | ·08 | 3 | *Carn.* | Llandudno ... ... | ·57 | 21 |
| " | South Farnborough ... | ·04 | 2 | *Angl.* | Llanerchymedd ... | ·79 | 21 |
| *Herts.* | Harpenden, Rothamsted | ·13 | 6 | *I. Man* | Douglas, Borough Cem. | 1·35 | 32 |
| *Bucks.* | Slough, Upton ... | ·05 | 2 | *Wigtown* | Newton Stewart ... | 2·47 | 57 |
| *Oxford* | Oxford, Radcliffe ... | ·21 | 10 | *Dumf.* | Dumfries, Crichton R.I. | 1·52 | 41 |
| *N'hants.* | Wellingboro' Swanspool | ·01 | 0 | " | Eskdalemuir Obsy. ... | 1·81 | 34 |
| *Essex* | Southend W.W. ... | ·13 | 8 | *Roxb.* | Crailing... ... ... | 1·04 | 44 |
| *Suffolk* | Ipswich, Belstead Hall | ·02 | 1 | *Peebles* | Stobo Castle ... ... | ·97 | 29 |
| " | Lowestoft Sec. School | tr | 0 | *Berwick* | Marchmont House ... | ·57 | 22 |
| " | Bury St. Ed., Westley H. | ·04 | 2 | *E. Loth.* | N. Berwick ... ... | ·59 | 24 |
| *Norfolk* | Sandringham Ho. Gdns. | ·13 | 5 | *Midl'n.* | Edinburgh, Blackf'd H. | ·47 | 18 |
| *Dorset* | Creech Grange... ... | ·34 | 11 | *Lanark* | Hamilton W.W., T'nhill | ·70 | 19 |
| " | Beaminster, East St. ... | ·06 | 2 | *Ayr* | Prestwick ... ... | 1·43 | 41 |
| *Devon* | Teignmouth, Den Gdns. | ·10 | 4 | " | Glen Afton, Ayr San. ... | 1·73 | 34 |
| " | Ilfracombe ... ... | ·40 | 12 | *Renfrew* | Greenock, Prospect Hill | 1·71 | 32 |
| " | Princetown ... ... | ·58 | 9 | *Bute* | Rothesay ... ... | 1·87 | 37 |
| *Cornwall* | Bude ... ... ... | ·29 | 10 | *Argyll* | Morven, Drimnin ... | 2·91 | 51 |
| " | Penzance ... .. | ·11 | 3 | " | Ardrishaig, Canal Office | 2·52 | 40 |
| " | St. Austell ... ... | ·14 | 4 | " | Inveraray Castle ... | 3·85 | 47 |
| " | Scilly, St. Marys ... | ·04 | 2 | " | Islay, Eallabus ... | 1·57 | 32 |
| *Somerset* | Bath ... ... ... | ·17 | 7 | " | Tiree ... ... ... | 2·12 | 51 |
| " | Taunton ... ... | ·16 | 7 | *Kinross* | Loch Leven Sluice ... | ·74 | 23 |
| *Glos.* | Cirencester ... ... | ·26 | 9 | *Fife* | Leuchars Airfield ... | ·44 | 18 |
| *Salop* | Church Stretton ... | ·02 | 1 | *Perth* | Loch Dhu ... ... | 1·85 | 27 |
| " | Shrewsbury, Monkmore | ·16 | 7 | " | Crieff, Strathearn Hyd. | ·71 | 21 |
| *Worcs.* | Worcester, Red Hill ... | ·18 | 9 | " | Pitlochry, Fincastle ... | ... | ... |
| *Warwick* | Birmingham, Edgbaston | ·17 | 7 | *Angus* | Montrose Hospital ... | ·68 | 26 |
| *Leics.* | Thornton Reservoir ... | ·11 | 5 | *Aberd.* | Braemar ... ... | ·64 | 22 |
| *Lincs.* | Cranwell Airfield ... | ·08 | 4 | " | Dyce, Craibstone ... | ·62 | 20 |
| " | Skegness, Marine Gdns. | ·13 | 7 | " | New Deer School House | 1·09 | 32 |
| *Notts.* | Mansfield, Carr Bank... | ·07 | 3 | *Moray* | Gordon Castle ... ... | ·96 | 31 |
| *Derby* | Buxton, Terrace Slopes | ·17 | 4 | *Inverness* | Loch Ness, Garthbeg ... | ·65 | 18 |
| *Ches.* | Bidston Observatory ... | ·28 | 11 | " | Fort William ... ... | 3·13 | 45 |
| " | Manchester, Airport ... | ·21 | 8 | " | Skye, Duntulm... ... | 3·59 | 71 |
| *Lancs.* | Stonyhurst College ... | ·55 | 12 | " | Benbecula ... ... | 2·59 | 61 |
| " | Squires Gate ... ... | ·23 | 7 | R. & C. | Fearn, Geanies ... | 1·03 | 46 |
| *Yorks.* | Wakefield, Clarence Pk. | ·11 | 5 | " | Inverbroom, Glackour... | 1·94 | 39 |
| " | Hull, Pearson Park ... | ·27 | 13 | " | Loch Duich, Ratagan... | 3·76 | 51 |
| " | Felixkirk, Mt. St. John... | ·24 | 10 | " | Achnashellach ... ... | 4·93 | 69 |
| " | York Museum ... ... | ·17 | 8 | " | Stornoway ... ... | 2·74 | 73 |
| " | Scarborough ... ... | ·38 | 18 | *Caith.* | Wick Airfield ... ... | 1·03 | 36 |
| " | Middlesbrough... ... | 1·03 | 51 | *Shetland* | Lerwick Observatory ... | 1·33 | 35 |
| " | Baldersdale, Hury Res. | 1·25 | 38 | *Ferm.* | Belleek ... ... ... | 2·07 | 46 |
| *Nor'l'd* | Newcastle, Leazes Pk.... | ·76 | 32 | *Armagh* | Armagh Observatory ... | 1·59 | 54 |
| " | Bellingham, High Green | 1·07 | 33 | *Down* | Seaforde ... ... | 2·45 | 68 |
| " | Lilburn Tower Gdns. ... | ·75 | 30 | *Antrim* | Aldergrove Airfield ... | 1·65 | 55 |
| *Cumb.* | Geltsdale ... ... | 1·65 | 46 | " | Ballymena, Harryville... | 1·70 | 43 |
| " | Keswick, Derwent Island | 1·23 | 21 | *L'derry* | Garvagh, Moneydig ... | 1·18 | 32 |
| " | Ravenglass, The Grove | 1·77 | 40 | " | Londonderry, Creggan | 1·25 | 29 |
| *Mon.* | A'gavenney, Plâs Derwen | ·03 | 1 | *Tyrone* | Omagh, Edenfel ... | 1·57 | 41 |
| *Glam.* | Cardiff, Penylan ... | ·25 | 7 | | | | |