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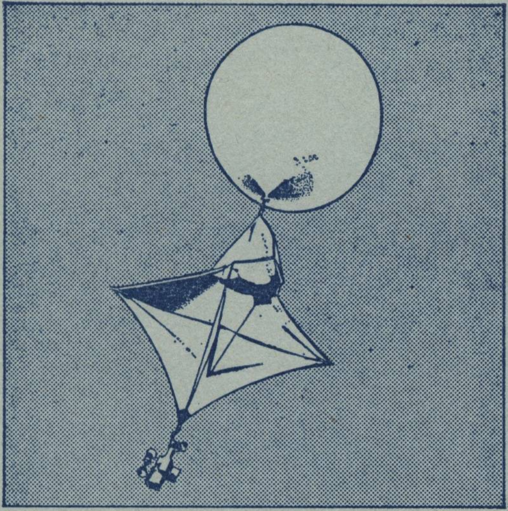

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SOME FEATURES OF THE LARGE-SCALE CIRCULATION ANOMALIES AND THE WEATHER OVER THE BRITISH ISLES IN AUTUMN 1965

By R. MURRAY

Summary.—The autumn of 1965 was remarkable both for the large inter-monthly changes and for the pronounced character of the weather within each month over the British Isles. This note shows how the anomalous circulation over the British Isles was related to the large-scale circulation over the northern hemisphere.

Broad-scale weather in Britain.—The weather of September 1965 was disturbed, wet and cool and continued the trend of the preceding summer. In the average year, September is significantly more anticyclonic than July and August, but on this occasion September was exceptionally cyclonic over the British Isles. The average monthly rainfall over England and Wales was 5·6 in (i.e. 187 per cent of the normal*) ; this has been exceeded on three occasions, namely 1927, 1918 and 1896, in the past 90 years, but the frequency of depressions over or very close to the British Isles was less in these Septembers than in September 1965. It was cool for most of the month, and the mean monthly temperatures were generally in the lowest decile or quintile of the distribution.

In spite of an unsettled start and a very stormy end, October was dominated by an anticyclonic block, i.e. the anticyclone of a blocking situation. Rainfall over the month was below normal nearly everywhere ; in particular over England and Wales the average rainfall was 1·2 in (i.e. 33 per cent of normal), and the only October in the past 150 years with less rain was in 1947. Mean monthly temperatures were generally above the long-term average, mostly in the warm quintiles 4 and 5. The contrast between the synoptic character and weather of September and October could hardly have been more marked ; both months were abnormal in quite different ways.

After a cyclonic westerly type at the beginning of November there was a reversion to an anticyclonic block for a week or so. However, after the 12th the weather became generally disturbed. Several vigorous depressions moved eastwards on tracks between northern France and southern Scotland ; the cyclonic systems produced blizzards, chiefly over south and central Scotland and the northern half of England and Wales. In extent and depth of snow lying and in frequency of snow falling, many places in northern England and southern Scotland experienced the most severe November weather for at least 100 years. The month had an exceptional deficiency of westerly synoptic

* In this paper normal for surface features refers to the period 1916–50.

types ; the blocking pattern was rather anticyclonic over Britain in the first half and very cyclonic in the second half of the month. The average rainfall for the month over England and Wales was about 115 per cent of normal, but it was very wet in north-east England (e.g. Durham had 250 per cent of the normal rainfall and much of the precipitation fell as snow). However, rainfall decreased to well below normal in northern Scotland. Monthly mean temperatures were mostly in the lowest quintile or decile, largely because of the severe wintry weather in the second half of the month.

Thus on a monthly time-scale the weather over the British Isles during each of the autumn months was highly abnormal in diverse ways. Anti-persistence was a feature of the month-to-month relationships ; but a good deal of persistence of weather type occurred within each month on a smaller time-scale. It is instructive to relate the abnormal developments over the British Isles to the large-scale circulation anomalies and changes in circulation patterns over much of the northern hemisphere. A multitude of maps would be needed to represent all relevant aspects of the morphology of the general circulation at different levels and in different sectors of the northern hemisphere, throughout the entire autumn. However, it is possible to depict many significant features of the large-scale circulation by means of a few skeleton diagrams, selected to highlight special points. The following two sections describe some important anomalous features and relationships on, first, a monthly time-scale and second, a time-scale of a few days.

The monthly circulation over the northern hemisphere.—The nature of the low-level circulation over the northern hemisphere each month can be inferred qualitatively from the locations and intensities of the mean monthly surface pressure anomaly centres shown in Figure 1. The pronounced negative anomaly centres (NAC) in September and November and the positive anomaly centre (PAC) in October near England epitomize the enormous month-to-month changes which took place over the British Isles. Thus the extreme cyclonicity of September is consistent with the NAC over central England. The anticyclonic blocking of October is evident from the PAC over the North Sea, surrounded by three NACs, namely west of Portugal, south of Greenland and over the northern Urals. Finally the cyclonic blocking with highly anomalous north-easterly winds over the British Isles in November is quite consistent with the NAC over north France and the large PAC (equal to at least 2½ times the standard deviation of monthly mean pressure) on the Greenland coast near the Denmark Strait.

Some significant features may be noted over the Pacific side of the hemisphere. The September PAC of 10 mb (equal to about 2½ times the standard deviation) at the head of the Gulf of Alaska in combination with smaller NACs in north-east Canada, south-west U.S.A. and in mid-Pacific is typical of a large-scale blocking pattern, with highly anomalous northerly flow over western America. However a drastic reorganization took place from September to October, as implied by the replacement of the large PAC by the NAC in the Gulf of Alaska. In spite of the collapse of the anticyclonic block near Alaska, the flow was anomalously meridional over the north-east Pacific as suggested by the two NACs at about the same longitude and the small PAC farther west in mid-Pacific. Thus the large-scale pressure changes over the Gulf of Alaska from September to October were the reverse of those near the British Isles. In November the large PAC south of the Aleutians (13 mb or 3 times the standard deviation) together with the large NAC off the Californian coast (−10 mb or 3 times the standard deviation) confirm that blocking, with which was associated highly anomalous northerly flow over much of the eastern Pacific, predominated during the month.

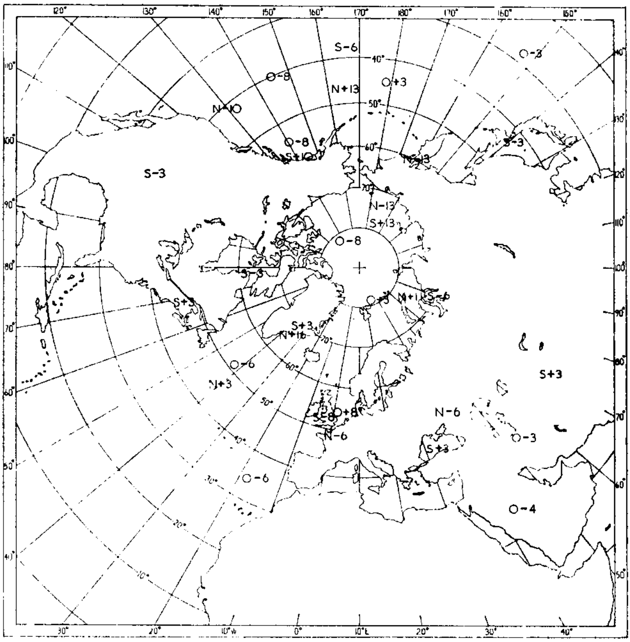

FIGURE 1—MONTHLY MEAN SURFACE PRESSURE ANOMALY CENTRES IN SEPTEMBER (S), OCTOBER (O) AND NOVEMBER (N), 1965

Centres at positions of + and − signs, pressure in millibars.

It is interesting to note the shift eastwards of the NAC in the Pacific at about 40°N from 170°W in September to 150°W in October to 130°W in November. Another interesting feature is that the high-latitude blocking over north-east Asia in September (suggested by the PAC in the Arctic and the NAC over Japan) weakened in October, but markedly anomalous meridional flow clearly developed in high latitudes in November (note the PAC near the Kara Sea and the NAC near the Arctic coast some 50 degrees of longitude to the east of the Kara Sea).

Various anomalous features of the upper circulation may be visualized with the assistance of Figure 2 which shows the positions of the main troughs on the monthly mean 300 mb maps and the locations of the polar vortices. That part of a trough between contours 940 and 900 geopotential decametres is shown as a continuous line ; the broken lines extend the trough to the 880 contour when the pattern allows this to be done. The troughs at 300 mb are in fact representative of the middle and upper troposphere. The 'normal' trough positions in October are taken from *Geophysical Memoirs* No. 103[1] and refer to the period 1949–53.

Usually there is a mean trough in the autumn in eastern Europe but none near western Europe. Figure 2 confirms that the upper circulation in the autumn of 1965 was extremely unusual in the European sector. In addition to significant troughs in eastern Europe in September and October, another trough occurred over the British Isles in September and westward of Ireland in October. No eastern European trough existed in November, but a marked trough was situated off south-east England, along the western European seaboard.

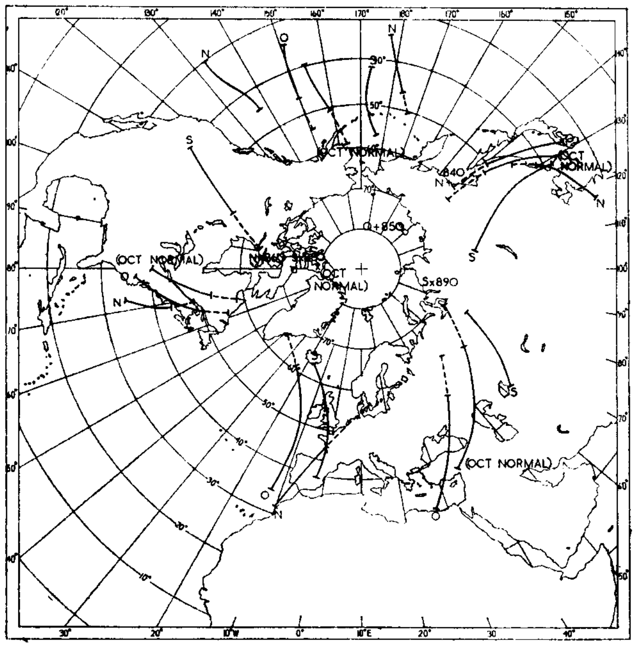

FIGURE 2—MONTHLY MEAN 300 MB TROUGHS IN SEPTEMBER (S), OCTOBER (O) AND NOVEMBER (N), 1965

Continuous line is trough from 940 to 900 geopotential decametres and broken line extends trough to 880 geopotential decametres whenever possible.

The next upstream trough is normally over eastern America ; on this occasion a pronounced trough was located exceptionally far west near the Rocky Mountains in September, but in October and November it was situated in the extreme east of America, a little east of the 'normal' position. Further upstream over the Pacific it is noteworthy that a mean trough was in positions successively farther east and in lower latitudes each month, whilst a second trough developed in the mid-Pacific in November. Over eastern Asia the trough positions each month do not appear to have been very abnormal.

It is particularly noteworthy and significant that the mean troughs in October were farther south than usual (about 5° latitude on average, judging by the positions of the 940 contours). The latitudinal extension in September appears to have been less abnormal except near western Europe, but in

November the troughs not only extended farther south than in October, as shown in Figure 2, but they penetrated to unusually low latitudes for the month of November. Such extensions to anomalously low latitudes were naturally associated with the fact that the main baroclinic zones and jet streams were stronger and further south than usual, especially near the base of the main troughs where the polar jet stream merges into the subtropical jet stream.

Further interesting characteristics of the upper circulation are worth noting, namely (i) the wave number each month was five in middle latitudes, (ii) the circulation in the Arctic was bipolar in September and November, (iii) a 3-trough system in high latitudes emanated from a single vortex in October and (iv) the main blocking ridge extended north into Alaska in September, to the Norwegian Sea in October and to Greenland in November.

The anomalous low-level flow implied by the distribution of pressure anomaly centres (Figure 1) and the locations of upper troughs (Figure 2) which are generally associated with cold tropospheric air near or somewhat west of their axes largely account for the mean monthly surface temperature anomaly distribution shown in Figure 3. For example, the exceptionally cold air over western America in September was largely the result of the very anomalous northerly surface flow (Figure 1) which brought much cold air far to the south ; the warm area in October from south-west France to the Norwegian Sea shown in Figure 3 was also clearly a consequence of the

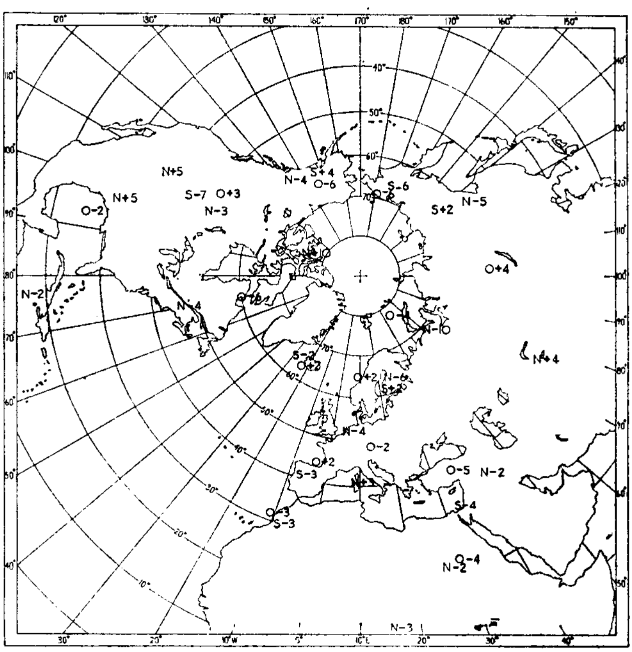

FIGURE 3—MONTHLY MEAN SURFACE TEMPERATURE ANOMALY CENTRES IN SEPTEMBER (S), OCTOBER (O) AND NOVEMBER (N), 1965

Significant centres with inner isotherm ≥ 2°C or ≤ −2°C ; centres at positions of + and − signs.

anomalous southerly advection implied by the large positive pressure anomaly centre in the North Sea (Figure 1) and the trough west of Ireland (Figure 2) ; and other instances may readily be seen.

Rainfall will not be discussed except to say that its distribution was broadly consistent with the location of the tropospheric troughs and the pressure anomaly centres (e.g. the above-normal rain over the British Isles in September was closely related to the upper trough and the large negative pressure anomaly).

The circulation on a time-scale of about five days.—On a time-scale much smaller than a month an increase in complexity is inevitable, and considerable simplification of diagrammatic representation is essential if bewildering details are to be avoided.

Important synoptic phases in the Atlantic sector can be linked to simple graphs (Figure 4) which show the time variation of 5-day mean surface

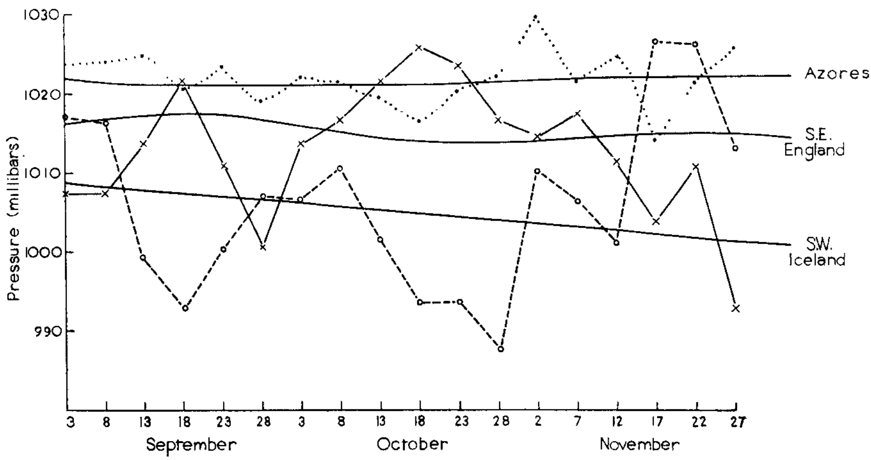

FIGURE 4—5-DAY MEAN PRESSURE AT THREE PLACES IN AUTUMN 1965

....	Azores, 35°N 30°W
x———x	South-east England, 50°N 00°
o– – –o	South-west Iceland, 60°N 35°W
———	Long-period average based on data from 1900–39

pressure at three points, namely near south-east England and at the two 'centres of action' near Iceland and the Azores. The large out-of-phase oscillations of the pressure curves for south-east England and Iceland are closely in agreement with the main cyclonic and anticyclonic phases near the British Isles and farther afield over the Atlantic. Pressure near south-east England was mostly below the long-period average (1900–39) until early October, apart from a short spell after mid-September associated with abnormally low pressure near Iceland. A major block developed near the British Isles and pressure rose to a maximum well above average in the third week of October before declining slowly ; after about 10 November pressure was increasingly below normal (this period was markedly cyclonic), whilst above-normal pressure near Iceland resulted from the great intensification of the polar anticyclone over Greenland (central pressure equalled or exceeded

1050 mb on 19 and 20 Nov.). The pressure oscillations near the Azores were clearly smaller in amplitude and more frequent than those at the other two places.

Longitudinal changes with time of positions at 50°N of minima in the 1000–500 mb thickness (Figure 5) help to clarify the picture of circulation change. The colder than usual major cold trough A remained nearly 50 degrees of longitude west of its average position (averaged over 1949–63) over America until past mid-September when it progressed quickly to a position somewhat east of its average longitude. Meanwhile significant variations took place downstream as shown by the movements of the thermal troughs and ridges in Figure 5. Troughs A, B, C and D all experienced a net drift eastwards in September, although trough A remained quasi-stationary for some 10 days longer than the other troughs and ridges. The exceptional nature of the circulation in September is emphasized again by the mere existence of troughs C and D in sectors where mean thermal troughs

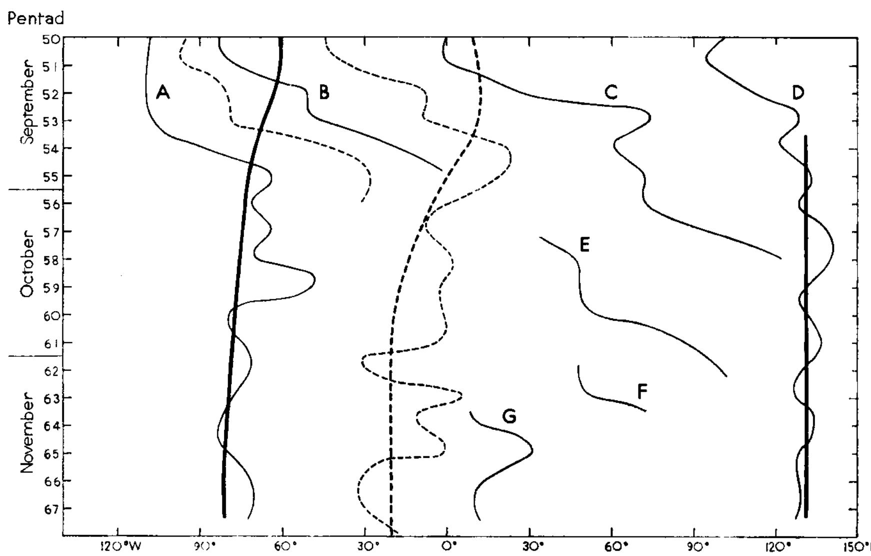

FIGURE 5—VARIATION OF 5-DAY MEAN 1000–500 MB COLD TROUGHS AND WARM RIDGES AT 50°N FOR PENTADS 50–67 (SEPTEMBER–NOVEMBER) 1965

——— Cold trough
- - - - Warm ridge
▬▬▬ Average cold trough
▪ ▪ ▪ ▪ Average warm ridge
(All data averaged over period 1949–63)

do not usually form. It was not until the latter part of September that trough D moved to the normal longitude over east Asia, where subsequently it settled down and intensified. The cyclonicity over the British Isles in September was linked to trough C in the first half and to trough B later in the month, whilst the temporary anticyclonic period already referred to (e.g. see pressure maximum in Figure 4) was related to the warm ridge. The anticyclonic block near the British Isles in October and early November occurred with a warm ridge near or just east of the average position and with no cold trough over the British Isles or western Europe. During this phase there was generally a trough over eastern Europe or western Asia ; but in the second week of November another important cold trough appeared over western Europe, and this was part of the large-scale changes which brought cold, cyclonic weather back to the British Isles (as suggested also by the trend of the curves in Figure 4).

On a broad time-scale there was clearly general similarity in behaviour of the two most intense troughs (A and D) and the eastern Atlantic ridge, but on the pentad time-scale the picture was not so simple. For instance the progressive and retrogressive shifts of troughs A and D were in phase from pentads 54 to 57, but thereafter they were clearly out of phase. It is hard to avoid the conclusion that the behaviour of the American trough was largely independent of the behaviour of the east Asian trough. However, the behaviour on the 5-day scale of the eastern Atlantic ridge was apparently linked to the shifts of the American trough with a lag of a pentad or two (Figure 5). Moreover, the re-formation of thermal troughs over Europe whenever the pre-existing European trough progressed into Asia was evidently in response to the lengthening wavelength between the progressing trough and the American trough.

Anomalous features of the tropospheric thermal structure throughout the autumn may be looked at rather differently with the aid of Figures 6, 7 and 8, which show the distribution of 5-day mean 1000–500 mb thickness anomaly centres, together with superimposed skeleton monthly mean 500 mb maps on which a few contours have been selected to show the main pattern of mid-tropospheric flow. Figure 6 suggests that the synoptic patterns were fairly

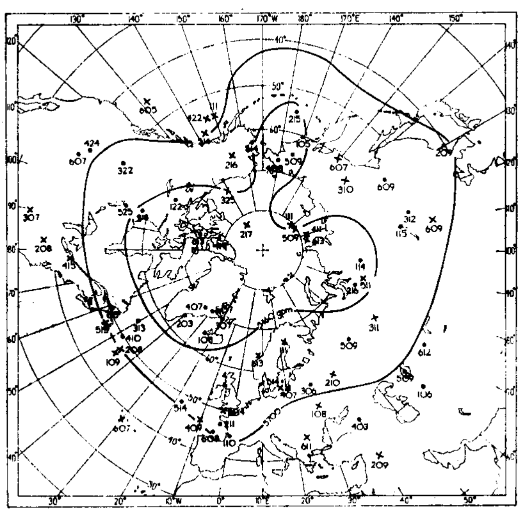

FIGURE 6—5-DAY MEAN 1000–500 MB THICKNESS ANOMALY CENTRES IN SEPTEMBER 1965

. Negative centres (NAC)		5-day periods in September	
x Positive centres (PAC)		No.	Begins
——— Selected monthly mean 500 mb contours in geopotential metres		1	3rd
		2	8th
In the 3-figure groups the first figure is the pentad number and the remaining figures give the anomaly in geopotential decametres.		3	13th
		4	18th
		5	23rd
		6	28th

homogeneous in September in many sectors (e.g. note the cluster of PACs in the Gulf of Alaska and the complete absence of positive anomalies from Greenland to south-western U.S.A.) ; evidently the cumulative effect of synoptic processes of similar type over several pentads was consistent with the circulation on the monthly scale, as shown in Figures 1, 2 and 3. A gradual increase in zonal flow from the Aleutians to northern Canada set in late in September more or less simultaneously with the eastwards motion of a depression across Alaska ; this significant change was associated with the transference of the NAC (525) from near Hudson Bay to NAC (613) near Newfoundland (a decaying cell (607) was left behind east of the Rockies), and with the weakening and movement south-eastwards of the PAC in the Gulf of Alaska (514 to 605). Meanwhile increased meridionality in the Atlantic led to blocking, characteristically shown by various interrelated features, such as the plunging south-eastwards of depressions towards the Bay of Biscay, the stagnation in the same area of the previously progressive NAC (608) and the thrust northwards of warm air over western Europe shown by the PAC (613) off the Norwegian Coast. Superficially the cyclonic block over the British Isles in the last week of September was similar to the cyclonic pattern of the first half of September. However, there were already symptoms of significant differences in the large-scale circulation, notably the tendency for higher pressure in the Norwegian Sea, the development of a thickness PAC off the Norwegian coast and the rapid retrogression of a NAC (613) to north Baffin Land from east Greenland, in addition to the sudden progression of the American cold trough (Figure 5).

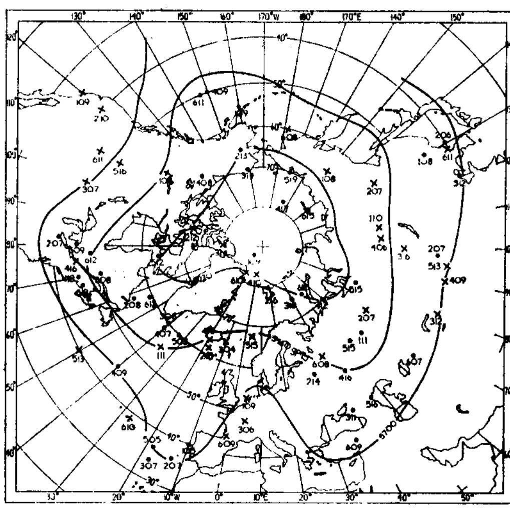

FIGURE 7—5-DAY MEAN 1000–500 MB THICKNESS ANOMALY CENTRES IN OCTOBER 1965

. Negative centres (NAC)
x Positive centres (PAC)
——— Selected monthly mean 500 mb contours in geopotential metres

In the 3-figure groups the first figure is the pentad number and the remaining figures give the anomaly in geopotential decametres.

5-day periods in October

No.	Begins
1	3rd
2	8th
3	13th
4	18th
5	23rd
6	28th

Figure 7 for October shows clearly that no NAC was observed over western America after these changes were set in train in the last week of September; and also that negative centres clustered over eastern America for most of October in association with a persistent or recurrent large-scale thermal trough, apart from a spell after mid-October (note NAC 416) when zonality across America to mid-Atlantic between latitudes 40° and 60°N was at a maximum relative to the flow earlier and later in October. Other noteworthy clusters of anomaly centres, confirming the existence of rather homogeneous large-scale circulation and thermal patterns, were the NACs near the Barents Sea, near southern Russia, off Portugal and near Alaska, and the PACs in or near the Norwegian Sea and near north Greenland.

The NAC over the Bay of Biscay and the associated cyclonic system over the British Isles late in September quickly sank south-westwards to form a very persistent cut-off depression near Portugal in October (note the cluster of NACs). This cutting-off development was part of the large-scale blocking process over the Atlantic and western Europe, but in turn the subsequent persistence of the cold depression near Portugal favoured persistence of broad-scale blocking by ensuring that the southern branch of the upper westerlies was held in unusually low latitudes in the eastern Atlantic. The northern branch of the upper baroclinic zone was usually in very high latitudes and depressions were steered eastwards in latitudes north of 65°N, although a temporary southwards shift of the blocking pattern around mid-month brought the depression track across the central Norwegian Sea. The virtual disappearance of the blocking pattern late in October was associated with a marked increase in zonality across the Atlantic and western Europe and with a depression track from the Davis Strait to the Baltic: this important phase can be related to increased zonal flow upstream over America about mid-month and progressively farther east later, consistent with the eastwards movement of the PAC (416) from east of the Great Lakes to the Azores some 10 days later.

The cyclonic westerlies over the British Isles late in October changed rapidly at the beginning of November; very marked amplification of the upper pattern took place (warm ridge over Atlantic and cold trough over western Europe), and the blocking pattern of the October type quickly emerged near western Europe. The location of the PAC (108) in the northern Atlantic and the NAC (109) off Portugal, shown in Figure 8, confirms that the thermal pattern was markedly amplified at this time. However, before mid-November the blocking pattern retrogressed to Greenland; the American circulation favoured much warm advection to the west of Greenland, and this led to strong anticyclonic development over Greenland. Almost simultaneously, very cold air moved west then south over western Europe, and the subsequent proximity of the quasi-stationary upper cold trough meant that vigorous cyclonic systems moved over or near the south of the British Isles throughout the second half of the month.

It is interesting that the November pentad thickness anomalies of the same sign were also grouped in limited geographical areas (Figure 8), particularly noteworthy being the clusters of NACs in the Gulf of Alaska, over eastern America, over north-west of Europe to off the south-west of the British Isles and over Siberia, suggestive of long spells with broad-scale homogeneity in circulation characteristics. Moreover, comparison of Figures 7 and 8 shows that there was considerable broad-scale resemblance from the western Pacific to off eastern America. However, the marked dissimilarities over western Europe essentially resulted from the retrogression of both the eastern European cold trough and the western European block.

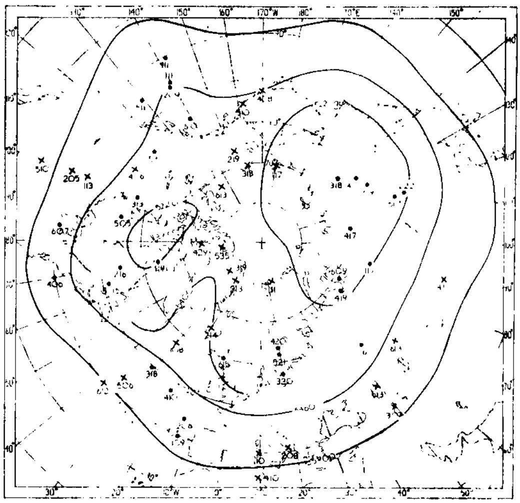

FIGURE 8—5-DAY MEAN 1000–500 MB THICKNESS ANOMALY CENTRES IN NOVEMBER 1965

. Negative centres (NAC)
x Positive centres (PAC)
——— Selected monthly mean 500 mb contours in geopotential metres
In the 3-figure groups the first figure is the pentad number and the remaining figures give the anomaly in geopotential decametres.

5-day periods in November	
No.	Begins
1	2nd
2	7th
3	12th
4	17th
5	22nd
6	27th

General remarks.—This descriptive account must be restricted in the interests of simplicity and clarity. Nevertheless, it should be clear that large anomalies and big month-to-month changes in circulation occurred in other sectors of the northern hemisphere as well as near the British Isles. The radical changes from September to October over the western Pacific and America and also over the eastern Atlantic and Europe were related to a marked shortening of the wavelength of the upper flow ; this was achieved by a quite sudden and large shift eastwards of the American cold trough, which had been exceptionally far west of the normal position, and to the retrogression of anomalous cold troughs near eastern and western Europe, as well as to warm ridge amplification between the European troughs. Anti-persistence in broad-scale synoptic type over the British Isles from October to November was related to complex changes which effectively resulted in retrogression of the European block to high latitudes of the Atlantic and Greenland and of the eastern European trough to western Europe, whilst the cold trough near eastern America progressed little compared with the major progression from September to October. The troughs on each side of the Atlantic in November were unusually cold and concentrated in lower-middle latitudes with the result that the subtropical jet stream was stronger than usual, and the upper westerlies between 40° and 70°N were abnormally weak from the Rockies to the Urals. Additionally it is well worth stressing that the abnormal cold troughs near western Europe in September and November, associated in each case with cold cyclonic weather over the British Isles, managed to exist with the American trough in strikingly different positions ; and that the quite different circulation pattern over western Europe in October was linked with an American trough which was not far away from the same position in November.

What can be said about the circulation anomalies within each month? The 5-day anomalies clustered within, say, a square of side about 15 degrees of latitude suggest that certain broad-scale circulation patterns commonly persisted for a few pentads, then changed to a new mode or returned to the original one after a transitional period of about a pentad. Around the transitional period the day-to-day synoptic changes in one sector were not only predictable by the normal subjective or objective procedures but were often obviously related to preceding modifications of the circulation in adjacent sectors. However, the interdependence of circulations in sectors very far apart (e.g. western Europe and western Pacific) was rarely obvious ; in these cases linkages were complex and indirect.

The ultimate causes of the large-scale circulation anomalies, such as those of the autumn of 1965, are not known. The importance of air-sea interaction is certainly well recognized (e.g. Namias[2] and Sawyer[3]), but our understanding of the interrelationship and feed-back mechanisms on different time-scales is still extremely limited.

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COMPARISON OF BRITISH STRATOSPHERIC AND MESOSPHERIC TEMPERATURE MEASUREMENTS WITH VALUES FROM AVAILABLE ATMOSPHERIC MODELS

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Temperature observed between 30 and 70 km at West Geirinish, Scotland (57°21′N, 7°23′W), during the period January and February 1964 and January to April 1965, are compared to the temperature–height profiles of various atmospheric models developed to represent mean monthly conditions near 60°N. Profiles from the Committee on Space Research (COSPAR) International Reference Atmospheres,[1] the Committee on Extension to the Standard Atmosphere (COESA) U.S. Standard Atmosphere Supplements,[2] and Air Force Cambridge Research Laboratories (AFCRL) models developed by Kantor and Cole,[3] are included in the comparison. The COESA models have been published as Air Force Interim Atmospheres, Cole and Kantor.[4]

The temperature measurements for West Geirinish were made with the SKUA meteorological rocket recently developed by the British Meteorological Office. The instrument package consists of a temperature measuring sonde attached to a parachute. The method of temperature measurement, immersion thermometry using a very fine tungsten wire, provides data at altitudes up to 60 to 65 km.

Vertical temperature structures of the atmospheric models were developed primarily from meteorological and experimental rocket soundings over North America. These soundings employed various types of sensors including bead thermistors, grenades, falling spheres and pressure gauges. The majority of the observations were taken at Churchill, Canada (58°44′N, 93°49′W).

Temperature–height profiles for an interpolated COSPAR January 57½°N atmosphere and the mean 60°N January COESA Atmospheres are compared

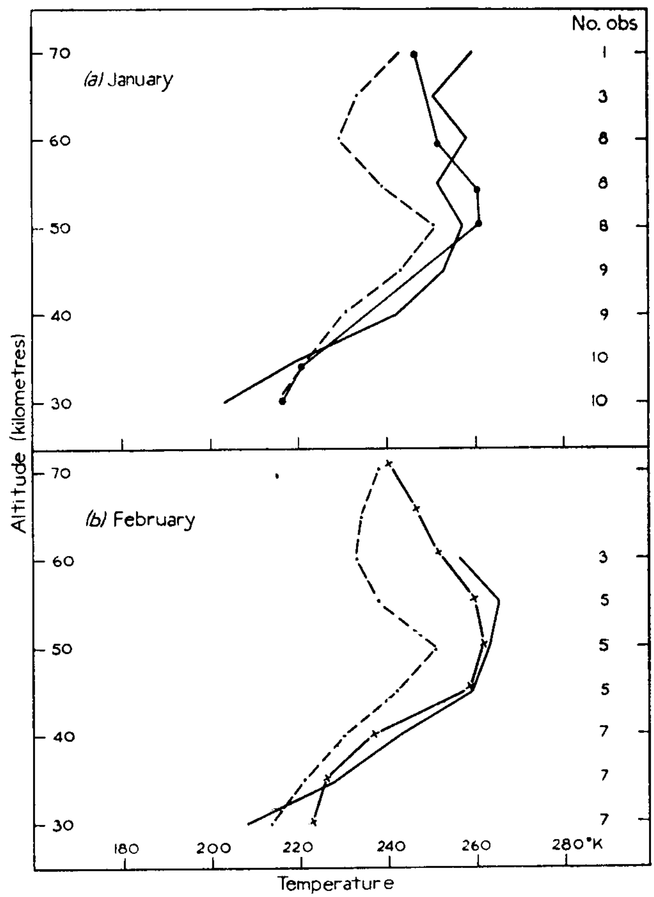

FIGURE I—COMPARISON OF RECENTLY OBSERVED JANUARY AND FEBRUARY TEMPERATURE–HEIGHT PROFILES WITH THOSE FROM PREVIOUSLY ESTABLISHED ATMOSPHERIC MODELS

——— West Geirinish, 57°N 7°W, observations   - - - COSPAR, 57½°N

·———· COESA, 60°N   x———x AFCRL, 60°N

in Figure 1(*a*) with the observed January means given by Farmer,[5] for West Geirinish. The number of observations on which the observed means are based is indicated on the right-hand margin. Similar comparisons are made between the observed data and temperature–height profiles for the AFCRL and COSPAR monthly atmospheres for February, March and April in Figures 1(*b*), 2(*a*), 2(*b*), respectively.

The observed monthly mean temperatures for West Geirinish are in relatively good agreement with the COESA and AFCRL temperature–height profiles but differ considerably from the COSPAR values. Observed values are 1 to 5 degC warmer than the AFCRL and COESA models between 35 and 50 km and slightly cooler in three of the four months between 50 and 55 km. The largest differences occur at 30 km where the January and February West Geirinish temperatures are 10 to 20 degC colder than those in the AFCRL models. Part of this difference is accounted for by the fact

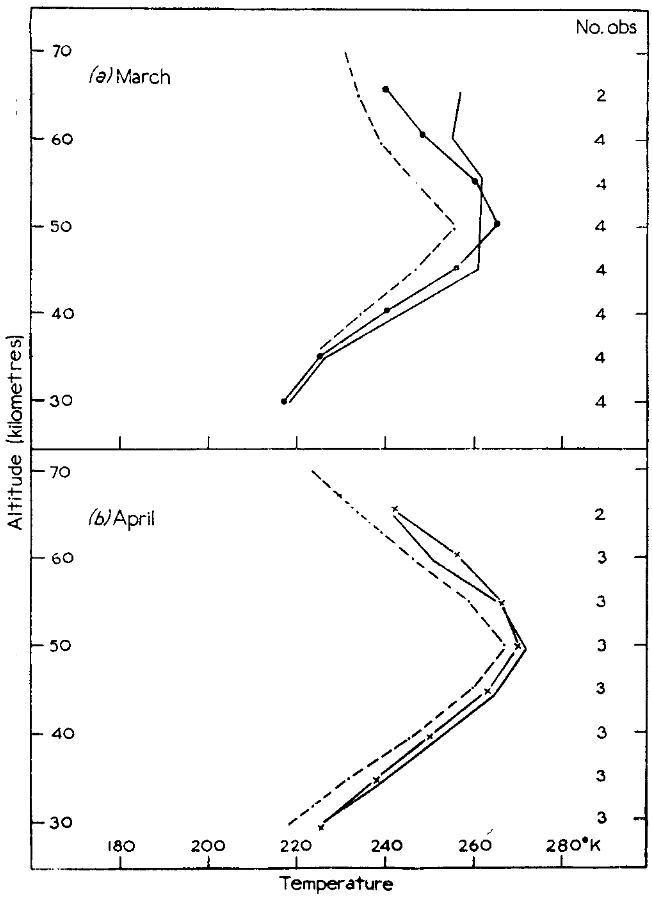

FIGURE 2—COMPARISON OF RECENTLY OBSERVED MARCH AND APRIL TEMPERATURE–HEIGHT PROFILES WITH THOSE FROM PREVIOUSLY ESTABLISHED ATMOSPHERIC MODELS

——— West Geirinish, 57°N 7°W, observations — — — COSPAR, 57½°N
·———· COESA, 60°N x———x AFCRL, 60°N

that the COESA and AFCRL temperatures at this level are based on hemispheric means computed from radiosonde data. An inspection of available radiosonde summaries indicates that the mean monthly January and February temperatures between 25 and 30 km for the region near West Geirinish are roughly 8 to 10 degC colder than the hemispheric mean at latitude 60°N. A possible explanation for the large differences between the COSPAR and AFCRL models which were prepared and published at approximately the same time and from the same data is that different weighting factors may have been used for the various types of observations.

The good agreement of the observed temperature–height profiles with the COESA and AFCRL atmospheres above 35 km suggests that conditions near Churchill, Canada, are similar to those at West Geirinish. It is also interesting to note that the large day-to-day temperature changes which are frequently observed in the upper stratosphere and lower mesosphere during January at Churchill, Canada, also occur at West Geirinish, Farmer[5] indicating that these phenomena may be a characteristic of all subarctic locations.

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METEOROLOGICAL CONTRIBUTIONS TO THE 1966 PHYSICS EXHIBITION

By J. I. P. JONES

Introduction.—From 28 to 31 March this year, the Institute of Physics and the Physical Society held their exhibition of scientific apparatus at the Alexandra Palace, London, the entire exhibition being gathered under one roof for the first time since 1955. The exhibition was the 50th in the series started by the Physical Society in 1905 with a modest three hours opening and 17 exhibitors. This year's contributors included 100 commercial firms, 21 government establishments, 24 universities and similar institutions of learning and 26 publishers.

Contributions comprising new wind measuring instruments and a cathode-ray tube (CRT) display technique were made by the Meteorology Research Division, Porton. Considerable interest was shown in the exhibits both by visiting scientists and by fellow contributors, and the Porton demonstrators were kept busy answering numerous questions. A brief description of the exhibits follows.

Portable sensitive anemometer* and wind velocity-component resolver.—These instruments[1] are shown in Plate I. The anemometer is fitted with a 12-cup rotor constructed of expanded polystyrene in order to obtain extra rapid response, but this may readily be replaced by a conventional 3-cup aluminium rotor if desired. The anemometer contains a photoelectric switch and a ratemeter which are supplied with power (12 V, 40 mA) from an external source. Both a.c. and d.c. outputs with frequency and voltage respectively proportional to wind speed, are provided by the instrument.

The resolver contains a low-friction sine-cosine potentiometer, and this is supplied directly with the d.c. voltage from the anemometer. Lightly sprung contacts, operating at 90° relative to one another on the potentiometer, are directly coupled to the wind vane, and provide output voltages proportional to orthogonal wind velocity-components. By appropriate orientation of the resolver case, voltages which represent algebraically two velocity-components in any specified mutually perpendicular directions, such as along and at right angles to the runway of an airfield, may be obtained.

The anemometer and resolver on display were designed originally as portable instruments for research into the statistics of atmospheric turbulence and the structure of wind eddies. All-weather instruments developed subsequently, having the same principle of operation though with a remote ratemeter of controllable output sensitivity, were mounted on the roof of the Palace for the exhibition. Outputs from these instruments were displayed on the stand using meters to indicate N–S and E–W 'sliding 2-min average' component velocities and wind speed. The voltages from the resolver were also processed electronically using the new CRT display technique outlined below, and the wind velocity was presented in vector form on a display oscilloscope. Duplexing at 200 c/s was employed to present, in effect simultaneously, both smoothed and fluctuation wind vectors. Plate II shows oscillograms of this type of display taken over periods of approximately 30 seconds.

Apparatus for displaying two-dimensional flow patterns using the cathode-ray tube.—This apparatus[2]† was designed for observing the surface wind field in real time by means of vectors on a cathode-ray tube, and for recording wind eddy patterns. Two voltages, representing orthogonal velocity-components of the wind, are passed to the apparatus (Plate III*a*) from each of a number of anemometer-resolver sets at selected positions in the field, and the winds are displayed, correspondingly arranged, as vectors on the cathode-ray tube. Oscillograms of eddy patterns (Plate III*b*) are obtained with the aid of electrical band-pass filters which emphasize fluctuations of the components within a particular frequency range as eddies traverse a cross-wind array of sensors. Alternatively, residual-vector displays, obtained by analogue subtraction of the spatial mean vector, can be used to examine eddy structure.

The system employs a combination of digital and analogue techniques in which all pairs of orthogonal input voltages are filtered, multiplexed, chopped and time-integrated, and then added sequentially to adjustable beam-switching voltages. The two final output signals are applied to the inputs

*United Kingdom Patent No. 1028494. †United Kingdom Patent application No. 21661/64.

To face page 240

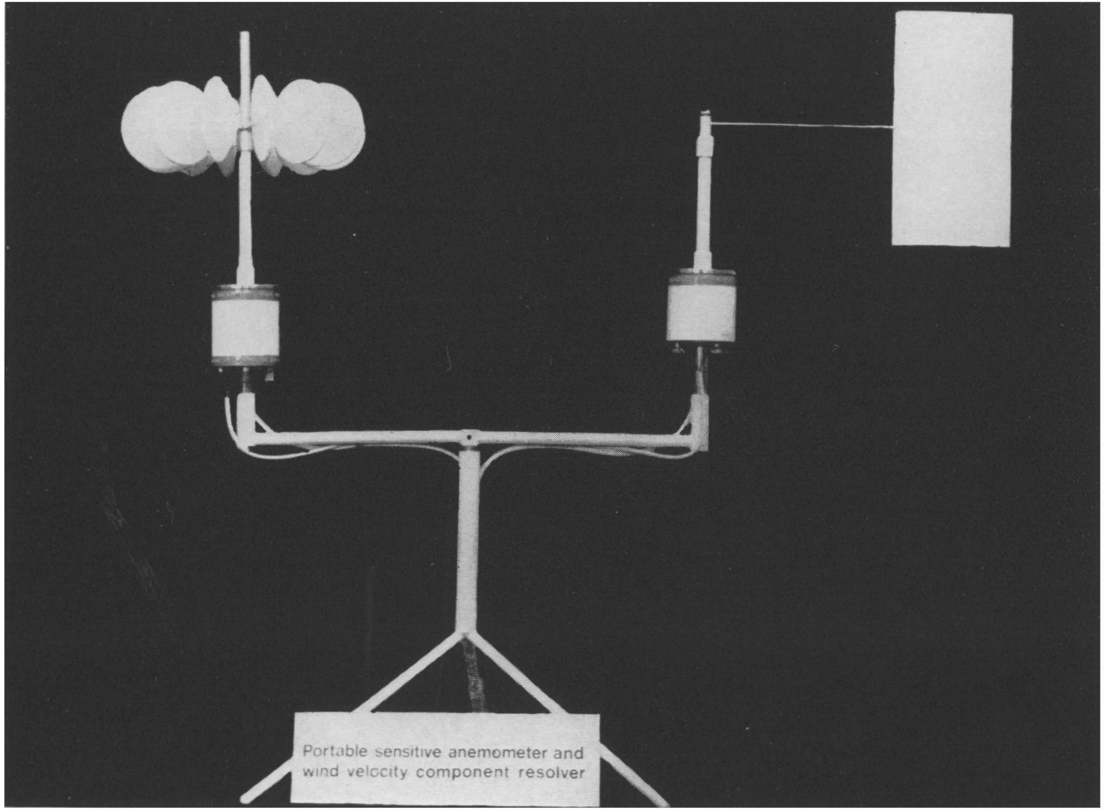


PLATE I—PORTABLE SENSITIVE ANEMOMETER AND WIND VELOCITY-COMPONENT RESOLVER

See page 239.

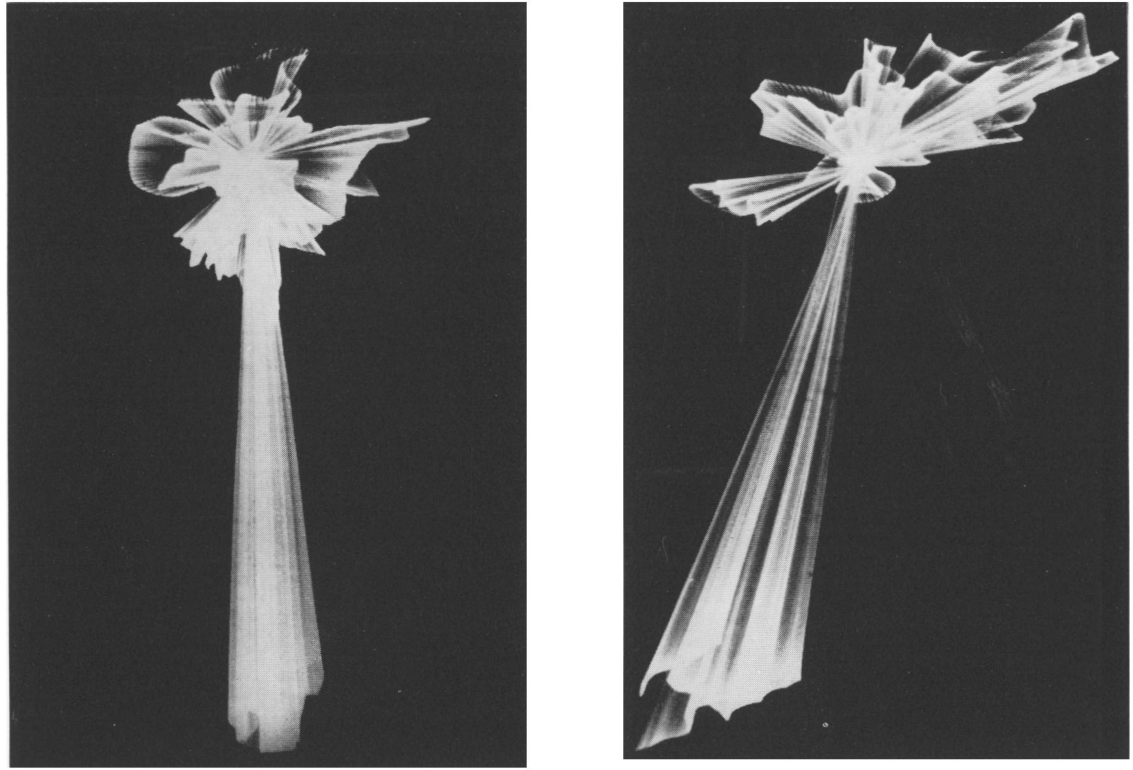


PLATE II—OSCILLOGRAMS OF WIND VELOCITY VECTORS

Photographed at the rate of 400 per second and showing both 'running mean' and fluctuation wind velocities over periods of approximately 30 seconds (see page 239).

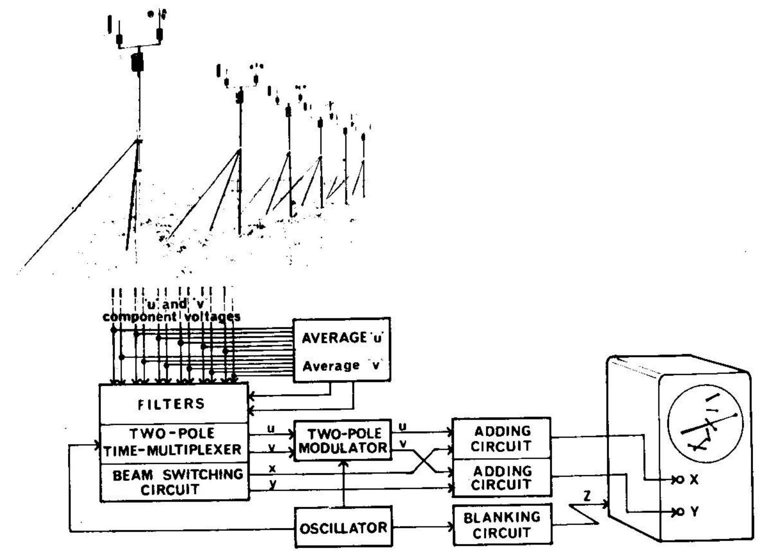
CRT vector presentation of surface wind data

This apparatus was designed for observing the surface wind at various positions in the field by means of vectors, correspondingly arranged, on a cathode-ray tube.

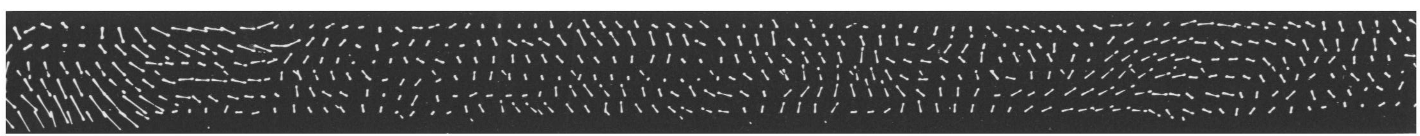
Two voltages, which represent orthogonal wind velocity-components, are passed to the apparatus from an anemometer-resolver set at each field position. All pairs of input voltages are multiplexed, chopped and time-integrated, and then added sequentially to beam-switching voltages. The final output signals are supplied to an X-Y oscilloscope, together with a blanking voltage to suppress the beam during switching and to eliminate direction ambiguity.

Oscillograms of eddy patterns are obtained with the aid of filters which emphasize wind fluctuations as the eddies traverse a linear array of sensors.

(a)



(b)



Crown copyright

PLATE III—CATHODE-RAY TUBE VECTOR PRESENTATION OF SURFACE WIND DATA

(*a*) The block circuit diagram of the system for recording oscillograms of eddy structure.

(*b*) An example of recorded eddy patterns at an open exposure at height 2 metres. Vectors of wind velocity fluctuations recorded as eddies pass through a cross-wind array of six sensors.
Scales — Vertical, 5 metres between vectors ; Horizontal, 1 second between vectors.
Filters used — Band-pass, centre frequency 2 c/min.

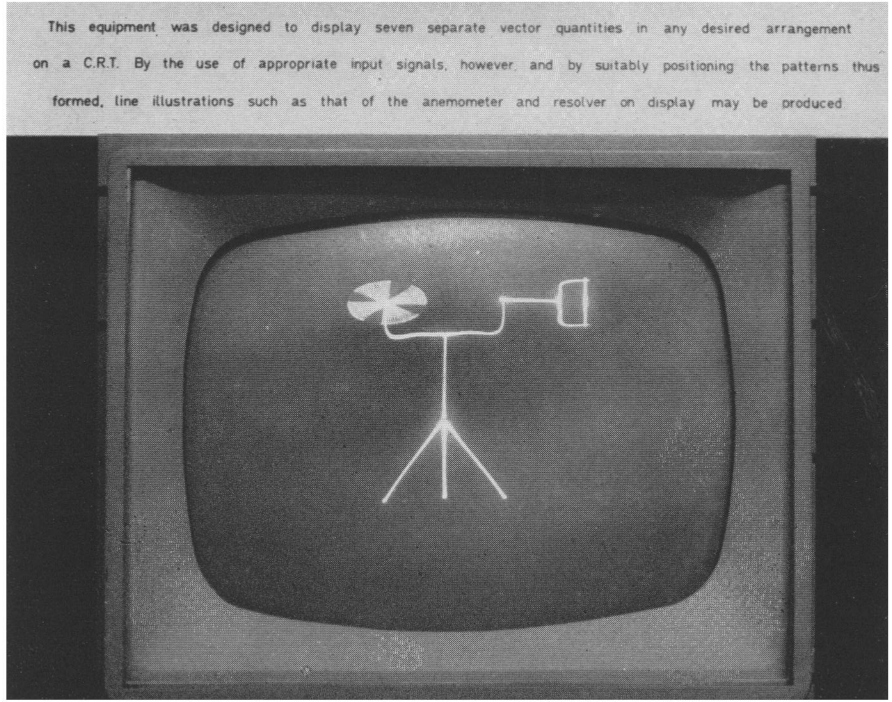


PLATE IV—LINE PICTURE PRODUCED WITH THE MULTI-VECTOR OSCILLOSCOPE DISPLAY EQUIPMENT AND USED TO DEMONSTRATE THE APPLICATION OF THE APPARATUS TO DISPLAY SYSTEMS IN GENERAL

A scanning frequency of 200 c/s was used (see page 239).

of an *X–Y* oscilloscope, together with a synchronized blanking signal to suppress the beam during switching from one vector position to the next and to eliminate direction ambiguity. Vectors are produced in sequence on the tube, although at a sufficiently high frequency to give the effect of simultaneity, the minimum scanning frequency being approximately 50 c/s. Each vector may be adjusted separately to any desired position on the tube by potentiometer control of the appropriate *X* and *Y* beam-switching voltages.

The flexibility of the apparatus and its consequent applications to display systems in general was demonstrated at the exhibition by displaying, on an oscilloscope, a line illustration of an anemometer and resolver mounted on a tripod (Plate IV), a rotating four-bladed rotor being produced by the application of quadrature 50 c/s voltages to one pair of input terminals.

Acknowledgements.—Acknowledgement is made to the Director, CDEE, Porton Down for the facilities provided, and to Messrs I. H. Simpson, G. D. Nichols and J. B. Tyldesley, Meteorological Office, who ably demonstrated the exhibits.

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551.510.42:551.524.4:551.553.6

AN INDICATOR OF SURFACE WIND DIRECTIONS POTENTIALLY FAVOURABLE FOR ATMOSPHERIC POLLUTION

By E. N. LAWRENCE

Summary.—At Crawley, Sussex, winter midday low-level inversions (taken to indicate at least 12 hours persistent inversion) are analysed according to light-wind direction (surface and 900 mb) and are shown to be associated more with light easterly winds than with westerlies. Inversions at Crawley with easterly winds tend to persist longer than those with westerlies. The distribution of temperature inversions with wind direction may thus indicate a light-wind direction favourable for persistent temperature inversion and hence potentially favourable for high concentrations of air pollution. The surface light-wind rose for all occasions may give some indication of directions favourable for persistent temperature inversion if some allowance is made for the fact that westerlies are generally more frequent than easterlies.

Introduction.—It is well known that atmospheric pollution is associated with stable atmospheric lapse rates or inversions of temperature near the ground.[1,2] Such inversions are usually associated with light winds, and so it might be thought that the surface light-wind rose would be a good indicator of the distribution, according to wind direction, of frequencies of low-level inversions and so indicate the wind directions potentially favourable for atmospheric pollution.

In some locations such as a sheltered valley, and during nights with high net outgoing radiation, there may be a simultaneous development of both a temperature inversion near the ground and a characteristic light local wind from a particular direction. A typical example has been described[3] for Point Arguello, California, where nocturnal surface inversions based below 1000 feet occur mostly with downslope surface winds. However, there need not necessarily be an all-round similarity between the direction rose for all occasions of light winds and the direction rose for winds which occur with low-level inversions.

Again, local winds are not necessarily light or very light and inversion frequencies do not always increase with decreasing surface wind speed. For example, an investigation into characteristics of low-level inversions at Budapest[4] shows that the highest percentage frequencies of inversions occur with medium wind speeds of 3–4 metres/second and not with lighter winds. Furthermore, over flatter terrain, light or very light winds could be more frequent from the prevailing wind directions, and these directions are not necessarily associated with persistent atmospheric stability.

Hence it does not follow that a strong relationship exists in general between the distribution of light winds and of low-level inversions according to the direction of wind, and the following study of persistent inversions at Crawley shows that in winter they are associated with light easterly winds more than with westerly light-wind directions. It is also shown that inversions at Crawley with easterly winds tend to persist longer than those with westerly wind directions. Thus the light-wind direction rose for winter inversions may be taken as an indicator of the wind direction potentially favourable for atmospheric pollution, though the direction rose for all occasions of light winds may not be a suitable indicator.

Data used.—The study was made for the meteorological station site at Crawley (51°05′N, 0°13′W, 471 feet above mean sea level) which is situated on the western end of a ridge running roughly east–west with broad valleys to the north and south beyond which lie the North and South Downs respectively (see Figure 1). The data refer to the five-year period from April 1960 to March 1965. Temperature profiles are obtained in considerable detail since the introduction of automatic (Cintel) radiosonde techniques in 1960.

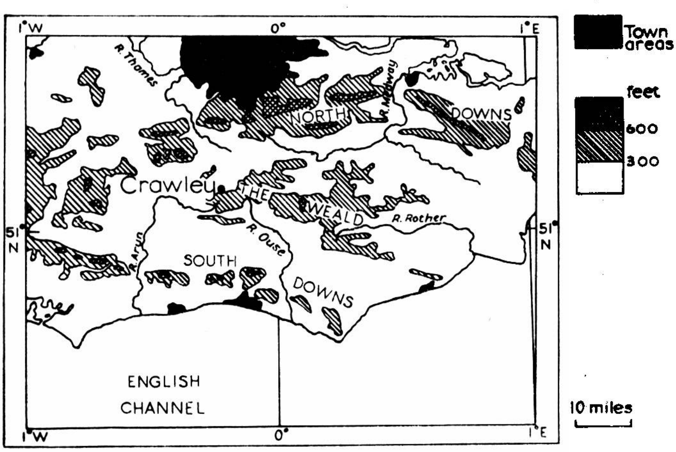
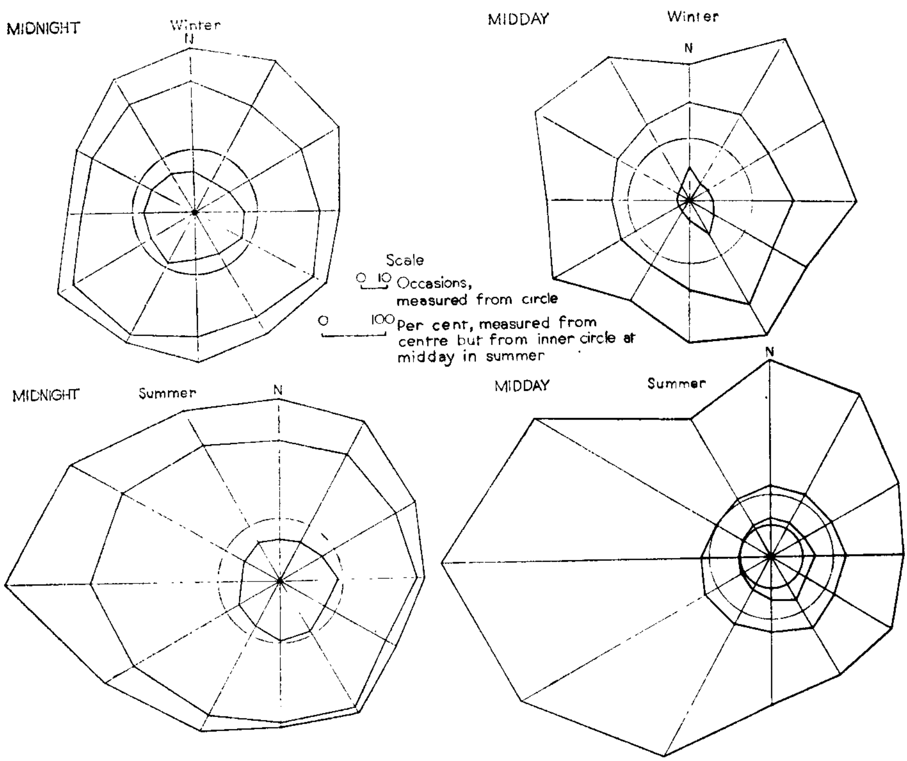


FIGURE 1—DIAGRAM SHOWING CRAWLEY IN RELATION TO LONDON AND THE NORTH AND SOUTH DOWNS

Analysis and discussion.—Figure 2 shows (i) the frequencies of light-wind directions at Crawley, (ii) the frequencies, according to light-wind direction, of inversions of base below 2000 feet above ground and (iii) the percentage ratios of (ii) to (i). The percentages indicate to what degree the number of inversions with winds from a particular direction is large as a result of a large number of winds from that direction.

The data are presented separately for midnight, midday, winter half-year (October–March) and summer half-year (April–September), and for surface wind speeds in the ranges of calm, 1–4 knots and 5–9 knots. Frequencies are given also for 900 mb wind speeds in the range 1–19 knots. Winds at 900 mb have the advantage over surface winds of being more representative of the region, and also the 900 mb wind speed is only rarely reported as calm. In contrast, the surface wind is often reported as calm ; for example, in winter, about 25–30 per cent of all occasions of inversion of base below 1000 feet above the ground occurred with reported calm.

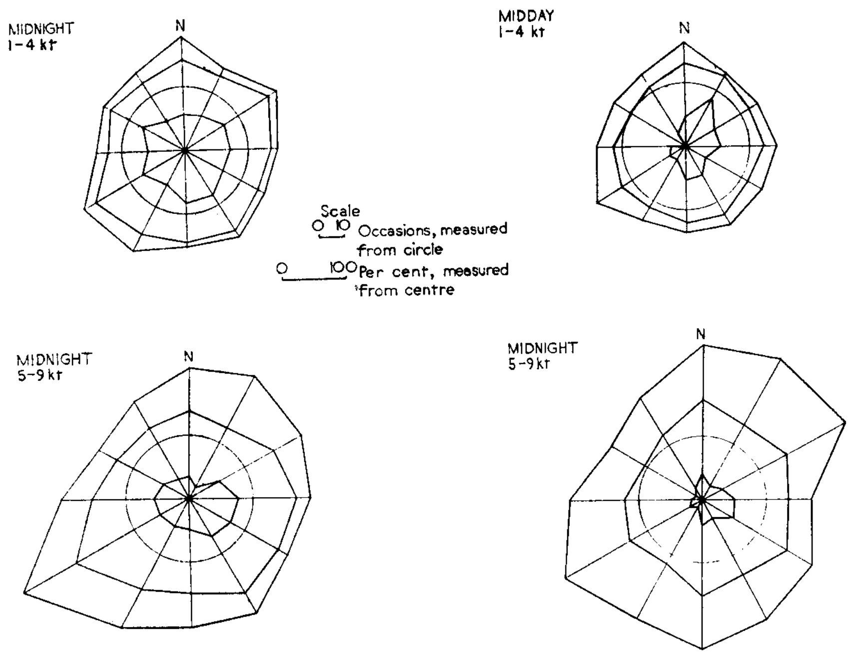
It can be seen from Figure 2 that winds at midday with an easterly component have a greater proportion of inversions of base below 2000 feet than



(*a*) 900 mb winds, 1–19 knots
Outer polygon — 900 mb wind Middle polygon — inversions
Inner polygon — percentage

FIGURE 2—LIGHT-WIND DIRECTION ROSES FOR 900 MB AND SURFACE FOR VARIOUS TIMES AND SEASONS COMPARED WITH THE ROSES FOR OCCASIONS OF INVERSION BASE BELOW 2000 FEET ABOVE GROUND AT CRAWLEY DURING THE PERIOD APRIL 1960 TO MARCH 1965

winds with a westerly component. On the other hand, the midnight data, at least for winter, do not show the same contrast between east and west percentages. At midnight for the 900 mb level in winter, Figure 2(*a*) shows a tendency for the reverse pattern, possibly reflecting the frequency of warm south-west airstreams over cold ground.



(*b*) Surface winds, winter
Outer polygon — surface wind Middle polygon — inversions
Inner polygon — percentage

	Midnight	Midday
Total number of calms	171	99
Number of calms with inversions	138	34
Inversion calms as percentage of total calms	81	34

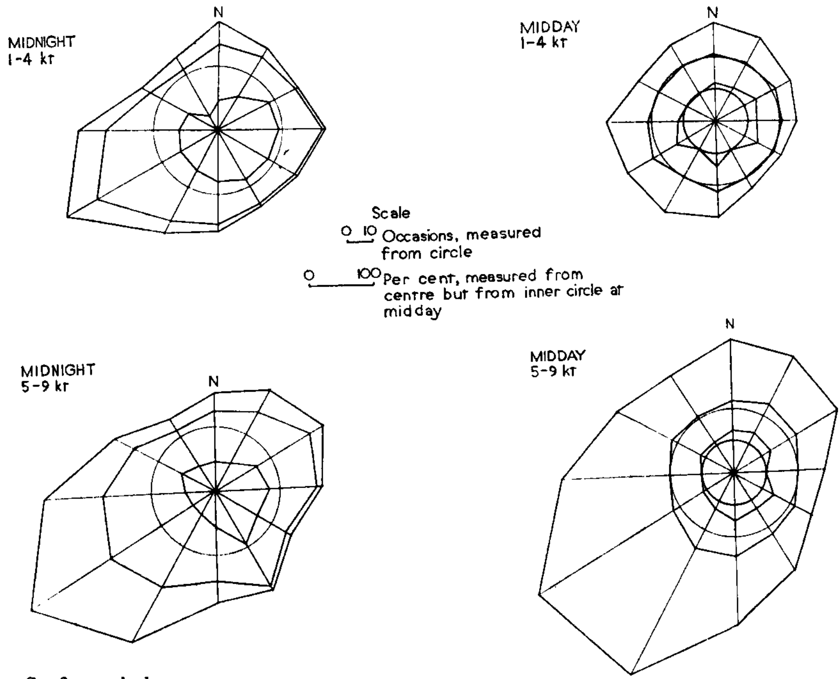
(The diagram at bottom right is for Midday, not Midnight)

FIGURE 2—*continued*

The probability of the dependence of (ii) on (i) was also examined by means of chi-square (χ^2) tests, Table I gives χ^2 obtained by comparing the two sets of frequencies. The degrees of freedom are listed as well as the probability that χ^2 would be exceeded by chance.[5] The degrees of freedom vary because in some categories the direction classes are combined in order to give classes with sufficient numbers for the application of the chi-square test.

Table I shows that for the midnight results for the various heights of inversion base, it is highly probable that inversion frequencies are dependent on the wind frequencies but that for the midday results the dependence is less.

The tendency for inversions to occur with preferred wind direction is rather more marked for surface wind speeds of 5–9 knots than for speeds of 1–4 knots, possibly because of the random nature of very light wind directions. At 900 mb the tendency for a preferred direction at midday in winter is more noticeable for inversions with base below 2000 feet than for inversions with base below 250, 500, or 1000 feet, presumably because the lower inversions are more likely to occur with light and variable winds.



(*c*) Surface winds, summer

Outer polygon — surface wind Middle polygon — inversions
Inner polygon — percentage

	Midnight	Midday
Total number of calms	282	75
Number of calms with inversions	222	6
Inversion calms as percentage of total calms	79	8

FIGURE 2—*contiuued*

Persistent inversions can be shown to be occasions of real importance from the pollution aspect. An inversion at midday probably follows an inversion at midnight and can be taken to indicate an occasion of over 12 hours persistent inversion. From the pollution aspect therefore the occasions of *midday* inversion are likely to be more significant than occasions of *midnight* inversion. The *midnight* low-level inversions of base below 250 feet were more frequent in the summer half-year than in the winter half-year ; namely 474 and 375 occasions respectively. However the corresponding *midday* frequencies are 2 and 31. Thus during the summer half-year, low-level inversions are not persistent through the day and so any air pollution occurring at night would have a chance to disperse during the day. The greater number of *midday* inversions in the winter half-year indicates that there are more persistent inversions and that a greater retention of air pollution is possible.

TABLE I—VALUES OF THE PROBABILITY OF THE DEPENDENCE OF LIGHT-WIND DIRECTION FREQUENCIES DURING INVERSIONS ON THE TOTAL LIGHT-WIND DIRECTION FREQUENCIES, PERIOD OCTOBER 1960–MARCH 1965

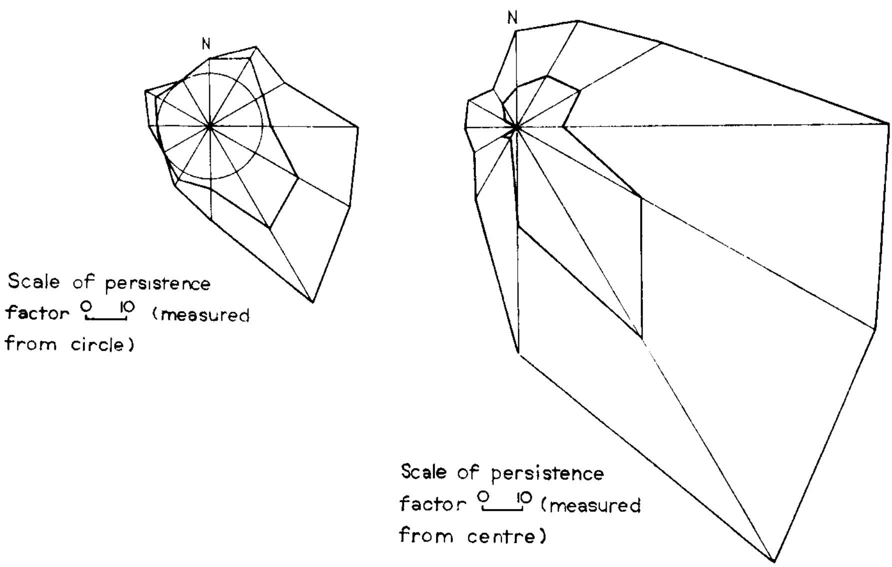
(*a*) 900 mb winds, 1–19 knots

Half-year	Time of observation	Base of inversion below : *feet above ground*	Chi-square	Degrees of freedom	Probability range
October to March	midnight	250	7·14	11	0.80–0.70
		500	6·26	11	0.90–0.80
		1000	8·13	11	0.80–0.70
		2000	7·10	11	0.80–0.70
	midday	250	3·72	3	0.30–0.20
		500	1·86	4	0.80–0.70
		1000	12·40	10	0.30–0.20
		2000	24·25	11	0.02–0.01
April to September	midnight	250	7·31	11	0.80–0.70
		500	7·95	11	0.80–0.70
		1000	8.37	11	0.70–0.50
		2000	9.24	11	0.70–0.50
	midday	2000	27·58	6	<0.001

(*b*) Surface winds

Half-year	Time of observation	Surface wind speed *knots*	Base of inversion below : *feet above ground*	Chi-square	Degrees of freedom	Probability range
October to March	midnight	1–4	250	4·09	11	0.98–0.95
			500	3·82	11	0.98–0.95
			1000	4·08	11	0.98–0.95
			2000	2·31	11	1.00–0.99
		5–9	250	13·18	11	0.30–0.20
			500	14·61	11	0.30–0.20
			1000	14·20	11	0.30–0.20
			2000	12·67	11	0.50–0.30
	midday	1–4	1000	12·64	11	0.50–0.30
			2000	11·58	11	0.50–0.30
		5–9	1000	10.45	11	0.50–0.30
			2000	21·23	11	0.05–0.02
April to September	midnight	1–4	250	9·50	11	0.70–0.50
			500	9·11	11	0.70–0.50
			1000	8·34	11	0.70–0.50
			2000	7·26	11	0.80–0.70
		5–9	250	11·63	11	0.50–0.30
			500	16·43	11	0.20–0.10
			1000	20·21	11	0.05–0.02
			2000	15.83	11	0.20–0.10
	midday	5–9	2000	14.91	6	0.05–0.02

Inversion spells longer than a day.—In the problem of air pollution from an external source it is important to consider persistent inversions in which wind directions are reasonably steady. The persistence of inversion spells according to the various persisting wind directions was analysed as follows. A stable spell was defined as a period of two or more consecutive midday observations with an inversion below 1000 feet above the ground (at Crawley) and with intermediate midnight observations also having such an inversion, and with the 900 mb wind directions remaining not more than 30° from the direction at midday on the first day of the spell, or not more than 50° for speeds smaller than or equal to 4 knots. The dates and wind directions for all such spells were listed. The second observation of a spell was given two points, the third observation was given three points and so on. The total number of points for each wind direction 30°, 60°, etc. was referred to as the relative persistence factor for that direction. The procedure was repeated for midday observations only and the whole procedure repeated for spells with inversion base below 2000 feet above the ground. The results in Figure 3 show peak values of the factor for 900 mb wind directions of 150° to 090°. These directions are approximately the range of 900 mb (1–19 knots) wind directions for the highest frequency of inversions of base below 2000 feet at midday (see Figure 2).



(*a*) Midday observations (*b*) Midnight and midday observations

FIGURE 3—VARIATION WITH 900 MB WIND DIRECTION OF SPELLS OF TEMPERATURE INVERSION, AS INDICATED BY RELATIVE PERSISTENCE FACTORS, AT CRAWLEY DURING THE WINTER HALF-YEARS IN THE PERIOD OCTOBER 1960 TO MARCH 1965

Inner polygon refers to inversions of base below 1000 feet.
Outer polygon refers to inversions of base below 2000 feet.

Application.—The results which relate wind directions to frequencies of low-level inversions apply in general to the 900 mb level at Crawley as well as to surface data. Therefore the conclusions apply not merely to the site at Crawley but more generally to inland areas of south-east England which could reasonably be assumed to have 900 mb winds similar to those at Crawley.

In air pollution problems, wind speed and direction at a site must be considered in relation to the distances and directions of any pollution sources.

In any assessment of possible air pollution it should be borne in mind that there may be significant differences between wind rose data obtained over different periods. For example the frequency of easterlies at Crawley during the winter half-years of the period October 1960 to March 1965 was greater than in the previous five-year period 1955–59 and was probably distinctly above the long-term average.

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551.509.324.2:551.509.542

THE FORECASTING OF SHOWER ACTIVITY IN AIRSTREAMS FROM THE NORTH-WEST QUARTER OVER SOUTH-EAST ENGLAND IN OCTOBER TO APRIL

By C. A. S. LOWNDES

Introduction.—In an earlier paper[1] a study was made of the shower activity in airstreams from the north-west quarter over south-east England in summer-time and the relative usefulness of a number of predictors for forecasting shower activity, thunder and hail was evaluated. This paper deals in the same way with the problem of forecasting shower activity over south-east England in the months October to April. The investigation was restricted to airstreams which approached the British Isles from the north-west quarter. The factors associated with shower activity which were considered were the same as in the previous investigation[1] and as before, the intensity of shower activity was classified as follows :

A Widespread showers with a good proportion of moderate or heavy showers (8 or more mentions of showers ; more than 25 per cent moderate or heavy showers).

B Widespread showers with few moderate or heavy showers (8 or more mentions of showers ; 25 per cent or less of moderate or heavy showers).

C Few showers (less than 8 mentions of showers).

D No showers.

Association with surface synoptic features.—

The position of the associated depression at midday.—No significant relationship could be found between the position of the depression with which the polar air was associated and the intensity of shower activity.

The curvature of the surface isobars over England.—On many days of widespread showers, a surface trough moved eastwards or southwards across England. Of the troughs which moved eastwards, 25 per cent were major features with the trough axis some 600 to 1000 miles in length and 75 per cent were minor perturbations with the trough axis some 200 to 600 miles in length. Of the 10 troughs which moved southwards, all but one were minor perturbations. Table I shows the number of these occasions for each class of shower activity.

TABLE I—SHOWER ACTIVITY RELATED TO THE CURVATURE OF THE SURFACE ISOBARS OVER ENGLAND (OCTOBER TO APRIL 1950–65)

	Class of shower activity			
	A	*B*	*C*	*D*
	number of occasions			
Surface trough moved eastwards across England	11	5	4	1
Surface trough moved southwards across England	5	5	0	0
Uniform cyclonic isobars over England	2	2	6	0
Neither surface trough nor uniform cyclonic isobars	13	14	34	37
Total	31	26	44	38

On 46 per cent of occasions of widespread showers (classes *A* and *B*) a surface trough moved eastwards or southwards across England. Of the 6 days on which a major surface trough moved across England, 5 were associated with widespread showers and thunder. Of the 25 days on which a minor perturbation moved across England, 21 (84 per cent) were associated with widespread showers and 14 (56 per cent) with thunder. Of the 10 days with uniform cyclonic isobars over England, only 4 were associated with widespread showers. There was only one occasion of widespread showers when the isobars over England were anticyclonic. On 94 per cent of occasions of few or no showers (classes *C* and *D*) no surface trough moved across England. On 23 per cent of occasions of few or no showers the isobars over England were anticyclonic.

Table II shows the number of occasions of each class of shower activity for days when no surface trough moved across England, for each month.

TABLE II—SHOWER ACTIVITY ON DAYS WHEN NO SURFACE TROUGH MOVED ACROSS ENGLAND, FOR EACH MONTH FROM OCTOBER–APRIL 1950–65

	Class of shower activity				
	A	*B*	*C*	*D*	Total
	number of occasions				
October	5	2	6	8	21
November	1	0	10	5	16
December	0	0	7	5	12
January	0	1	7	6	14
February	0	2	6	6	14
March	3	1	2	1	7
April	6	10	2	6	24

Most of the days with widespread showers (classes *A* and *B*) occurred in the Autumn and Spring and few in the winter months November to February. Table III shows the number of days with few or no showers (classes *C* and *D*) with no surface trough, expressed as a proportion of the days when no surface trough moved across England, for each month.

TABLE III—PROPORTION OF DAYS, IN EACH MONTH, WITH FEW OR NO SHOWERS WHEN NO SURFACE TROUGH MOVED ACROSS ENGLAND (OCTOBER–APRIL 1950–65)

Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
14/21	15/16	12/12	13/14	12/14	3/7	8/24

For the winter months November to February 1950–65, 93 per cent of the days with no surface trough were associated with few or no showers. On the other hand, for the months October, March and April, the proportion ranged from 33 per cent for April to 67 per cent for October. It is clear that for the winter months November to February, widespread showers are unlikely in the absence of a surface trough. Of the 18 days during the winter months when a surface trough moved across England, 15 (83 per cent) were associated with widespread showers and 9 (50 per cent) with thunder.

Association with 700 mb temperature and surface pressure.—The following data were extracted for the period 1950–65 :

(i) The 700 mb temperature anomaly at Crawley for 1200 GMT (1500 GMT before 1957) ; for 1950–52 Larkhill was used. The anomaly was based on the 5-day mean temperatures given in Table IV.

(ii) The mean-sea-level pressure at Heathrow for 1200 GMT.

TABLE IV—FIVE-DAY MEAN 700 MB TEMPERATURE AT CRAWLEY* IN °C

Period	Mean	Period	Mean	Period	Mean
28 Sept. – 2 Oct.	−2	25 Feb. – 1 Mar.	−10	1 – 5 Apr.	−8
3 – 7 Oct.	−2	2 – 6 Mar.	−9	6 – 10	−8
8 – 12	−2	7 – 11	−9	11 – 15	−8
13 – 17	−3	12 – 16	−9	16 – 20	−7
18 – 22	−3	17 – 21	−8	21 – 25	−7
23 – 27	−3	22 – 26	−8	26 – 30	−7
28 Oct. – 1 Nov.	−4	27 – 31	−8		

* Obtained from 5-year monthly means[2] for the period 1951–55.
(Larkhill 1951–52, Crawley 1953–55)

It became clear that the 700 mb temperature anomaly and mean-sea-level pressure were of no use as predictors for the winter months November to February. However, for the months October, March and April, Figures 1, 2 and 4 of the earlier paper[1] can be used to give some indication of shower activity, rainfall amount and thunder. The skill scores obtained are given in Table VI. The skill score S[3] is defined by

$$S = \frac{\text{number of correct forecasts} - \text{number correct by chance}}{\text{total number of forecasts} - \text{number correct by chance}}$$

It ranges from 0 for no success to 1 for complete accuracy.

Association with 1000–500 mb thickness and surface pressure.— The 1000–500 mb thickness anomaly at Crawley for 1200 GMT (1500 GMT before 1957) was extracted for the period 1950–65 ; for 1950–52 Larkhill was used. Anomalies were measured from the 5-day mean 1000–500 mb thickness values for Crawley given in Table V.

TABLE V—FIVE-DAY MEAN 1000–500 MB THICKNESS AT CRAWLEY* IN DECAMETRES

Period	Mean	Period	Mean	Period	Mean
28 Sept. – 2 Oct.	550	25 Feb. – 1 Mar.	534	1 – 5 Apr.	538
3 – 7 Oct.	550	2 – 6 Mar.	535	6 – 10	539
8 – 12	549	7 – 11	536	11 – 15	539
13 – 17	549	12 – 16	537	16 – 20	540
18 – 22	548	17 – 21	537	21 – 25	541
23 – 27 Oct.	547	22 – 26	538	26 – 30	542
28 Oct. – 1 Nov.	546	27 – 31	538		

* Obtained from 5-year monthly means[2] for the period 1951–55.
(Larkhill 1951–52, Crawley 1953–55)

Analyses were carried out with the 1000–500 mb thickness anomaly in place of the 700 mb temperature anomaly and again no useful results could be obtained for the winter months November to February. For the months October, March and April, Figures 6, 7 and 8 of the earlier paper[1] can be used to give some indication of shower activity, rainfall amount and thunder. The skill scores obtained are given in Table VI.

An analysis was also carried out with the 1000–700 mb thickness anomaly in place of the 700 mb temperature anomaly and similar results were obtained. The corresponding skill scores for the months October, March and April are also shown in Table VI.

Association with the instability indices.—The Boyden instability index,[4] the Rackliff instability index,[5] the Jefferson instability index[6] and the modified Jefferson instability index[7] were calculated for the Crawley 1200 GMT ascents (1500 GMT before 1957). The critical values of the indices which gave the highest skill scores in forecasting either widespread showers or few showers/no showers were obtained. A similar procedure was carried out for rainfall amount, thunder and hail. Some skill scores of 0·5 or above were obtained for the months October, March and April, but not for the winter months November to February. The skill scores and critical values of the indices for the months October, March and April are given in Table VI.

The relative usefulness of the predictors.—Assuming that the predictors can be forecast, their relative usefulness in forecasting shower activity, rainfall amount, thunder and hail can be assessed by a comparison of skill scores. Table VI shows the skill scores obtained and the critical values of the indices for the months October, March and April.

TABLE VI—A COMPARISON OF SKILL SCORES FOR OCTOBER, MARCH AND APRIL

Predictors	Shower activity	Rainfall (limit 0·1 mm)	Rainfall (limit 0·5 mm)	Thunder	Hail
700 mb temperature anomaly and surface pressure	0·58	0·58	0·35	0·50	0·35
1000–500 mb thickness anomaly and surface pressure	0·54	0·54	0·34	0·47	0·34
1000–700 mb thickness anomaly and surface pressure	0·58	0·51	0·30	0·44	0·30
Boyden instability index (critical values)	0·64 (93/94)	0·58 (93/94)	0·51 (94/95)	0·57 (94/95)	0·32 (94/95)
Rackliff instability index (critical values)	0·58 (28/29)	0·58 (28/29)	0·43 (30/31)	0·42 (30/31)	0·37 (30/31)
Jefferson instability index (critical values)	0·45 (20/21)	0·52 (20/21)	0·39 (23/24)	0·46 (23/24)	0·26 (23/24)
Modified Jefferson instability index (critical values)	0·58 (18/19)	0·58 (18/19)	0·40 (19/20)	0·49 (24/25)	0·21 (24/25)

The Boyden instability index gives the highest scores in general. However, which predictor is to be preferred depends largely on which is easiest to forecast. None of the predictors provide a useful indication of the likelihood of hail. The skill scores are mostly lower than those obtained for the summer months May to September.[1]

Forecasting thunder in the winter months November to February.—A useful indication of thunder during the months November to February can be obtained from the instability indices if thunder is forecast only when the mean-sea-level pressure at Heathrow at 1200 GMT is expected to be less than 1005 mb. Table VII shows the skill scores obtained and the critical values of the indices.

TABLE VII—A COMPARISON OF SKILL SCORES FOR NOVEMBER TO FEBRUARY

Predictors	Thunder	Thunder*
Boyden instability index	0·21	0·40
(critical values)	(93/94)	(93/94)
Rackliff instability index	0·32	0·53
(critical values)	(33/34)	(33/34)
Jefferson instability index	0·46	0·64
(critical values)	(25/26)	(25/26)
Modified Jefferson instability index	0·40	0·56
(critical values)	(23/24)	(23/24)

* Including mean-sea-level pressure as a predictor

The Jefferson instability index gives the highest score. It is interesting to note that the Boyden index which provides the highest scores in the remaining months of the year is of little use in the winter months.

Conclusions.—This investigation was concerned with airstreams from the north-west quarter affecting south-east England in the months October to April and was restricted to days when no fronts were situated over south-east England. Widespread showers are likely if a major trough or minor perturbation moves across England and thunder is likely to occur on about half of these occasions. During the winter months November to February widespread showers or thunder are unlikely to occur in the absence of a surface trough. For the months October, March and April the best indication of shower activity, rainfall amount and thunder is given by the Boyden instability index. For the winter months November to February no predictor provides a useful indication of shower activity. However, a good indication of the likelihood of thunder can be obtained from the Jefferson instability index and the surface pressure. The relative usefulness of the predictors has been evaluated ; which is to be preferred in forecasting depends largely on how successfully each can be forecast.

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REVIEWS

Humidity and moisture : Volume two, *Applications*, edited by Elias J. Amdur. 10½ in × 7 in, pp. xv + 634, *illus.*, Chapman and Hall Ltd., 11 New Fetter Lane, London EC4, 1965. Price : £11.

This is the second of four substantial volumes containing a group of 74 papers presented at the 1963 International Symposium on Humidity and Moisture held in Washington, D.C. The volume concerns 'measurements unique or special to various fields or disciplines ; studies and investigations in which humidity or moisture is the critical parameter'. The volume is divided into : I. Biology and Medicine (10 papers) ; II. Agriculture (19 papers) ; III. Environmental Chambers (7 papers) ; IV. Air Conditioning (11 papers) ; V. Process Control (6 papers) ; VI. Meteorology (12 papers) ; VII. Radio Propagation and Atmospheric Refraction (9 papers). Deliberately there was no strong, overt, editorial policy, and papers range from 'descriptive reviews which may be evaluated by any technically trained person having a general familiarity with humidity instrumentation, to reports of investigations which can properly be reviewed only by specialists.' Clearly therefore it is presumptuous of one person to attempt a review in other than general terms.

When faced with a compendium of this sort one asks : (1) Are all the obvious user interests catered for ? (2) Under any particular head, is a wide spectrum of interest covered ? (3) Is the documentation sufficient, or such as to 'open-up' the literature ? (4) Is the layout, presentation, and indexing such as to permit ready access to papers on any topic ?

With respect to (1), readers will be disappointed not to find papers dealing explicitly with the processing of timber and construction materials generally (there is nothing on metal corrosion), on the handling of long-distance cargo and freight and the packaging and storage of retail goods, and possibly also on the interactions between aerosols and atmospheric moisture. However a topic expected by the reviewer of Volume I,* but noted as missing, namely micro-wave refractometry is here dealt with in some detail—suggesting that inquirers on some particular topic might be advised to consult all volumes rather than that which appears most appropriate (no cross-volume indexing is provided). Regarding (2), all sections start with, in effect, a general survey and move on to papers of specialist interest. On (3), the references are almost exclusively from U.S.A. and only in Section VI are a substantial number of U.K. workers mentioned—notably those presenting or analysing Meteorological Office Research Flight data. Concerning (4), the subject index contains little more than the key words in the titles of papers, but together with the informative titles given in the 'Contents', easy access to any topic is provided. It is worth mentioning that the Fahrenheit scale is used in most applications except those in Sections VI and VII.

In Section VI apart from three papers—one on 'the state of the art' in measuring atmospheric humidity, a second on 'dew' and a somewhat unexpected paper on the forecasting of five-day precipitation patterns by correlation methods —the topic considered is the estimation of moisture in the upper atmosphere or the whole atmosphere either by ground-based or balloon-carried equipment

*SPARKS, W. R.; *review of* Humidity and moisture ; Volume one, Principles and methods of measuring humidity in gases. *Met. Mag., London*, **94**, 1965, p. 377.

(namely spectroscopy, adsorption and other direct sampling devices, and frost-point indicators), and includes comparisons between different methods. Papers 60, 61, 62, 63, contain critical discussions of the distribution of moisture and suggestions for 'model' atmospheres. The same topic is examined by radio-refractometry in Section VII (which is perhaps the most severely technical of all the sections).

Boundary layer phenomena are dealt with in Papers 5, 42, 44 (in Number 5 by radio-refractometry). The determination of soil moisture by neutron scattering, and of moisture in hygroscopic substances by nuclear resonance, are described respectively in Papers 14 and 19.

Amongst papers on evaporation (Numbers 6, 7, 9, 12, 14), Number 7 deals with the method of measuring transpiration by following the movement, up the stem of the plant, of sap heated electrically to a moderate temperature by a coil wrapped around the stem.

Applied climatologists will find much of value in Sections I and II although whenever external conditions are relevant, these are almost invariably of hot-dry or hot-wet climates.

The volume is well produced, with clear diagrams and remarkably few 'printer's errors' (Figure 9 on p. 500 is printed upside down). There is some repetition, e.g. the psychrometric chart is described in a number of papers—but to the 'specialist' inquirer this is a convenience. All four volumes are obviously desirable for both reference and browsing.

R. W. GLOYNE.

Elements of cloud physics by H. R. Byers. $9\frac{1}{4}$ in × $6\frac{1}{4}$ in, pp. ix + 191, *illus.*, The University of Chicago Press, 6a Bedford Square, London WC1, 1965. Price : 56*s*.

One's first impression is that this is a well-produced book, pleasant to handle, well laid out, well illustrated and clearly printed on good quality paper. In his preface Professor Byers says that he designed the book for meteorologists taking up cloud physics — rather than for the physicists and chemists who also take up the subject. His first chapter covers the thermodynamics of moist air and is clearly of more use to the non-meteorologist who must be introduced to such concepts as virtual temperature, wet-bulb temperature and adiabatic processes with vapour condensation. Nevertheless it is convenient for meteorologist and non-meteorologist alike to have meteorological book-work within the covers of a cloud physics text and it is disappointing therefore that this chapter contains several misprints which make it difficult to recommend as a handy reference. Two examples will suffice. On page 5, mC_v should be $m^{-1}C_v$. On page 15 there is confusion over the sign of lapse rates in equation 1·54 and g has been omitted.

Professor Byers's stated aim is to stress basic principles. He does this in a logical fashion for the microphysics in Chapters 2 to 6. Chapters 2 and 3 cover the physical chemistry of phase changes, the equilibrium between phases and over solutions, the processes of nucleation of the vapour to initiate the liquid phase and nucleation to initiate the ice phase. Chapter 4 is a comprehensive account of both condensation and ice nuclei found in the atmosphere and is perhaps the best chapter in the book. Chapter 5 deals with the growth of cloud particles from the vapour and Chapter 6 the subsequent growth by collision. The treatment in these chapters is straightforward and specialists will find it convenient that some of the tables and results presented in them have been brought together.

While stressing basic principles Professor Byers has also given a comprehensive review of the nucleation and growth of cloud particles. In contrast, his treatment of the growth of precipitation is brief, surprisingly brief when for so many people the water which clouds release—or may perhaps be induced to release—is the subject's main interest.

Chapter 7 on cloud dynamics is also brief and much that might be regarded as part of the core of the subject has been left for consideration in special treatises on this topic.

The main virtue of this book is that its eminent author has given most weight to the best-founded parts of the subject. As indicated in the preface, however, several aspects have been excluded or given scant treatment so that meteorologists and students of cloud physics must be recommended not to rely on this book alone.

S. G. CORNFORD

OBITUARIES

Mr E. E. Jessop.—It is with deep regret that we have to report the death of Mr E. E. Jessop, Chief Experimental Officer, at his home in Edinburgh on 8 April, 1966. Although he had been ill for some time, he fought with characteristic courage and determination, and, although recovery appeared to be slow, the news of his death when it came was a profound shock to his many friends.

Mr Jessop joined the Meteorological Office in 1937, but some years before becoming a professional meteorologist his interest in the subject had found expression in post-graduate research at the University. He went first to Calshot in the days when forecasting for flying boats was an important task. Subsequently, like many others in those days of pre-war expansion and actual war, he served in a number of places, including Marham, Norwich, Aldergrove and Iceland. He was commissioned in the RAFVR in 1943. During the latter part of the war and for some years subsequently he was on the forecast roster at Prestwick. This was work which he thoroughly enjoyed and here he developed the full powers as an analyst and forecaster in which he was quite outstanding. This was followed by a tour in Germany as Senior Meteorological Officer, No. 83 Group from which post he returned to the United Kingdom to become Senior Meteorological Officer, No. 18 Group, Pitreavie.

It is impossible in cold print to do full justice to Edgar Jessop. He was unusually clear-thinking and able, co-operative and loyal to his colleagues and of absolute integrity and honesty. A hard worker always setting himself the highest standards, there was nothing he asked of others which he was not prepared and able to do himself.

He will be greatly missed as a friend and as a colleague who can ill be spared. We offer our sincerest sympathy to his widow and family.

H. M.

Mr G. A. W. Clark.—We deeply regret to report the unexpected death of Mr George Clark in Athens on 18 April 1966 at the comparatively early age of 47. Mr Clark was one of the band of forecasters who came to the

Meteorological Office as Assistant Grade III just before World War II. His early promise well merited his promotion to forecasting duties in 1942 followed by commissioning in the RAFVR in 1943. After his demobilization in 1947, George Clark's service was concerned largely with forecasting for the Royal Air Force at many stations at Home and abroad including Libya and Pakistan. He was promoted to Senior Experimental Officer in 1957 and later spent some years working with the Army at the Artillery Ranges, Shoeburyness, before leaving for the tour in Muharraq from which he was returning at the time of his death. Apart from his other interests which included the Church, much of Mr Clark's leisure in latter years was spent with his young family. The deep sympathy of his friends and colleagues is extended to his widow and two children in their tragic loss.

D.W.R.

Mr W. J. Fowler.—It is with deep regret that we have to record the death of Mr W. J. Fowler on 28 April 1966. Mr. Fowler, a disestablished XO at Hurn, joined the Office as a Boy Clerk over 50 years ago. An appreciation of Mr Fowler's work was published on page 30 of the January 1961 issue of the *Meteorological Magazine.*

HONOURS

The following awards have recently been announced:

I.S.O

Mr A. F. Crossley, Principal Scientific Officer, Meteorological Office, Bracknell.

B.E.M.

Miss D. J. Wordsworth, Scientific Assistant, Meteorological Office, Bracknell.

I.S.M.

Mr. N. W. Howlett, M.B.E., Radio Supervisor (retired)

Mr. E. W. E. Reid, Radio Operator (retired)

AWARD

We note with pleasure that the International Meteorological Organization Prize for outstanding work in meteorology and international collaboration has been awarded for 1966 to Professor Tor Bergeron of Sweden by the Executive Committee of the World Meteorological Organization during its 18th session.

CORRIGENDA

Meteorological Magazine, May 1966, page 157, line 15 : for '0600 GMT, 25 May 1964' read '0600 GMT, 26 May 1964' ; page 158, Figure 9 : for '26 May 1965' read '26 May 1964'.

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NOTICES

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