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THE SUMMER WEATHER OF 1968: RELATED ATMOSPHERIC CIRCULATION AND SEA TEMPERATURE PATTERNS

By R. MURRAY and R. A. S. RATCLIFFE

Summary. In the British Isles the summer of 1968 showed some unusual weather features. These features are described and related to the large-scale circulation patterns both in the preceding spring and in summer. Atlantic sea surface temperature anomalies were also very unusual; the formation of the very large area of negative temperature anomaly which dominated the Atlantic pattern from June to November is described and a possible relation to the high-summer pressure pattern near the British Isles is discussed. A search through past records for a similar summer achieved only limited success. Other factors which might have had some relevance to the unusual summer, such as the biennial oscillation and the position in the solar cycle, are also considered. It is concluded that all the relevant factors taken together might have led to a fairly satisfactory forecast of the pressure anomaly pattern, but the weather associated with this pattern was most unlikely to have been predicted.

Weather and synoptic types over the British Isles. The main synoptic feature of the summer of 1968, particularly in July and August, was the degree of blocking near the British Isles and the unusually frequent occurrence of easterly and northerly winds over the United Kingdom. Progressive synoptic types predominated in June, apart from anticyclonic blocking from the 9th to the 16th. In the normal year there is generally a notable increase of progressive synoptic types in July and August but on this occasion an outstanding reversal of the normal trend took place. Indeed blocking, as measured by negative values of the *P*-index of Murray and Lewis,[1] reached the extreme (since 1873) figure of –63 units for the period July to August. Moreover, the northerly bias in high summer was also very pronounced (*S*-index = –27 units). For the most part anticyclonic centres north of about 55°N were the main feature but occasionally cyclonic centres south of 55°N were more significant. One such centre which moved north-east across England and Wales on 9–10 July brought at least 75 mm of rain in 24 hours to a broad area from Dorset to Lincolnshire.

The weather in the summer of 1968, particularly in high summer, was highly anomalous over the British Isles with an inverted pattern of weather.

The normally dull and wet north-western seaboard had long fine spells, whereas eastern parts of England were unusually cool, dull and wet. Although it was very cool in July in south-eastern districts, a brief hot spell culminated with a temperature of 33°C in London on the 1st. On the same day fine dust from Spain and northern Africa was deposited in heavy thundery rain in many places and record hailstones (7 cm in diameter) fell at Glamorgan/Rhoose Airport near Cardiff. For the rest of the summer the weather in the eastern half of England was dismal for the most part, despite a mainly dry spell from about 18 July to 6 August when dull, cool weather was associated with persistent north-easterly winds.

The geographical variations of mean daily maximum temperature and mean sunshine are shown in Figure 1. The marked difference between

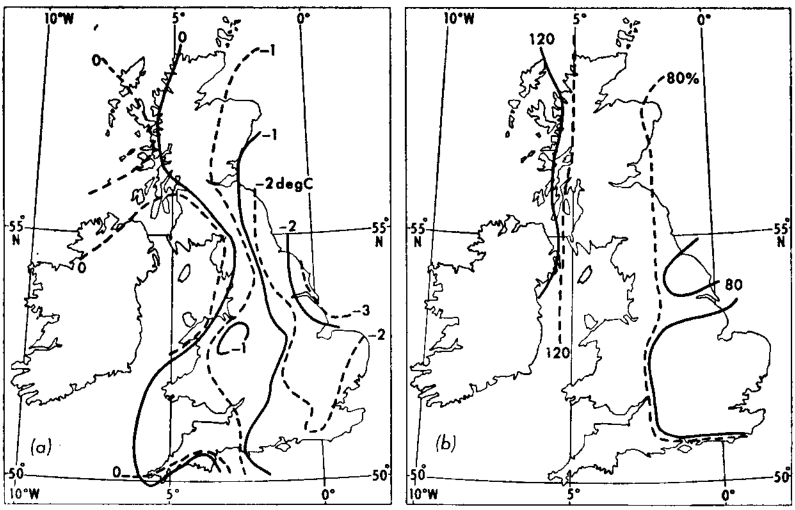

FIGURE 1—*(a)* ANOMALIES (degC) IN 1968 OF DAY MAXIMUM TEMPERATURE FROM THE 1931–60 NORMAL *(b)* SUNSHINE IN 1968 AS PERCENTAGES OF THE 1931–60 NORMAL

——— Summer (June, July and August) - - - High summer (July and August)

eastern England and the area west Scotland–Northern Ireland is striking. The sunshine contrast in high summer is particularly noteworthy—mean sunshine ranged from less than 70 per cent of normal in many places from the Thames to Yorkshire (mostly less than four hours per day) to over 130 per cent in the Hebrides (about seven hours per day). Rainfall had a similarly abnormal spatial distribution, as may be seen from Figure 2, which presents information on rainfall amounts and rain-days. Both these rainfall measurements have excesses in the eastern parts of England and deficiences in Northern Ireland and western Scotland. A useful summary of the overall character of the summer is given in Figure 3 which shows the departure from average of the Summer Index of Davis.[2] This Summer Index combines sunshine, rainfall and daily maximum temperature. Broadly speaking, negative anomalies signify 'poor' weather and positive anomalies 'good' weather. The negative anomaly centre near the Wash and the major positive centre in

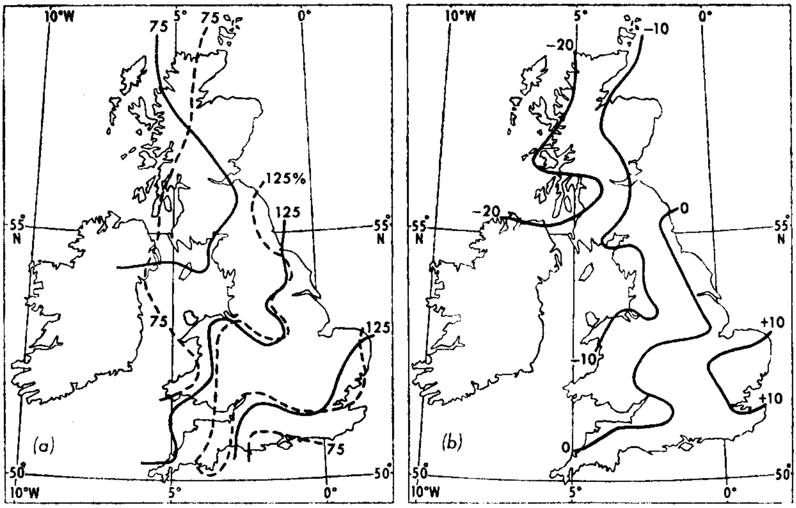

FIGURE 2—(*a*) RAINFALL IN 1968 AS PERCENTAGES OF THE 1931–60 NORMAL
(*b*) ANOMALIES IN 1968 OF RAIN DAYS FROM THE 1931–60 NORMAL
——— Summer (June, July and August) - - - High summer (July and August)

west Scotland are each equal to about 2·2 times the standard deviation of the Summer Index in each locality. Considered separately each anomaly centre might be expected to occur in the same position with the observed intensity once or twice per 100 years. The correlation between the indices in the south-east and north-west of Britain is small, so that the combination shown in Figure 3 must be extremely rare.

Broad-scale circulation. The seasonal circulation patterns in spring and summer at the surface and 500 mb are shown in Figures 4 to 9. The following discussion is largely centred on the anomalies which are shown as continuous lines.

The main features of the spring surface patterns in Figure 4 are the anomalously deep low-pressure systems near the Arctic coast of Russia and the area of above average pressure in the North Atlantic. Between these two anomaly centres the anomaly pattern corresponds to an anomalous component of flow from north-west to north over the British Isles. The associated 500-mb patterns are shown in Figure 5, in which the shift of the polar vortex towards the Russian Arctic is clearly in evidence.

The summer surface patterns (Figure 6) appear to show continuity with the spring patterns (Figure 4). There is evidently persistence in the negative anomaly centre in the Russian Arctic, and in the areas of below average pressure near the Pacific (about 160°W) and America (about 100°W). The main changes from spring to summer are the shift of the positive centre from the Atlantic to north-east of Scotland and the formation of a negative anomaly in the Atlantic. The July to August patterns are depicted in Figure 8, which shows most of the features of the whole summer, but the positive anomaly centre near the Shetlands exceeds 8 mb and the anomalous east to north-east component in the flow is pronounced over Britain. The corresponding 500-mb

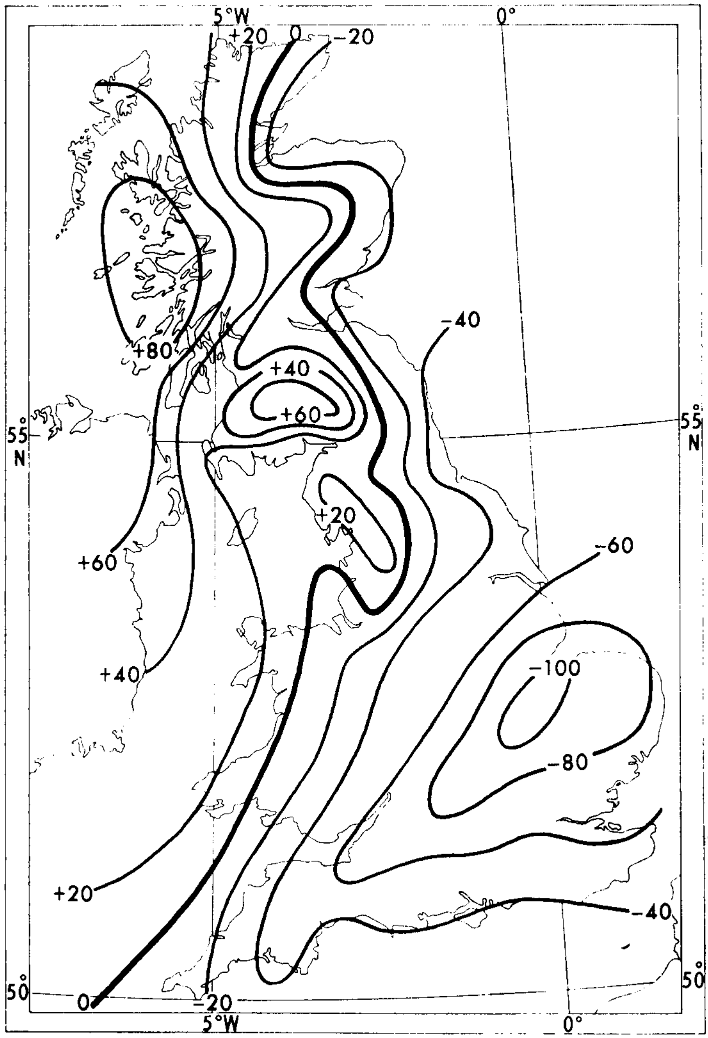

FIGURE 3—DEPARTURE IN 1968 FROM THE AVERAGE OPTIMUM SUMMER INDEX OF DAVIS[2]

maps are shown in Figures 7 and 9. The marked blocking in the north-east Atlantic is most clearly shown in high summer by the large positive anomaly centre between Iceland and Scotland in Figure 9.

Sea temperature anomalies. Over the Atlantic Ocean, one of the most noticeable features of the 1968 summer was the development of very large negative anomalies of sea surface temperature over a huge area covering thousands of square miles and centred to the south-east of Newfoundland near ocean weather station (OWS) 'D' (44°N 41°W).

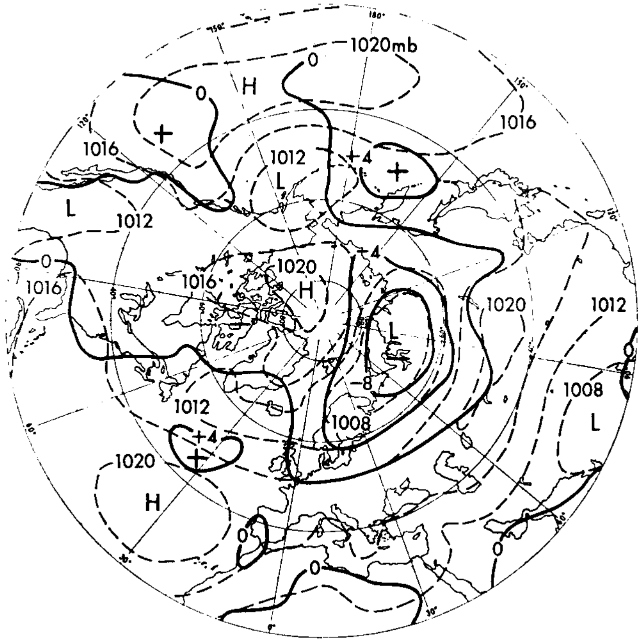

FIGURE 4—MEAN SURFACE PRESSURE AND PRESSURE ANOMALIES IN SPRING 1968
– – – Surface pressure ——— Pressure anomalies
Isopleths at 4-mb intervals

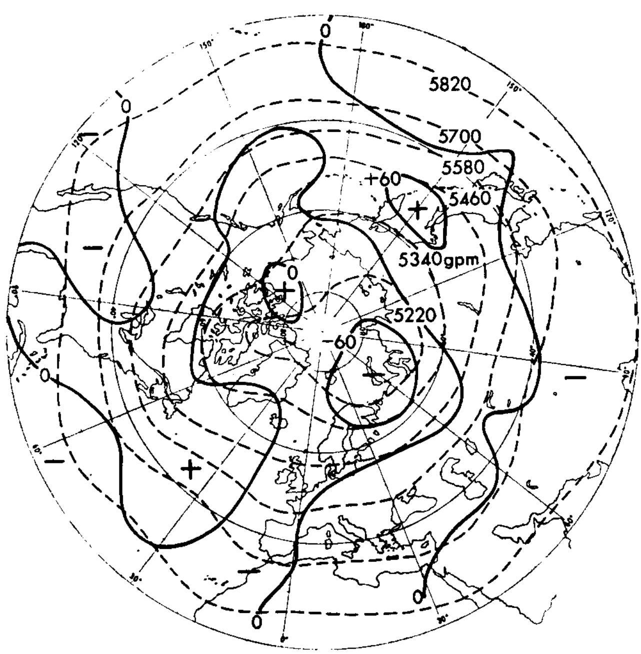

FIGURE 5—MEAN 500-MILLIBAR CONTOURS AND ANOMALIES FOR SPRING 1968
– – – Mean 500-mb geopotential heights at intervals of 120 gpm
——— 500-mb anomalies at intervals of 60 gpm

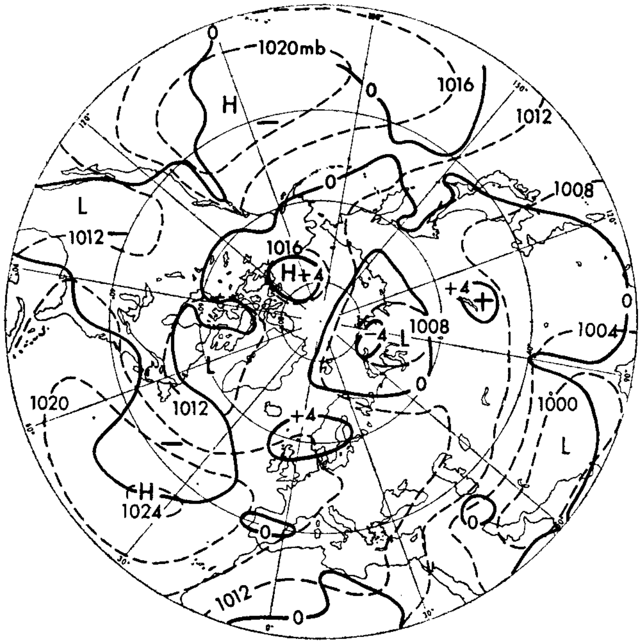

FIGURE 6—MEAN SURFACE PRESSURE AND PRESSURE ANOMALIES IN SUMMER 1968
– – – Surface pressure ——— Pressure anomalies
Isopleths at 4-mb intervals

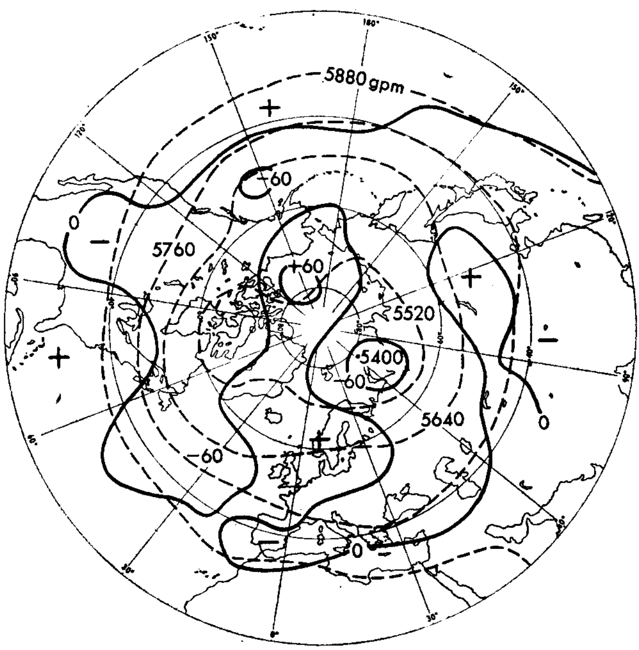

FIGURE 7—MEAN 500-MILLIBAR CONTOURS AND ANOMALIES FOR SUMMER 1968
– – – Mean 500-mb geopotential heights at intervals of 120 gpm
——— 500-mb anomalies at intervals of 60 gpm

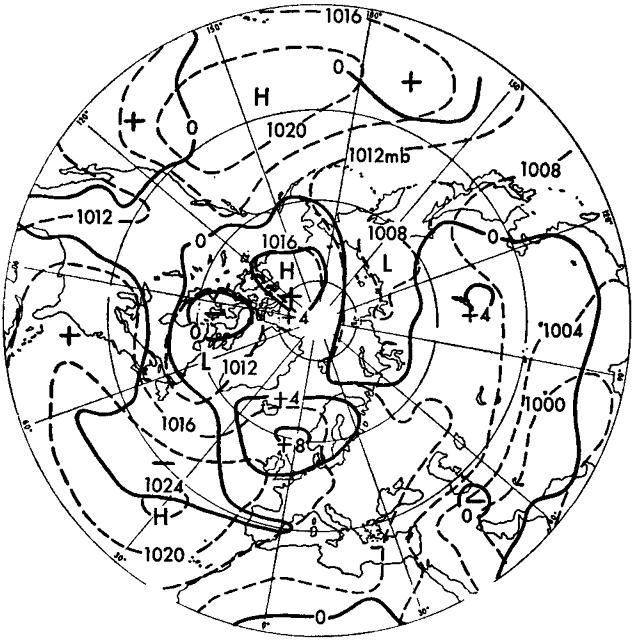

FIGURE 8—MEAN SURFACE PRESSURE AND PRESSURE ANOMALIES IN JULY AND AUGUST 1968

– – – Surface pressure ——— Pressure anomalies

Isopleths at 4-mb intervals

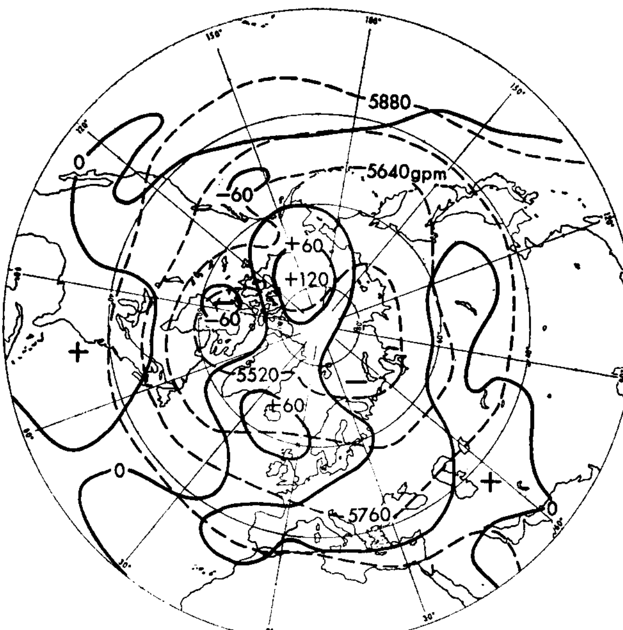

FIGURE 9—MEAN 500-MILLIBAR CONTOURS AND ANOMALIES IN JULY AND AUGUST 1968

– – – Mean 500-mb geopotential heights at intervals of 120 gpm

——— 500-mb anomalies at intervals of 60 gpm

Figure 10 shows the variation of sea surface temperature anomaly along a line from 43°N 55°W to 53°N 20°W over the period from October 1967 to August 1968. It shows that the pattern of anomalies underwent a complete reversal over the period and, further, that the negative anomaly near OWS 'D' began to develop in late May reaching its peak (equal to about two-thirds of the annual variation) in August. There was some sign of a negative anomaly developing from February onwards but the main large anomaly did not appear until June.

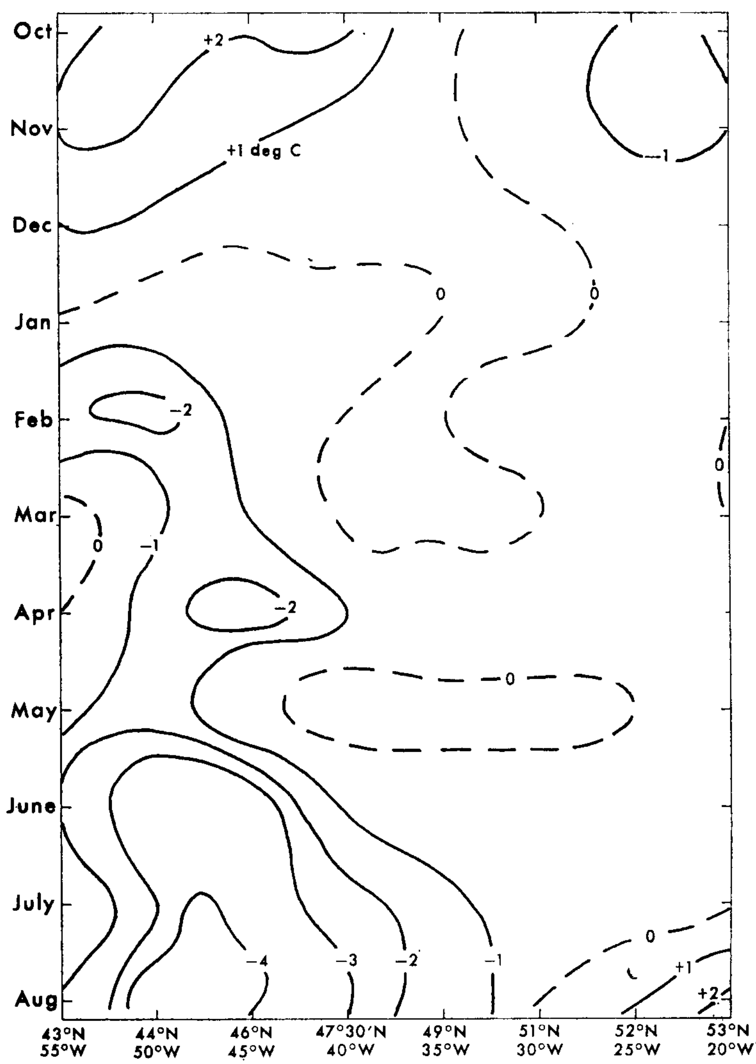

FIGURE 10—SEA SURFACE TEMPERATURE ANOMALIES (degC) FROM OCTOBER 1967 TO AUGUST 1968 BETWEEN 43°N 55°W AND 53°N 20°W

Data extracted from maps of the U.S. Fleet Numerical Weather Facility, Monterey, California.

Hay (personal communication) considers that the formation of this large area of negative anomaly was mainly due to upwelling following persistent cyclonicity in the area. The surface winds of such a quasi-stationary cyclone must react on the ocean through frictional Ekman stresses to produce divergence of the surface waters, as described by Bjerknes.[3] The resulting upwelling of water near the cyclone centre would clearly bring cooler water from below and result in negative sea temperature anomalies at the surface. Support for this theory largely accounting for the formation of the negative sea surface temperature anomaly on this occasion is shown in Figure 11. The lower part of this figure shows that, over a big area near OWS 'D', the 1000-mb (approximately surface pressure) anomaly was very consistently negative from the second pentad in May until the end of July. The predominance of negative 1000-mb anomaly in Figure 11 is a rough measure of enhanced cyclonic activity. Independent confirmation of enhanced cyclonic activity near OWS 'D' in May 1968 was obtained by counting the number of days with centres of depressions in the area 40°–55°N, 35°–55°W; in this area depressions were

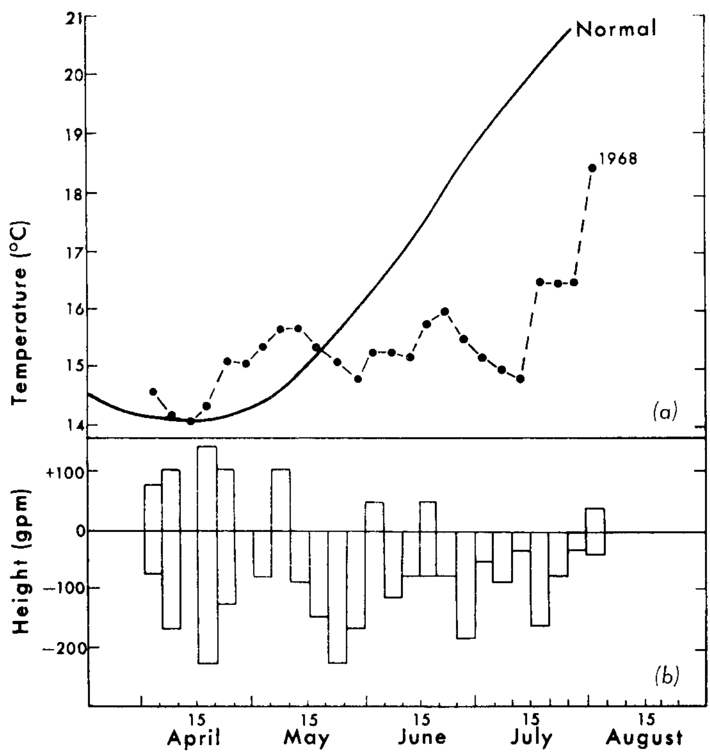

FIGURE 11—*(a)* PENTAD-MEAN SEA SURFACE TEMPERATURES IN 1968 AND THE 1944–61 AVERAGE AT OCEAN WEATHER STATION 'D' *(b)* HISTOGRAM OF INTENSITIES OF POSITIVE AND NEGATIVE PENTAD-ANOMALY CENTRES AT 1000 MILLIBARS WITHIN THE AREA 35°–55°N, 60°–20°W

– – – Sea surface temperatures ——— 1944–61 averages
Based on a figure supplied by R. F. M. Hay in a personal communication.

almost 40 per cent more frequent and anticyclones nearly 50 per cent less numerous than the normal values for May as given by Klein.[4] The upper part of Figure 11 shows how the sea surface temperature at OWS 'D', which was above normal until about mid-May, reacted to this unusual cyclonic activity and fell well behind the normal seasonal warming for the rest of the summer. However, it is unlikely that upwelling accounted for the whole of the observed anomaly; Figure 12 shows that at OWS 'D' mean cloud amount was consistently and increasingly above normal from May to August 1968, and this situation would clearly help to create a negative anomaly of sea surface temperature by reducing incoming solar radiation. How the isotherms of sea temperature and their anomalies were distributed in depth is illustrated

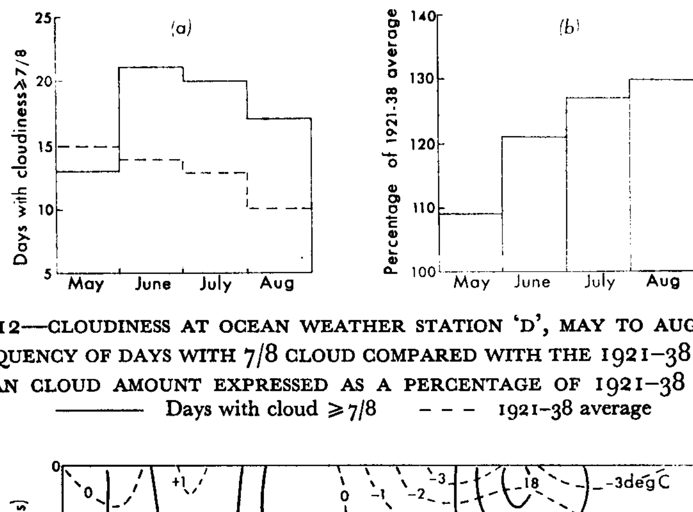

FIGURE 12—CLOUDINESS AT OCEAN WEATHER STATION 'D', MAY TO AUGUST 1968
(a) FREQUENCY OF DAYS WITH 7/8 CLOUD COMPARED WITH THE 1921–38 AVERAGE
(b) MEAN CLOUD AMOUNT EXPRESSED AS A PERCENTAGE OF 1921–38 AVERAGE
——— Days with cloud ≥ 7/8 - - - 1921–38 average

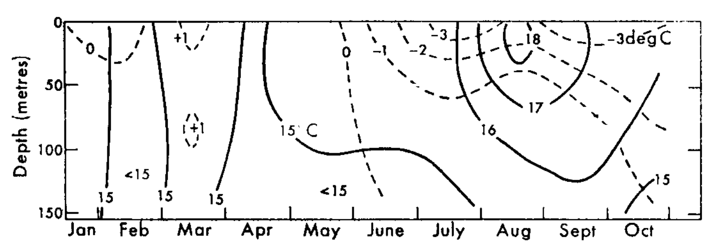

FIGURE 13—VARIATIONS OF SEA TEMPERATURE AT THE SURFACE AND IN THE TOP 150 METRES AT OCEAN WEATHER STATION 'D' FROM JANUARY TO OCTOBER 1968
——— Isotherms - - - Anomalies

in Figure 13 for OWS 'D'. It is interesting to note that negative anomalies of more than 1 degC were confined to about the topmost 50 m until the end of the summer, but in autumn the anomaly increased notably at depths between 50 and 150 m. Figures 14 and 15 show the large-scale pattern of sea surface temperature anomalies over the Atlantic and Pacific Oceans in May and August 1968. The main features to note are the development of the big negative anomaly in the Atlantic, already referred to, and a negative area almost as large in the Pacific near 40°N 160°W: significant areas of positive sea temperature anomaly also existed in August in both oceans, notably south of Iceland and near 30°N 130°W in the Pacific.

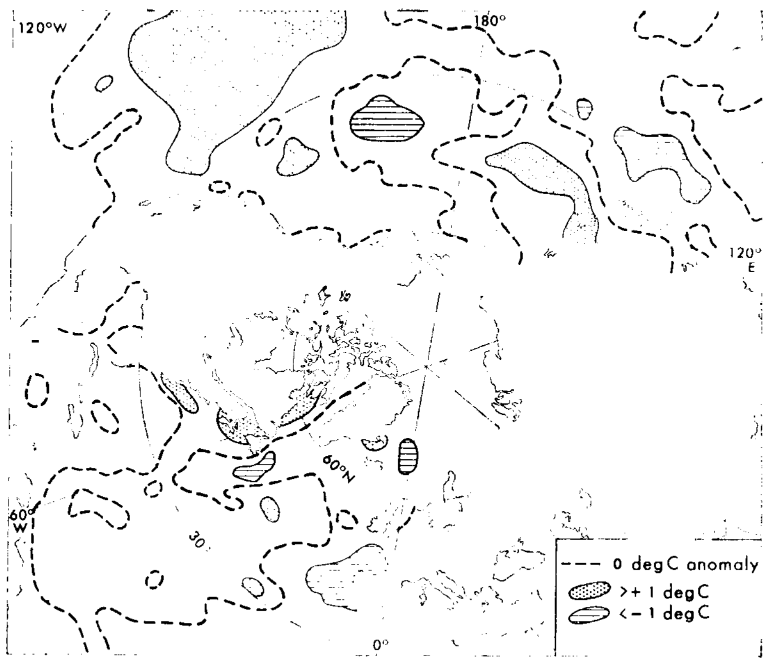

FIGURE 14*—MEAN MONTHLY SEA SURFACE TEMPERATURE ANOMALY IN MAY 1968
After U.S. Fleet Numerical Weather Facility, Monterey, California.

After the unusual sea surface temperature anomaly pattern over the Atlantic in the summer of 1968 had been noticed, other years in the past with similar sea temperature distributions were studied. Data exist in the long-range forecasting section of the Meteorological Office for most of the last 80 years, but it was immediately apparent that 1968 was the most extreme example of colder than normal water over such a wide area in the Atlantic in summer. Well-marked sea temperature patterns are quite persistent, the average length of time for which a well-defined pattern persists being at least three to four months. In fact the pattern established in June 1968 persisted until December. Because of this persistence and also because the input of heat and moisture to the lower layers of the atmosphere is largely controlled by the state of the underlying surface, several writers, e.g. Sawyer[5] and Namias,[6] have suggested that the patterns of sea surface temperature anomaly are probably important from the point of view of forecasting on the monthly time scale. It was therefore decided to see if Junes in the past which had an Atlantic sea surface temperature anomaly pattern similar to June in 1968 were followed by Julys which had any recognizable similarities. There were 11 Junes of this type (excluding 1968) with a mean anomaly over the sample of about −1·5 degC near OWS 'D'. The mean sea-level pressure map for the 11 Julys following showed positive

* Note : Small positive area near east Greenland to be ignored.

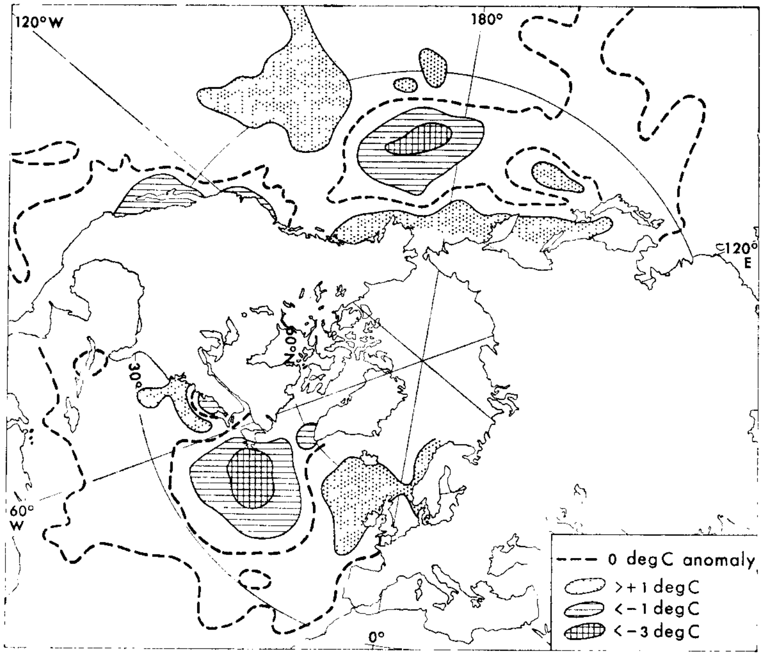

FIGURE 15—MEAN MONTHLY SEA SURFACE TEMPERATURE ANOMALY IN AUGUST 1968

After U.S. Fleet Numerical Weather Facility, Monterey, California.

anomalies of about 1½ mb in the area from Greenland to north of Scotland and negative anomalies of the same order near the Azores. Eleven Junes with the opposite sea temperature anomaly pattern proved to have approximately the reverse mean pressure anomaly in July. Figure 16 shows the difference between the mean July pressure maps averaged for each of the 2 samples of 11 years. It shows that the occasions with colder than normal ocean to the south-east of Newfoundland in June, tend to be associated in July with higher than normal pressure to the north of Scotland and with lower than normal pressure near the Azores. Statistical tests show that this pattern is almost certainly significant, the areas of more than $\pm$ 2 mb representing areas where the anomaly of pressure is between two and three times the standard deviation of random samples about the mean. The similarity of pattern between Figures 16 and 8 is striking; if it is borne in mind that the 1968 sea temperature anomaly pattern was more extreme over a wider area than in any other year, it strongly suggests that the sea temperatures played a part in determining the weather of July and August in Britain in 1968.

Some analogues. An attempt was made to find analogues on the basis of the broad-scale surface pressure patterns in spring and summer (most weight being given to the sector from America to Europe), and the monthly sea temperature anomaly patterns in the Atlantic from April to June. No good analogue was apparent, especially when the inverted weather distribution in the summer over Britain was also taken into account. The year 1899 was probably the best broad-scale circulation analogue for both spring and summer,

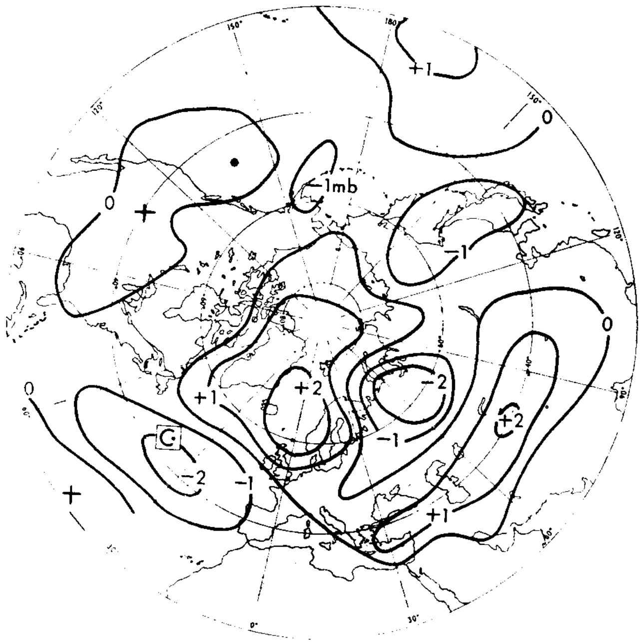

FIGURE 16—DIFFERENCE BETWEEN *(a)* JULY MEAN PRESSURE ANOMALIES (MILLIBARS) AFTER JUNES WITH COLD SEA SURFACE SOUTH-EAST OF NEWFOUNDLAND AND *(b)* JULY ANOMALIES AFTER JUNES WITH WARM SEA SURFACE

Note (i) Each July mean pressure anomaly is a mean of 11 years.
(ii) The mean anomaly centre for the cold sea surface is about − 1·5 degC at position 'C'.

and the sea temperature patterns in the Atlantic were also like those in 1968, although not so strong. Figure 17 shows the spring (dashed lines) and summer (full lines) anomaly patterns superimposed. The spring patterns of 1899 and 1968 (Figure 4) each show blocking over the Atlantic, negative pressure anomalies over north Russia consistent with displacements of the tropospheric polar vortex to the Russian side of the Arctic, enhanced zonal flow between 40°N and 60°N over Asia, some similarity of pattern in the Pacific and finally an anomalous component from north-west to north in the flow over the British Isles. The summer patterns in Figures 17 and 6 are clearly similar in the east Atlantic and west Europe. Nevertheless the summer in 1899 was dry and warm over Britain.

The spring of 1968 resembled 1885 over the Atlantic and western Europe but had little resemblance elsewhere (sea temperature comparisons were not possible). The summer pattern in 1885 showed positive anomalies of + 4 mb over Scotland and south Norway with anomalous easterly flow over England and France, quite like 1968. However, in 1885 the summer was dry over England and Wales unlike 1968, although the temperature in central England was below normal as in 1968.

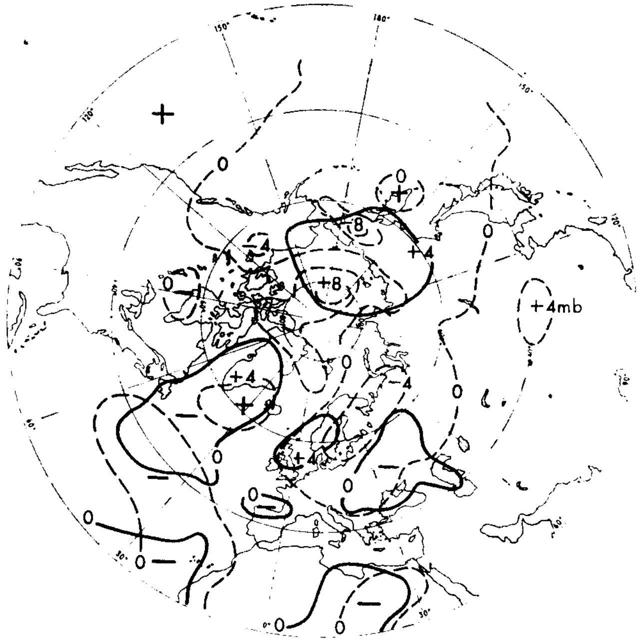

FIGURE 17—SEASONAL MEAN SURFACE PRESSURE ANOMALIES (MILLIBARS) IN 1899

- - - Spring ——— Summer
Isopleths at 4-mb intervals

The circulation in the spring of 1902 was very like that in 1968 only over the Atlantic where sea temperature patterns were also fairly similar. The anomaly pattern in the summer of 1902 certainly indicated blocking in the north-east Atlantic with east to north-east winds over the British Isles, but the main positive anomaly centre was in the Arctic instead of near north Scotland although pressure was somewhat above normal over Scotland. In the summer of 1902 the rainfall was below normal over Scotland and near normal over England and Wales, and it was very cool over central England. There was a general contrast in weather, including sunshine, between the south-east and north-west of Britain although the inverted pattern was not so extreme as in 1968.

The pressure pattern over the British Isles in the summer of 1955, especially in high summer, resembled that of 1968. The pressure anomaly in high summer of + 8 mb off north-east Scotland and the anomalous east to north-east wind over most of Britain and France (see Figure 18) were very like the anomalies in 1968 (see Figure 8), but the weather on these two occasions was quite different. It must be said that the atmospheric circulation in spring and the sea temperature pattern in 1955 were not analogues of 1968. Moreover, the high-summer circulation in 1955 away from the British Isles and adjacent areas, particularly over the Greenland–Iceland area, was quite unlike that of 1968 (compare Figures 18 and 8). Despite the close similarity of surface

FIGURE 18—SEASONAL MEAN SURFACE PRESSURE ANOMALIES (MILLIBARS) IN 1955

- - - Spring ——— Summer
Isopleths at 4-mb intervals

pressure patterns over the British Isles, examination of the upper air temperature fields clearly indicates that considerably more subsidence took place over the British Isles in 1955 than in 1968. In the earlier year a south-westerly mean jet stream just south of Iceland in high summer was both anomalously strong and in unusually high latitudes over the North Atlantic and Norwegian Sea; pronounced subsidence on the right side of the jet stream, that is, over the British Isles, was dynamically reasonable and consistent with the fine weather over the whole country.

It is of interest that in five other years in the period back to 1874 the summer rainfall was simultaneously above average (tercile 3) over England and Wales and below average over Scotland (tercile 1), as in 1968. In two of these years, namely 1878 and 1909, the actual England mean temperature was much below average (quintile 1) and in the other years, 1880, 1936 and 1939, it was about average (quintile 3); these may be compared with a mean summer temperature of quintile 2 in 1968. In terms of weather there was some rough similarity. However, only 1878 showed any real resemblance to 1968 in broad-scale circulation in spring and summer. The sea temperature patterns in 1909 were roughly analogous to those in 1968, but in the other four years they were poorly defined or not known.

These examples show that it was not possible to find analogues acceptable at the same time in terms of broad-scale circulation in spring and summer, sea temperature pattern and weather over the British Isles in the period with reasonably complete synoptic records.

Other factors of possible relevance.

(i) *Excessive sea ice near Iceland.* Pack ice was exceptionally abundant in the spring off east Greenland and around Iceland, as has been pointed out by Marshall.[7] A rather cursory examination of the summer weather over Britain, and pressure anomalies at selected points in Greenland and western Europe following 10 other springs with heavy ice, did not suggest that the existence of abundant ice near Iceland and east Greenland was materially important in determining the summer weather or pressure pattern over the British Isles.

(ii) *Biennial oscillation.* The existence of a quasi-biennial oscillation has been noted by many authors and Davis[8] has stressed its importance in relation to summer weather, particularly mean daily maximum temperatures in summer. Briefly, since 1880 summers in odd years tend to be warmer and drier than in even years. Over England and Wales the summer of 1967 was rather warm and dry; the deterioration in 1968 was undoubtedly in agreement with the tendency expected with the biennial oscillation.

(iii) *Date of change-over to summer circulation at 50 mb.* Ebdon[9] has suggested that 'good' summers in south-east England do not occur when the change from winter to summer type circulation at 50 mb over the British Isles is late. Figure 19 shows that the change-over from west to east winds at Shanwell was certainly not early. However, Ebdon's criterion does not enable a positive prediction of 'poor' weather to be made, since an average type of summer would still satisfy the condition that the summer was not 'good'.

(iv) *Blocked/northerly springs over the British Isles.* Blocked/northerly springs, like that of 1968, may be classified synoptically by the *P*- and *S*-indices of Murray and Lewis[1] as those in which each index is either quintile 1 or quintile 2 (i.e. P_1 or P_2 *and* S_1 or S_2). There appears to be a tendency for rather cool and wet summers over England and Wales to follow blocked/northerly springs. Table I shows the frequency distribution for England and Wales rainfall and central England temperature.

TABLE I—SUMMER RAINFALL OVER ENGLAND AND WALES AND SUMMER TEMPERATURE OVER CENTRAL ENGLAND FOLLOWING BLOCKED/NORTHERLY (P_{12} S_{12}) SPRINGS

	Rainfall (terciles)			Temperature (quintiles)				
	R_1	R_2	R_3	T_1	T_2	T_3	T_4	T_5
Frequency	3	3	8	3	7	1	2	1

In all but one case the summers were more northerly (i.e. S_{12}) or more cyclonic (i.e. C_{45}) than usual.

(v) *Solar cycle.* In order to see if there was any systematic difference between mean July pressure just before the sunspot maximum (as in 1968) and mean July pressure just before the sunspot minimum, all such years for which pressure data were available were analysed by computer, the earliest year being 1878. There were nine Julys in the first class and eight in the second. Mean pressure maps were formed for each class for each grid point in the Atlantic area and the two means were subtracted. The result is shown in Figure 20. The significance of this figure is difficult to estimate owing to correlation between pressure at adjacent grid points, but the high value in high latitudes and the low value in low latitudes are both equal to

Photograph by courtesy of Dr H. A. Lang

PLATE I—NOCTILUCENT CLOUD OBSERVED FROM NEWTON STEWART, WIGTOWNSHIRE, ON THE NIGHT OF 28–29 JUNE 1968 AT 0151 UT

See page 221

Photograph by courtesy of Dr H. A. Lang

PLATE II—NOCTILUCENT CLOUD OBSERVED FROM NEWTON STEWART, WIGTOWNSHIRE, ON THE NIGHT OF 28–29 JUNE 1968 AT 0200 UT

See page 221

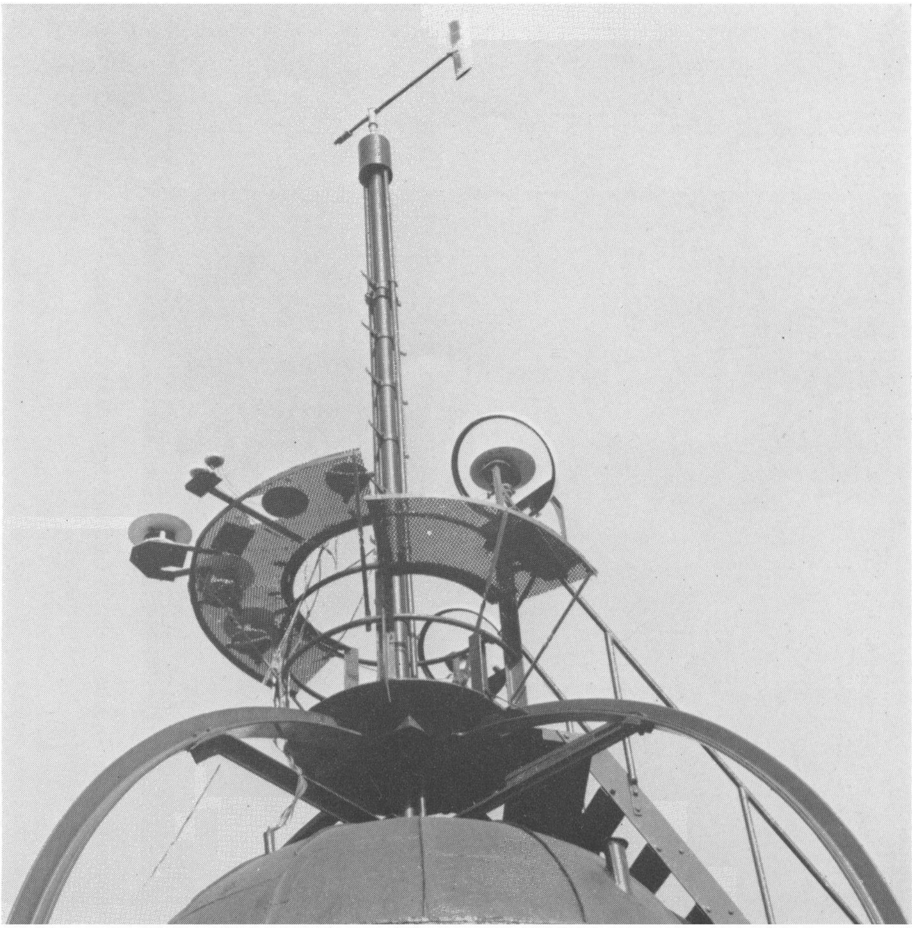

PLATE III—THE MAIN RADIATION RECORDING INSTRUMENTS

The site of the main radiation recording instruments on top of the dome, accessible by a ladder, seen in the background, from the Observatory roof. In the centre is the head of the pressure-tube anemograph. On the platform to the left of the picture are the solarimeters for measuring global solar radiation, the daylight illuminator and a number of other radiation instruments exposed for experimental purposes. On the platform to the right is the solarimeter for measuring diffuse solar radiation. Behind the pressure-tube anemograph mast is the illuminator for measuring diffuse illumination — this is only partly visible. Other radiation instruments are on the roof below. For recording equipment see Plate IV. (See page 225.)

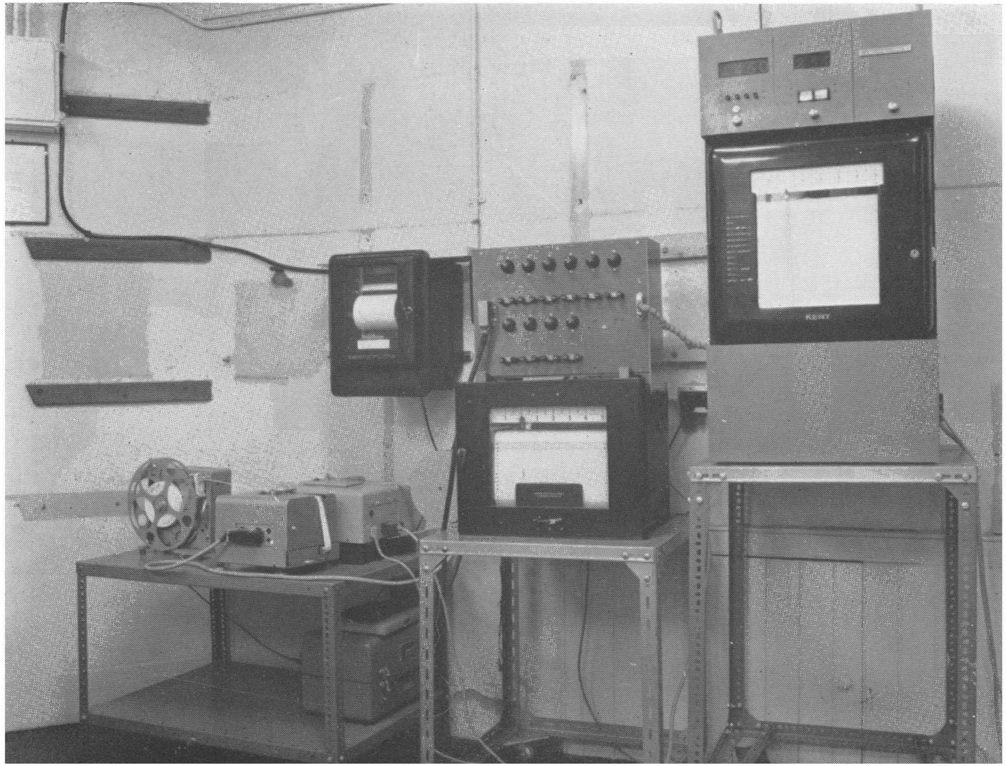

PLATE IV—THE METEOROLOGICAL OFFICE DATA LOGGING EQUIPMENT (MODLE) FOR RADIATION INSTRUMENTS.

This equipment is now in the basement at the Observatory. On the right, on the stand, is the MODLE and on the far left is the paper-tape punch. In the centre are two standby recorders (See page 226.)

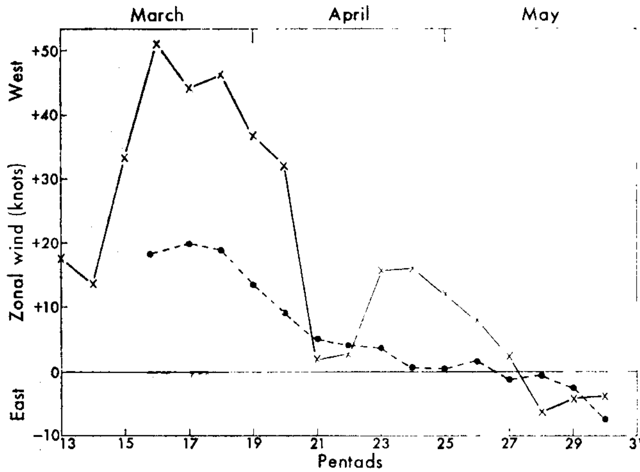

FIGURE 19—PENTAD-MEAN ZONAL WIND COMPONENTS AT 50 MILLIBARS AT SHANWELL

——— 1968 - - - 1957–68 average

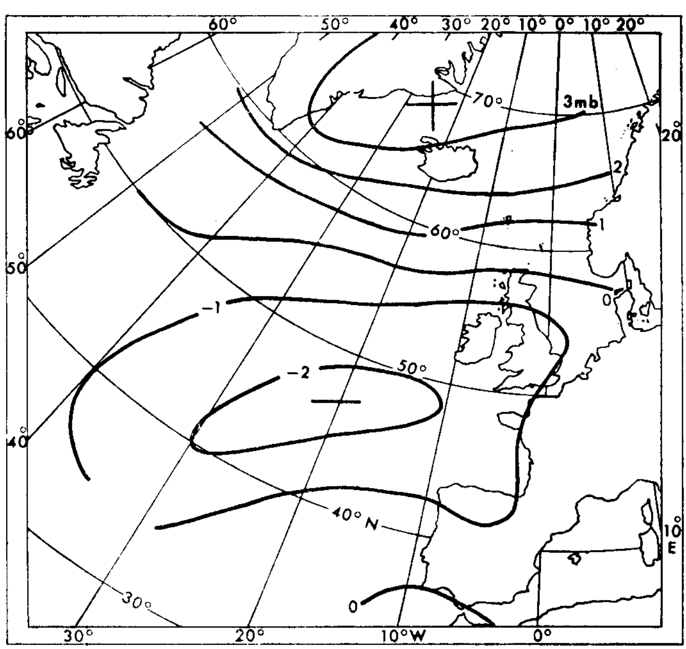

FIGURE 20—DIFFERENCE BETWEEN JULY MEAN PRESSURES (MILLIBARS) IN ACTIVE AND QUIET SUN YEARS (EIGHT SOLAR CYCLES)

about twice the standard deviation. It would thus appear that Julys near the solar maximum are likely to have pressure above normal to the north of the British Isles with lower than usual pressure near the Azores.

(vi) *April 500-mb trough position and summer weather.* In a recent paper Ratcliffe and Collison[10] have shown that there is some association between the longitude of the European trough on the April 500-mb mean chart and the rainfall in England and Wales in the following summer. If the April trough is definitely west of 10°E a wet summer is unlikely — out of 22 years with this type of trough only 5 had wet summers. Nevertheless in 1968 the April trough was in this category and the summer was wet. This highlights the unusual type of summer in 1968; it is probable that Ratcliffe's rule indicates that Aprils similar to 1968 are usually followed by upper ridges near Britain much of the summer, a situation satisfied in 1968 (see Figure 6), and normally not resulting in a wet summer. The year 1968 thus appears as an exceptional case of this rule also.

Concluding remarks. In this article certain facts have been recorded concerning the unusual weather and circulation patterns. Clearly no satisfactory explanation can be given for the abnormal developments. The empirical evidence on pressure anomalies associated with cold sea surface temperature patterns over the west Atlantic suggests that positive pressure anomalies were likely near and north of Britain. The fact that the negative anomaly near OWS 'D' was much larger in extent and intensity in 1968 than in the other years with broadly similar sea surface temperature patterns might suggest that the associated pressure anomaly in the north-east Atlantic should be appreciably larger than the 1 or 2 mb indicated by the mean map, and so could account for a considerable part of the large positive pressure anomaly which was a feature of the high summer of 1968 in the north-east Atlantic.

There is also the tendency for above average surface pressure to occur in high latitudes in Julys in active sun years; on this account positive pressure anomalies were to be expected in 1968 in the north-east Atlantic.

Another feature which could be invoked to aid the tendency for positive pressure anomalies in high latitudes was the existence of the cold vortex in the Russian Arctic in spring and early summer. Associated with the vortex was an extensive snow cover over northern Europe in April. The snow limit gradually retreated north-eastwards until it was confined to the Arctic coast of north-east Siberia at the end of June, leaving a cold waterlogged surface over northern Russia and north-west Siberia. The importance of this feature is not known, but it may have been a contributory factor. Certainly a source of anomalously cold air was available in these areas, and cold outbreaks to the south readily occurred in the summer. These conditions are at least consistent with the occurrence of higher pressure than usual farther west over Scandinavia and the Norwegian Sea, although it is recognized that cause and effect cannot be specified.

The cumulative effect on surface pressure anomalies associated with the cold sea temperature pattern, the position in the solar cycle and the slow-moving cold tropospheric vortex near Novaja Zemlja, could well have gone quite far towards predicting the large positive pressure anomaly in high latitudes over the north-east Atlantic as occurred in the high summer of 1968. There would still have remained the difficulty of predicting the actual weather, since the pressure pattern which occurred in 1968 would normally be associated with fine weather over Britain, as in 1899 or 1955. Indeed, the summer under study highlights the great difficulty of forecasting the seasonal weather even when the mean pressure map is correctly predicted by whatever means. Fortunately this type of inconsistency between pressure anomaly and weather is fairly unusual, and in most cases correct prediction of the pressure anomaly pattern implies a satisfactory forecast of summer weather.

Acknowledgement. Permission to publish the maps shown in Figures 14 and 15 has been kindly given by the U.S. Fleet Numerical Weather Facility, Monterey, California, who are also responsible for the data on which Figure 10 is based.

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NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1968

By J. PATON

A list of displays of noctilucent clouds (NLC) observed from western Europe during 1968 is contained in Table I. The first three columns give the night of the display, the period of time during which the NLC were observed, and details of the cloud forms and progress of the display when these are available; when observations permit the location of the southern boundary of the clouds, this is given in the notes.[1] The last four columns contain observations from selected stations, giving latitude and longitude to the nearest half degree, universal time, the maximum elevation above the northern horizon and the limiting azimuths of the NLC. Nights when the sky is sufficiently clear of ordinary clouds at many stations to permit the decision that no NLC are present, are noted. When tropospheric clouds prevailing at most stations make it impossible to decide whether or not NLC are present, 'cloudy' is entered in the notes.

The frequency of occurrence of the clouds was not significantly different from that of previous years but many of the displays were much brighter than during 1967.[2] As is usual, the clouds first appeared early in June and receded northwards during the first week in August to be last visible from northern Scotland on 5 August. The most spectacular displays occurred on the nights of 19–20, 23–24 and 28–29 June and 23–24 July.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1968

Date–night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths
31 May–1 June		No NLC.				
1–2 June		Cloudy.				
2–3		No NLC seen over British Isles. Weak display reported from Denmark.	55°N 15°E	0020–0030	8°	360°–045°
3–4		Cloudy.				
4–5		No NLC.				
5–6		No NLC.				
6–7		No NLC.				
7–8		Cloudy.				
8–9	2310–0110	Faint veil and bands.	56·5N° 7°W	0050		020°
			56°N 4·5°W	2310	15°	340°–020°
			55°N 4·5°W	0010	23°	010°–045°
				0058	10°	020°–070°
9–10		No NLC.				
10–11		No NLC.				
11–12		No NLC.				
12–13		No NLC visible from British Isles but very weak display seen from near Kiel, Germany, and from aircraft over western and mid-Atlantic between 0200 and 0400 h.				
13–14 June	2140–0110	Faint veil and bands. Whirls seen from Denmark.	57·5°N 7·5°W	0020	10°	320°–020°
				0040	10°	340°–020°
			57°N 2°W	0001	12°	360°–012°
				0100	15°	308°–320°
			56·5°N 3°W	2324	7°	320°–340°
				0106	7°	340°–360°
			55·5°N 1·5°W	2350	12°	330°–010°
			55°N 15°E	2140	No elev. given.	045°–090°
14–15	2300–0010	Faint veil.	55·5°N 4·5°W	2300	7°	360°–020°
15–16		No NLC.				
16–17		No NLC.				
17–18		No NLC.				
18–19	2345–0154	Moderately bright veil, bands and billows.	56·5°N 3·5°W	2345	12°	330°–020°
			55·5°N 7·5°W	0042	16°	360°–045°
			54°N 4·5°W	0035	7°	340°–030°
19–20	2200–0305	Cloudy north of 53°N. Clear in south. Bright veil, bands, billows and whirls, bluish white in colour, and visible down to northern horizon. Detailed observations from Plymouth, St Mawgen, Exeter and Chivenor indicate that just after 0245 h 'streaks' were seen to extend to the southern horizon. So the southern boundary of the clouds was probably at least as far south as 45°N.	53°N 1·5°W	2300	6°	Hidden by cloud.
			52°N 1·5°W	2305	15°	330°–050°
			51·5°N 1°W	2230	15°	350°–360°
			50·5°N 5°W	2230	9°	300°–030°
				2310	5°	360°–030°
			50·5°N 4°W	2230	8°	328°–006°
			50·5°N 3·5°W	2200	35°	270°
				2225	12°	288°–029°
				0230	27°	331°–049°
				0245	34°	310°–027°
20–21		No NLC.				
21–22		No NLC.				
22–23	2350–0250	Moderately bright veil, and bluish-white bands. The southern boundary of the clouds was about 52°N.	58°N 6·5°W	0115	17°	360°–090°
				0145	70°	340°–120°
			57·5 °N7·5°W	2350	11°	030°–060°
				0100	14°	010°–080°
				0220	90°	300°–130°
				0240–0250	135°	135°
			50·5°N 5°W	0145	12·5°	350°–083°
				0245	32°	350°–085°
23–24	2110–0208	Veil, bands and billows, very bright around 2120 h and again at 0100–0130 h.	55°N 15°E	2120	35°	045°
			52·5°N 1°E	0150	13°	055°
				0208	35°	No record.
24–25	2200–0201	Veil and bands.	58°N 6·5°W	2305	90°	No record.
			56·5°N 3°W	0046	7°	020°–040°
				0201	15°	340°–010°
25–26		Cloudy.				
26–27		No NLC.				

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths
27–28	2245–0107	Very faint veil and bands seen from aircraft over northern Scotland at height of 36 000 feet and from Leuchars.	58°N 3°W	0030	70°	360°–060°
			56·5°N 3°W	0100	10°	040°–060°
			55°N 4·5°W	2245	20°	020°
28–29	2345–0255	Spectacular display of veil, bands, billows and whirls seen from Shetland to northern England and north of Ireland. Cloudy elsewhere The predominant feature of the early part of the display was a sharply defined long and persistent band extending from north to north-east at an elevation of 7° above the northern horizon as observed at Malin Head and about 19° seen from Kinloss. As dawn approached, the cloud became visible in the southern sky in fine filaments resembling condensation trails and patches like dense cirrus. The southern boundary of the clouds was probably about 53°N.	58·0°N 6·5°W	0019	18°	350°–040°
			57·5°N 3·5°W	2350	30°	340°–080°
				0115	110°	300°–120°
				0230	167°	180°–210°
			56·5°N 7°W	0001	14°	315°–045°
				0200	70°	315°–090°
			55·5°N 3°W	0015	10°	360°–030°
				0105	20°	350°–050°
			55·5°N 7·5°W	0027	12°	315°–060°
				0220	80°	310°–100°
				0230	100°	295°–110°
				0240	135°	—
			55·5°N 1·5°W	0030	20°	340°–030°
				0150	135°	315°–135°
			55°N 4·5°W	0157	120°	340°–120°
			55°N 3°W	2345	10°	360°–045°
				0100	14°	340°–070°
29–30	2250–0145	Bright greenish bands seen from Denmark and northern Germany. Low cloud widespread over the British Isles but NLC seen from Abingdon, Berks.	56°N 12·5°E	2300	8°	360°
				0030	30°	360°–020°
			54°N 10°E	No time given.	12°	350°–045°
			51·5°N 1·5°W	0100	5°	350°–010°
				0145	6°	350°–360°
30 June–1 July		No NLC.				
1–2 July		No NLC.				
2–3		No NLC.				
3–4		No NLC.				
4–5	2315–0225	Bands. Southern boundary about 55°N.	55·5°N 3°W	2330	45°	310°–060°
				0010	90°	
			55°N 3°W	0100–0200	90°	
			54°N 6·5°W	2315	28°	360°
5–6		NLC reported from Uppsala, Sweden. No details given. Mainly cloudy over western Europe.				
6–7	2130–0145	Faint veil and bands.	55°N 4·5°W	0115	5·5°	360°–045°
7–8	2350–0230	NLC seen from north of Ireland.	No details.			
8–9		No NLC.				
9–10		No NLC.				
10–11		Mainly cloudy.				
11–12	2228–0230	NLC seen from Shetland, two aircraft over North Sea and from southern Yorkshire. Bands.	60°N 1°W	2312	47°	200°–270°
			56·5°N 1°W	0010	20°	350°–070°
			56·5°N 0°	0030	20°	360°–080°
			53·5°N 0°	2240	9°	310°–360°
12–13	2200–0115	Faint veil and band.	55°N 4·5°W	0100	6°	340°–070°
13–14		Cloudy.				
14–15		Low cloud prevalent but NLC bands seen at Tiree (56·5°N 7°W) and Harlov, Sweden (57°N 14·5°E).	No details.			
15–16		Cloudy.				
16–17	0050	NLC seen through low cloud at Tiree.	56·5°N 7°W	0050	9°	020°
17–18	0045–0150	Thin band seen through low cloud.	58°N 6·5°W	0045	—	070°–090°
			56·5°N 7°W	0050	6°	050°
			55·5°N 1·5°W	0100	5°	010°–020°
18–19		No NLC				
19–20 July		Cloudy.				
20–21	0030	NLC seen in Denmark. Cloudy over British Isles.	56°N 12·5°E	0030	7°	360°
21–22		Cloudy.				
22–23		Cloudy.				
23–24	2110–0130	NLC seen from ship in Skagerrak, and from Denmark and Scotland. Very bright blue-green bands and billows 0030–0045 h.	59°N 10°E	2200	40°	020°
			56°N 10°E	2130	10°	045°
				2230	8°	045°
			55°N 4·5°W	0110	8°	010°–070°
24–25	2235–0100	Blue bands and billows seen at Uppsala, Sweden, from an aircraft over the North Sea and from Scotland.	56·5°N 1°W	0045	12°	360°
			56·5°N 3°W	0045	9·5°	357°–003°
25–26	2115–2225	Very faint bands seen from Uppsala and Denmark. Not visible from British Isles though skies clear at some stations.	56°N 10°E	2115	8°	045°
26–27		Cloudy.				

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths
27–28	2330–0250	Moderately bright bands and billows. Southern boundary of display about 59°N.	58°N 6·5°W	0050	10°	350°
			57·5°N 3·5°W	0140	10°	350°–035°
				0215	23°	340°–035°
				0250	25°	350°–020°
			57·5°N 7·5°W	2350	12°	—
			56·5°N 7°W	2330	4°	340°
				0250	12°	340°–040°
28–29		NLC seen from Kinloss (57·5°N 3·5°W) through gaps in low cloud.				
29–30		Cloudy.				
30–31		Bands seen at Uppsala, Sweden. Cloudy over British Isles.				
31 July–1 Aug.		NLC seen at Uppsala, Sweden, and from aircraft over western Atlantic between 53°N 53°W and 55°N 45°W (0300–0330 h). Cloudy over British Isles.	No details.			
1–2 Aug.	2315–0200	Veil and bands seen from Lerwick and Benbecula and from aircraft over Atlantic. Southern boundary about 63°N.	60°N 1°W	2315	13°	350°–020°
			57·5°N 7·5°W	0100	5°	340°–010°
				0120	5°	340°–020°
			57°N 45·5°W	0200	5°	
2–3		No NLC.				
3–4		No NLC.				
4–5		No NLC.				
5–6		NLC seen from Kinloss (57·5°N 3·5°W) through gaps in low cloud.				

A feature of the displays of 1968 was the large number that extended far southwards. The southern border of the majority of displays observed from the British Isles is situated to the north of these islands, but on at least eight nights during 1968 (June 19–20, 22–23, 23–24, 24–25, 27–28, 28–29, July 4–5 and 27–28), the clouds were overhead over some part of the British Isles. On the first of these nights, 19–20 June, observers in the south-west of England observed NLC bands before dawn close to the southern horizon, so that the southern border of the display may have been as far south as latitude 45°N. If the NLC consist of ice crystals, as has been indicated by rocket experiments, then the formation of the clouds will be largely controlled by the temperature at the mesopause. The NLC may therefore provide a visible indication of the meridional extent of the region of abnormally low temperature at the level of 80 kilometres, where they are situated.

Observations in Poland show that NLC were visible there on the nights of 21–22 and 29–30 July, when it was cloudy over western Europe, and on the nights of 30 June–1 July, 9–10 July and 4–5 August when no NLC were visible from western Europe.

The assistance of the large number of observers who, by providing visual observations, photographs and sketches, have made this analysis possible, is gratefully acknowledged. These synoptic studies will continue and observers are invited to send observations to the Balfour Stewart Auroral Laboratory, The University, Drummond Street, Edinburgh 8. A general account of NLC appeared in the *Meteorological Magazine,* Vol. 93, 1964, pp. 161–179, and notes on observations in the *Meteorological Magazine,* June 1967, p. 189.

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KEW — THE NATIONAL RADIATION CENTRE

By R. H. COLLINGBOURNE

This paper describes the work carried out at Kew Observatory, or by staff intimately connected with the Observatory, in the field of solar and atmospheric radiation measurement.

Early work. Attempts to measure the 'sun's heat' or 'amounts of sunshine' have always been important to scientists interested in the atmosphere, and so it was natural that this task should be included in the work of Kew from an early stage. The first serious instrument was that of Campbell; in its original form a water-filled hollow glass sphere was supported at the centre of a wooden hemispherical bowl so that in clear conditions an image of the sun was formed on the bowl's inner surface, charring the wood. Because the rotation of the earth causes the sun's image to trace out a line, it was possible to see from the charring when the sun was 'shining'. A fresh wooden bowl was placed in position at each summer and winter solstice (21 June and 21 December); because of the sun's changing declination, the lines traced on successive days by the centre of the solar image did not overlap. It was possible in this way to form a general picture of the pattern of sunshine during the six-month period and an estimate of the total sunshine was found by measuring the volume of wood which was charred. A discussion of 20-years record (1855–74) obtained with this instrument (after a few years the water-filled globe was replaced by a glass sphere) in the centre of London, is given by Roscoe and Balfour Stewart.[1] In 1874 this instrument was transferred to Kew and operated in this form for several years. The limitations of the crude six-month record were, of course, recognized and, both at Kew and at the Royal Greenwich Observatory, experimental records were made with cards which were clipped or fastened into the appropriate place on the inner surface of a hemispherical bowl.[2,3] The modern form of card holder with three sets of slots (for summer, equinoctial and winter cards respectively), was described by Stokes[4] in 1880 and was soon brought into general use.

As would be expected from its function as the Central Observatory of the Meteorological Office (from 1867) all the important radiation instruments at this time were tested at Kew. A new pattern of the Jordan sunshine recorder was compared with the Campbell-Stokes instrument for one month in 1887,[5] and there is still at Kew a specimen of the Macleod sunshine recorder which was also tested.[6]

Instruments designed to measure the intensity of solar radiation, rather than its duration, were also examined and tested. There are still at Kew two specimens of the Hodgkinson actinometer,[7] and Balfour Stewart's instrument[8] may also be mentioned; although neither of these instruments came into widespread use, their basic principle of operation is similar to that later adopted for the well-known Abbot silver-disc secondary standard pyrheliometer.

Commencing about 1875, observations were also made with 'solar-radiation thermometers' or 'black-bulb thermometers in vacuo'; these were maximum thermometers with their bulbs painted black, or made of black glass, enclosed in an evacuated glass tube and freely exposed to solar radiation. The difference between the maximum temperature recorded by these thermometers and the maximum true air temperature was considered to be proportional to the maximum intensity of solar radiation. It was, however, early shown that different specimens of this type of instrument could not be made to give concordant results, and in a later study[9] it was shown that the temperature difference must depend on other important factors besides radiation.

The gradual development. A great step forward in the international field of solar radiation measurement was made in Europe by the development of the Ångström pyrheliometer for measuring the intensity of direct solar radiation, i.e. solar radiation falling on a surface placed perpendicular to the direction of the sun. Following its adoption by the International Meteorological Congress at Innsbruch in 1905 as a standard instrument, specimens were obtained for use at the British observatories at Kew and at Eskdalemuir. Observations were made regularly at Kew from 1907, usually within half an hour of noon whenever the weather was clear. Results were published in the *British Meteorological and Magnetic Year Book;* this publication was later superseded by the *Observatories' Year Book.* A specimen of the Abbot silver-disc pyrheliometer was also obtained and one of the early comparisons of these two instruments and thus of the Ångström and Smithsonian scales was carried out at Kew.[10] As a natural development, following on from this, continuous records of direct solar radiation have been made at Kew from July 1932 using a Gorczynski pyrheliograph.

Measurements of long-wave (thermal) radiation emitted by the atmosphere were started at Kew when the W. H. Dines differential radiometer (comparing radiative temperatures of the sky and of a tank of water) was transferred to Kew from Dines's home at Benson; an irregular series of observations covering the period 1930–40 was published in the *Bulletin Actinometrique International.**

The modern scene. Up to the 1939–45 war, the measurement of radiation was a relatively minor part of the varied geophysical work at Kew Observatory, but in 1946 the emphasis was changed, and from then on radiation measurement and research became a major interest. It is convenient to sub-divide the discussion of this later phase into five parts, which follow.

Development of instruments. The recording of global solar radiation and diffuse solar radiation on a horizontal surface (the diffuse radiation is the component coming from the sky and clouds and not direct from the sun) began at Kew in 1946 using Moll-Gorczynski solarimeters made in Holland. These instruments have been carefully investigated in the laboratory at Kew and the measurements have been repeated with gradually increasing precision, as successive improvements have been made in the instrument by the manufacturers. Apparatus has now been built at Kew to enable the deviations of the response of any particular solarimeter from the cosine law to be measured using a stationary artificial light source, and using an intensity

* Observatoire Léon Teisserenc de Bort, Trappes.

which is not much less than that of the sun on a clear day (about 50 milliwatts per square centimetre is usually used). The solarimeter is kept in its normal horizontal position. In addition, reliable measurements have been made of the linearity of the solarimeter output, up to full solar radiation intensity, and of the solarimeter temperature coefficient. It is hoped that these results will be published soon.

Soon after the start of the recording of global solar radiation it was decided to record as well the corresponding intensity of daylight illumination; this is the intensity of solar radiation evaluated in proportion to its ability to stimulate the average human eye. Suitable instruments were not available commercially and, after taking advice from the National Physical Laboratory about suitable cells and correcting filters, experimental instruments were built at Kew and these were followed by improved versions.[11] Development has continued and, in particular, it has proved necessary to keep a continual check on the spectral response of the cells and the transmissions of the correcting filters. Recording at Kew has been continuous since 1947.

During this period also, a much improved version of the Robitzsch bimetallic actinograph was built[12] and this has been made commercially in London. The instrument naturally requires regular recalibration against a standard instrument.

It had long been realized that measurements should also be made of the long-wave radiation exchange. A long series of measurements of downcoming atmospheric radiation was made with the Dines radiometer and the Linke-Fuessner actinometer,[13] but these instruments are not suitable for continuous recording, and it was decided to concentrate further developments on the construction of a radiation balance meter, an instrument for the measurement of the difference between the downward and upward streams of radiation. An early Kew instrument, based on the type originally built in America by Gier and Dunkle has been described by MacDowall.[14] In an international comparison of radiation balance meters (organized by the World Meteorological Organization (WMO) during the period 1964–67), specimens of the latest version of this instrument compared well with the three other types in routine use; however, the need for some improvement in all the types became evident.

The equipment in general use at Kew and at other Meteorological Office stations recording solar radiation in 1961 has been described by Jacobs;[15] a view of the main solar radiation instruments is in Plate III.

Instruments for special investigations have also been devised. An important project has been the measurement of a spectral distribution of solar radiation on a routine basis. This has involved the development of complex equipment using a set of 15 narrow-band interference filters and has been described in general terms by Collingbourne.[16]

A major improvement in the facilities at Kew, in 1966, was the installation of an integrating sphere for the inter-comparison of solarimeters. This enables three solarimeters to be inter-compared. The measurements take about half an hour; previously the inter-comparison had to be done outdoors and required several days of fine weather.

Short, *ad hoc*, investigations were also undertaken which occasionally required special instrumentation. One such was the operation for about a year of an extra-sensitive illuminometer to investigate the daylight intensity around sunrise and sunset.

Development of recording methods. The continuous records from the radiation instruments were originally made on the type of recording galvanometer in which the trace appears in the form of a series of dots. These records had to be hand-scaled, and this is a tedious task which cannot be performed accurately when the record is fluctuating. It was natural therefore that a search should be made for ways of recording which would both save labour and, if possible, be more accurate.

The first improvement that was adopted involved the use of a low-inertia electric motor of which the speed of rotation is accurately proportional to the applied voltage over a large range of inputs. If such a device is coupled to a counter so that the number of revolutions of the motor can be indicated, then the difference in counter readings between the beginning and end of any period of time is proportional to the integral of the applied voltage, which is just what is required for hourly or daily mean values. A description of the system used has been given by Blackwell.[17] This method, however, had a number of drawbacks, notably the necessity for careful maintenance of the brush contacts on the motor. A major step forward was the production of the Meteorological Office Data-Logging Equipment (MODLE) as a combined effort by Kew, the Instrument Development Branch of the Meteorological Office and the manufacturers. The first prototype was received in June 1961 and this was brought into routine use from 1 January 1962. With this equipment the outputs from up to 12 different instruments can be converted into digital form on a scale from 0 to 999 and punched on to paper tape for subsequent analysis and processing by an electronic computer. The introduction of this equipment was foreshadowed by Jacobs.[15] The output in each channel is sampled at the rate of once per minute, and subsidiary experiments at Kew have shown that this rate of sampling is adequate for the calculation of hourly mean values even when the radiation is very variable.

The computer programmes to enable the Meteorological Office computer to produce hourly and daily totals of the radiation components, and to ensure that faulty data are not used, were written by Kew staff. A chart record is also obtained to safeguard against faults in the paper-tape output. An improved version of MODLE was produced in 1964 (see Plate IV) and is now in routine use at Kew and 10 other Meteorological Office stations.

With the first Meteorological Office computer it was possible to obtain only a printed output of processed data, but, following the introduction of the second Meteorological Office computer, the data are now stored on magnetic tape as well as being printed out. A series of computer programmes has been written so that data on magnetic tape can be added to, amended or modified in any necessary way, and so that any required tabulation can be prepared automatically. The time saved by this application of automation is available for a critical examination and analysis of the data.

This data-processing system, based on the widespread use of automatic data-logging apparatus, pioneered and largely devised by the staff at Kew

Observatory, is at present unique in the Meteorological Office and perhaps in the world. It has been favourably commented on by Filippov.[18]

A future planned development for MODLE is the replacement of the paper-tape punch by a magnetic-tape recorder, because this should lead to increased reliability. On the same general lines a simple magnetic-tape recording system has been designed for recording the output of a single solarimeter (e.g. on ships) and some instruments of this type have been tested.

The organization of a radiation network. Observations of solar radiation prior to 1939 at Meteorological Office stations other than Kew were sparse. Occasional observations with the Ångström pyrheliometer were made at Eskdalemuir from 1909 to 1939, and a continuous record of solar radiation on a horizontal surface was made, with a Callendar radiograph, at South Kensington from 1911 to 1939.[19]

After the 1939–45 war, however, it was decided, partly in connection with research work being started in agricultural meteorology, that solar radiation should be measured at other stations, and a network was gradually built up. In 1951–52 measurements of global and diffuse radiation were started at Lerwick and Eskdalemuir and by 1957 had been extended to Aberporth, Cambridge and central London (Victory House). Illumination measurements were started in central London in 1950, and in 1958 at Lerwick and Eskdalemuir. Measurements of radiation balance started at Lerwick and at Eskdalemuir in 1964.

The International Geophysical Year (IGY) (July 1957–December 1958) proved to be a stimulus in this field of activity, as in so many others, and, as one of its contributions, the Meteorological Office decided to set up radiation measuring equipment at Malta, Aden and Stanley (Falkland Islands), measuring global and diffuse solar radiation, and radiation balance, and also to equip the four British Ocean Weather Ships with equipment for measuring global solar radiation and radiation balance. All this equipment was installed by June 1957. In addition to these Meteorological Office stations, help was given to the observatories at Halley Bay and Argentine Island. Later, in 1965, routine recording of solar radiation was started at Bracknell.

This large expansion of radiation recording threw a correspondingly large and continuing burden of extra work on to the staff of Kew Observatory. All the solarimeters and illuminometers had to be calibrated at Kew, advice and instructions on recording and tabulating procedures had to be given, the radiation balance meters had to be constructed in the workshop and then calibrated, and the routine of regular recalibrations had to be built up. Many visits of inspection have been made to stations both at home and overseas. Since this extra work was also coincident with a reduction of Scientific Officer staff, it was inevitable that there had to be a shift from the more fundamental experimental investigations of 1947–55 to the more routine, but still very necessary, calibration and investigation of routine instruments of the later years.

In parallel with this development of the radiation network using official Meteorological Office stations, there was an effort to encourage those non-Meteorological Office stations desirous of making solar radiation observations for their own purposes to use solarimeters calibrated at Kew (or calibrated against solarimeters which have themselves been calibrated at Kew), and to collect such data in a uniform manner. It was planned to store all the radiation data on punched cards and this has now largely been carried out.

The completed tabulation forms have all been sent to Kew for critical scrutiny, and thus Kew Observatory has truly developed into the National Radiation Centre. Since about 1956, an effort has also been made to obtain solar radiation measurements on ships making regular voyages. Solarimeters and potentiometric chart recorders have been installed on a number of naval survey ships, British Antarctic Survey (BAS) ships and research vessels (so far six in all) and later, when the magnetic-tape recorders, mentioned above, are proved to be satisfactory, it is intended to extend this scheme.

There have also been close links between Kew Observatory and the radiation measurements undertaken by the Meteorological Research Flight (MRF). The solarimeters and illuminometers of the MRF are regularly calibrated and every assistance is given in the instrumental problems encountered.

The analysis of the collected data. It is not possible here to do more than indicate the main feature of this work. The first major discussion on the radiation data collected at Kew was by J. M. Stagg[9] who analysed some 14 years of direct solar radiation data. At about the same time Robinson[13] produced his important papers on atmospheric radiation.

This was followed by Blackwell's papers on the first five years of global and diffuse radiation[20] and of daylight illumination.[21] These summarized the main instrumental factors and produced average values for various conditions. Using these records and the first records of the radiation balance, it was found possible to estimate the reflection and absorption of solar radiation in a cloudless atmosphere,[22] and the magnitude of the various terms of the local energy balance of the atmosphere.[23,24] These studies showed the value of the radiation observations it was proposed to make during the IGY.

Robinson[25] further developed this work by using the surface observations to estimate the absorption of solar radiation by atmospheric aerosols. It was shown fairly conclusively that this was often appreciable but there were some curious features about the results that were further brought out in a paper by Hamilton and Collingbourne.[26] It now seems probable that the small discrepancies reported were due in part to a wrong application of previous results on aerosol scattering, and in part to small errors in the cosine response of the solarimeters. A direct result of the radiation measurements is to show the increase of solar radiation received in central London,[27] following the 1956 Clean Air Act.

A summary of the much larger amount of data now available for stations covering much of the United Kingdom is obviously a much larger problem than the use of data from one or two stations only. A start has been made by Day,[28] and Lumb[29] has analysed data from Ocean Weather Ships but a more ambitious publication is now planned.

Many inquiries concerning radiation problems have been answered over the years. One particular item may perhaps be cited; a study of the one year's record with a sensitive illuminometer at Kew has produced a valuable summary of the illumination around sunrise and sunset which has been of help to engineers concerned with street lighting, and to construction engineers and animal physiologists.

International comparisons and work. There is a great need to ensure that the measurements of radiation made in different countries are concordant. Kew Observatory has always kept several Ångström pyrheliometers which are inter-compared with each other. From the early days there has been a series of recalibrations against the Swedish standard. The comparison of the Smithsonian and Ångström scales by R. E. Watson,[10] already mentioned, and a similar later comparison by Eldridge[30] showed agreement with such comparisons elsewhere. That the accuracy was being maintained was confirmed by further measurements at Davos, Switzerland, in 1959 and 1964 when a Kew representative took one of the Ångström instruments to join in the international comparison of standard pyrheliometers organized by WMO. Since 1957 the measurements at Kew have been expressed in the International Pyrheliometric Scale (IPS), recommended by WMO. This is an attempt to assess the true pyrheliometric scale based on the estimated errors in both the Smithsonian and Ångström scales. At the same time, however, a close contact has been kept with the independent scale of radiation maintained by the National Physical Laboratory (NPL). It seems likely that the difference between the IPS and the NPL scales is less than one per cent.

The staff at Kew Observatory have always played their share in the work of international organizations, in close consultation with the Headquarters Branch which since 1957 has been Met. O.14. The international representation at present is by Met.O. 14 members; L. Jacobs is a member of the Working Group on Radiation Climatology, WMO Commission for Climatology, while R. H. Collingbourne is a member of the WMO Commission for Instruments and Methods of Observation Working Group on radiation instruments and methods of observation for general use, and of the Regional Association (RA) VI (Europe) Working Group on Radiation.

Kew Observatory, because of its equipment and facilities, was designated one of the European regional radiation centres by RA VI in 1965, i.e. it is recognized as being competent to calibrate instruments and supervise radiation observations.

The future. The staff and facilities at Kew Observatory over the years have played a major part in the recording of solar radiation in the United Kingdom, at certain overseas stations and at sea. There is a slight shift of emphasis now as the data processing provided by the Meteorological Office Headquarters becomes more important, but the facilities of the Observatory and the expert knowledge of its staff will be required for many years to come.

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Note : In the June *Meteorological Magazine*, Vol. 98, p. 165, line 1, the term 'House Guards' has been quoted. Although it appears in the original journal of 1882, there is no doubt that the reference is to the well-known Horse Guards.

REVIEW

Graphical rational patterns, a new approach to graphical presentation of statistics, by Roberto Bachi. 170 mm×245 mm, pp. xvii+243, *illus.*, Israel Universities Press, Jerusalem, 1968. Price: 80*s*. (Distributors, H. A. Humphrey Ltd, 5 Great Russell Street, London, W.C.1.)

The author, who is Professor of Statistics and Demography at the Hebrew University of Jerusalem, has suggested a new solution to the problem of presenting statistical material in graphical form. In essence this consists of representing numbers relative to a fixed base (such as percentages) by the proportion of a standard area which is printed in black (or other colour). If, say, the base is 100, then 1 per cent is represented by a just visible black dot, the 10, 20 and 30, etc. percentages correspond to one or more black areas of respectively 10, 20 and 30, etc. times the unit size, arranged more or less like the pips on a playing card, with a space for any odd units, while for 100 per cent the whole area is black. Patterns are suggested for bases of 10, 40, 100 and 1000; in the last case, the total pattern measures just over one inch square. This method of graphical representation is used in many variants through 13 chapters, typical examples being the distribution of average income in each province in Italy, or the percentage distribution of population in Sweden by quinquennial age-groups for the period 1850 to 1950. One or more graphical rational patterns are shown in each subcell, and the reader will understand these as soon as he has learned the appropriate code.

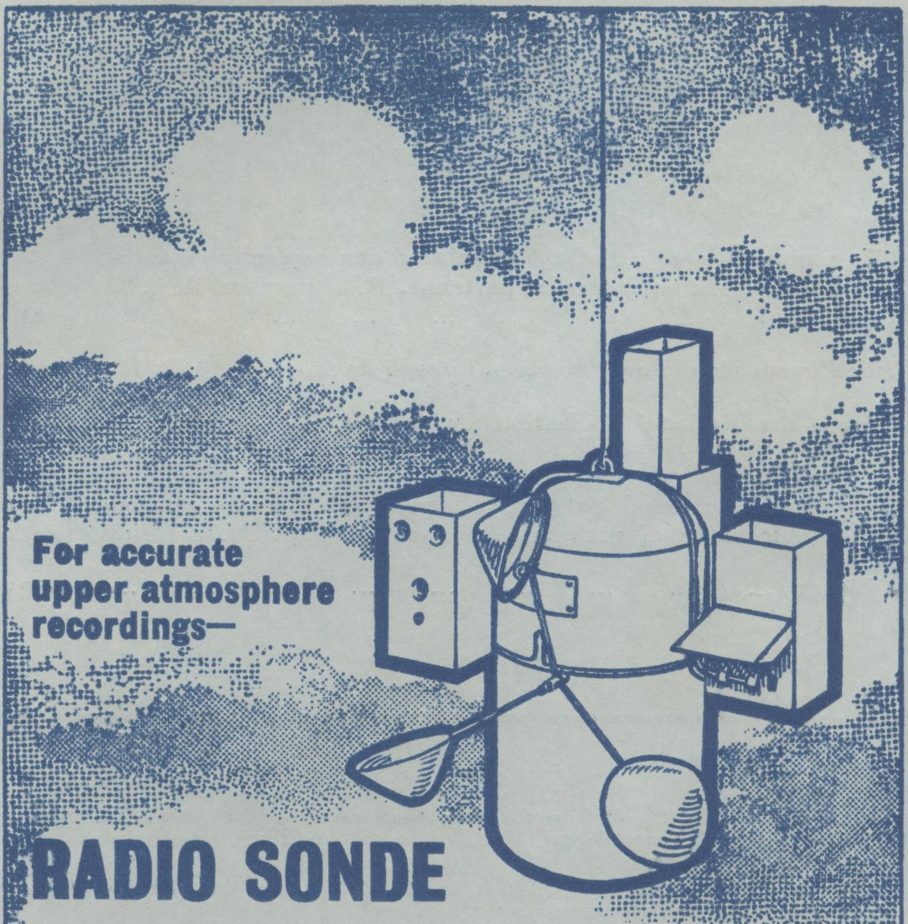
The idea is well presented, and well executed, although I find many of the resulting graphs rather heavy and unsightly in areas of high percentages. However, the reader will ask what advantages these patterns have over the more familiar graphical patterns for conveying numerical information, the ordinary Arabic numerals. Certainly the amount of information contained in an ordinary weather observation, plotted around the station circle, far exceeds what could be conveyed in the same time by these graphical rational patterns.

The book is easy reading, although Figure 12.5B is puzzling until the reader looks at it in a mirror. Meteorologists, however, will probably share the feeling that in many problems the advantages claimed for this idea can be obtained more simply by the judicious use of ordinary numerals, and some isopleths.

J. M. CRADDOCK

OBITUARY

It is with regret that we have to record the death of Mr M. A. H. Williams (T.T.O. 1) on 17 April 1969.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