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THE 1975/76 DROUGHT OVER THE UNITED KINGDOM— HYDROMETEOROLOGICAL ASPECTS

By R. MURRAY

SUMMARY

Some outstanding features of the rainfall deficiency over the United Kingdom from May 1975 to August 1976, notably the 16 month period of rainfall deficiency which was unprecedented over England and Wales as a whole since records began in 1727, are discussed. The patterns of change of evaporation, including transpiration, and soil moisture deficit during the summer half-years of 1975 and 1976 are compared.

The abnormal dryness, which led to severe difficulties in water supply in many parts of England and Wales and to agricultural droughts in the summers of 1975 and 1976, came to an end with heavy rain in some areas, mainly in southern Britain, in the last few days of August and nearly everywhere else around 10 September 1976.

1. INTRODUCTION

Miles (1977) has described various features of the atmospheric circulation over the northern hemisphere, particularly over the Atlantic–European sector, over many months. He has pointed out that abnormally high surface pressure occurred over and near southern Britain during much of 1975 and 1976. As part of the abnormal atmospheric circulation much more dry anticyclonic weather than usual occurred over a wide area centred on southern Britain during the period from May 1975 to August 1976. As a consequence of the anomalous meteorological patterns, a prolonged and marked rainfall deficiency developed in most parts of Britain. The deficiency of rainfall, combined with the loss of water by considerable evaporation and transpiration during the two very warm, sunny summers of 1975 and 1976 led to shortages of water for general use, that is, to drought conditions.

Drought can be defined objectively in numerous ways to suit particular purposes and different climates. A WMO *Technical Note* (1975) discussed, *inter alia*, the classification of droughts. More recently Tabony (1977) presented arguments for the use of indices which differentiate between meteorological drought, agricultural drought and hydrological drought, and he employed these indices to rank the different types of drought at Kew. Whatever objective indices might be used to classify droughts, it has long been recognized that the root cause of drought is a rainfall deficiency of considerable duration and that there is a difference between hydrological drought and agricultural drought. Over the United Kingdom, reservoirs, lakes and aquifers are normally replenished by rainfall in the winter half-year when evaporation is low; if rainfall is sufficiently below average, surface water and ground water reserves may be inadequate for all requirements during the summer half-year and the drought may be termed a hydrological drought. On the other hand a drought in the growing season, i.e. in the summer half-year, when the loss of water to the atmosphere by evaporation and transpiration is generally greater than the total rainfall, may be called an agricultural drought.

The demand for water is such that water managers become very concerned when rainfall is substantially deficient over the winter half-year especially if the preceding seasons have been drier than usual. On the other hand most farmers want dry weather in the winter half-year, since many farming operations are difficult or even impossible in wet winter months when the ground may be waterlogged. This article presents a description of the rainfall patterns over the United Kingdom and draws attention to some features of evaporation (transpiration) and soil moisture deficits during the drought period. These hydrometeorological aspects, which result from essentially meteorological causes, are only part of the hydrological cycle. However, they are important parts of the drought story for the water industry, as well as to the scientist.

2. Some rainfall features

Figure 1 shows the sequence of monthly rainfall as percentages of average for England and for Wales from December 1974 to October 1976. A wet autumn in 1974 was followed by mainly wet months (apart from February 1975) to April 1975. In the subsequent period, up to August 1976, the monthly rainfall in each country was markedly below average for 13 months out of 16 months—rainfall was above average in July 1975, well above average in September 1975 and near average in May 1976. The dramatic change from the exceptionally dry summer month of 1976 to the remarkably wet autumn months stands out. The England and Wales rainfall for the two month period September and October 1976 was 313 mm, a figure never previously reached in the 250 years of the England and Wales rainfall series; the next highest rainfall for the same two month period was 310 mm in 1903. From a hydrological point of view the drought can be said to have started in May 1975 and ended in September 1976. From an agricultural point of view there was a drought in the summer of 1975 and an even more notable one in summer 1976.

The monthly rainfall sequence for Scotland and for Northern Ireland, shown in Figure 2, is broadly similar to those for England and for Wales throughout 1975; however, much more rainfall variability on a monthly time-scale is in evidence in Figure 2 than in Figure 1 during the winter and spring of 1976 when January, March and May were wet months over Scotland and Northern Ireland. The dry summer and wet autumn sequence in 1976 was broadly similar over England, Wales, Scotland and Northern Ireland.

The spatial distribution of the rainfall pattern over the United Kingdom for the 16 months from May 1975 to August 1976 is depicted in Figure 3, where it is seen that the main rainfall deficiency (50 to 60 per cent of average) extends from southern parts of England to Yorkshire, but all regions except north-west Scotland experienced rainfall less than or equal to 90 per cent of average. The most intense period of the drought was from June to August 1976 and Figure 4 shows the rainfall patterns for summer 1976. Most of the United Kingdom experienced less than 60 per cent of average rainfall, with some localities in England and Wales having less than 20 per cent.

In Table I is shown the rainfall (as percentages of average) for the UK and for individual countries of the UK for various periods from 3 to 18 months ending in August 1976. Rainfall was clearly deficient in all countries for each of the specified periods, with the lowest percentages of rainfall for England and Wales. Over England and Wales combined the rainfall was slightly less in the 3 month period June to August in 1800 than in 1976, and in the 6 month period March to August in 1741 than in 1976, but for the other periods shown in Table I the rainfall over England and Wales was the lowest on record for the 9, 12, 15, 16 and 18 month periods with return periods of at least 250 years. On the other hand, over Scotland the rainfall was very much less remarkable in each of the periods from 6 to 18 months, although the summer (June to August) 1976 was the second driest since 1869.

TABLE I(a)—RAINFALL, AS PERCENTAGE OF AVERAGE (1916–50), FOR VARIOUS PERIODS FROM 3 TO 18 MONTHS ENDING IN AUGUST 1976 OVER PARTS OF AND THE WHOLE OF THE UNITED KINGDOM

	3 months June 76 –Aug. 76	6 months Mar. 76 –Aug. 76	9 months Dec. 75 –Aug. 76	12 months Sept. 75 –Aug. 76	15 months June 75 –Aug. 76	16 months May 75 –Aug. 76	18 months Mar. 75 –Aug. 76
United Kingdom	41	64	68	74	73	73	76
England and Wales	35	52	55	63	63	64	70
England	37	52	55	63	63	64	70
Wales	27	50	57	64	64	64	68
Scotland	48	79	83	86	85	83	84
Northern Ireland	48	74	74	80	76	73	75

TABLE I(b)—ESTIMATED AVERAGE FREQUENCY OF OCCURRENCE (ONCE IN N YEARS) OF RAINFALL PERCENTAGES FOR ENGLAND AND WALES AND FOR SCOTLAND SPECIFIED IN TABLE I(a)

Number of years = 250 for England and Wales and 108 for Scotland.

	3 months June 76 –Aug. 76	6 months Mar. 76 –Aug. 76	9 months Dec. 75 –Aug. 76	12 months Sept. 75 –Aug. 76	15 months June 75 –Aug. 76	16 months May 75 –Aug. 76	18 months Mar. 75 –Aug. 76
				N years			
England and Wales	125	125	⩾250	⩾250	⩾250	⩾250	⩾250
Scotland	54	8	8	4	4	6	6

Table II lists the 10 driest spells over England and Wales since 1820 for various periods from 3 to 24 months. In this table the spells of the same duration are non-overlapping, but they are not restricted to beginning with a particular month. The recent drought was unprecedented for periods of 12, 16 and 18 months irrespective of starting month. For 3 and 24 months the rainfall totals during the recent drought were not the minima which have been recorded for comparable periods since 1820, except when comparisons are made with other 3 month periods starting in June, and with other 24 month periods starting in September. It is interesting to note in Table II that two separate or non-overlapping 24 month periods, one beginning in July 1972 and the other in September 1974, are in the top 10, thus emphasizing the dryness of the past 5 years.

TABLE II—ENGLAND AND WALES RAINFALL: 10 DRIEST PERIODS OF DURATION FROM 3 TO 24 MONTHS SINCE 1820

(starting date and rainfall totals given)

	3 months		*mm*	6 months		*mm*	12 months		*mm*
1	1938	Feb.	56	1921	Feb.	179	1975	Sept.	570
2	1929	Feb.	71	1976	Mar.	204	1854	Feb.	618
3	1893	Mar.	71	1887	Feb.	221	1920	Nov.	618
4	1868	May	74	1929	Jan.	230	1887	Feb.	624
5	1854	Feb.	74	1870	Apr.	241	1963	Dec.	637
6	1976	June	76	1826	Mar.	249	1933	Apr.	651
7	1844	Apr.	77	1893	Mar.	256	1857	Dec.	661
8	1947	Aug.	82	1959	Apr.	261	1904	Mar.	667
9	1963	Dec.	83	1896	Jan.	263	1955	July	670
10	1921	May	88	1939	Feb.	264	1863	Nov.	673
	16 months		*mm*	18 months		*mm*	24 months		*mm*
1	1975	May	756	1975	Mar.	908	1853	Oct.	1439
2	1854	Feb.	811	1853	Dec.	933	1932	Nov.	1439
3	1933	Apr.	855	1887	Jan.	997	1862	Nov.	1461
4	1887	Feb.	857	1933	Apr.	1003	1887	Feb.	1493
5	1920	Aug.	880	1873	Feb.	1031	1974	Sept.	1496
6	1873	Apr.	899	1857	Dec.	1032	1972	July	1497
7	1857	Nov.	907	1863	Feb.	1043	1904	Oct.	1507
8	1943	Feb.	909	1943	Feb.	1044	1857	Feb.	1512
9	1963	Dec.	920	1963	Dec.	1047	1920	Aug.	1513
10	1869	June	928	1921	Jan.	1061	1947	Aug.	1520

3. EVAPORATION AND SOIL MOISTURE ASPECTS

Drought is naturally linked to excessive evaporation from water surfaces and transpiration from grass, plants and forests as well as to prolonged rainfall deficiency. Evaporation and transpiration are generally almost negligible in midwinter and reach a maximum in the summer months in the United Kingdom. In the 16 month period of rainfall deficiency from May 1975 to August 1976 there were two summers (June to August) which were predominantly dry, warm and sunny over most of England and Wales. The summer of 1976 was the drier, warmer and sunnier of the two fine summers. The exceptional warmth of summer 1976 may be seen from the anomalies of mean daily maximum temperature for the 3 month period June to August in Figure 5: particularly noteworthy are the remarkably large anomalies of +4°C or more from Devon to Cambridgeshire. The exceptional sunshine of summer 1976 is shown in Figure 6.

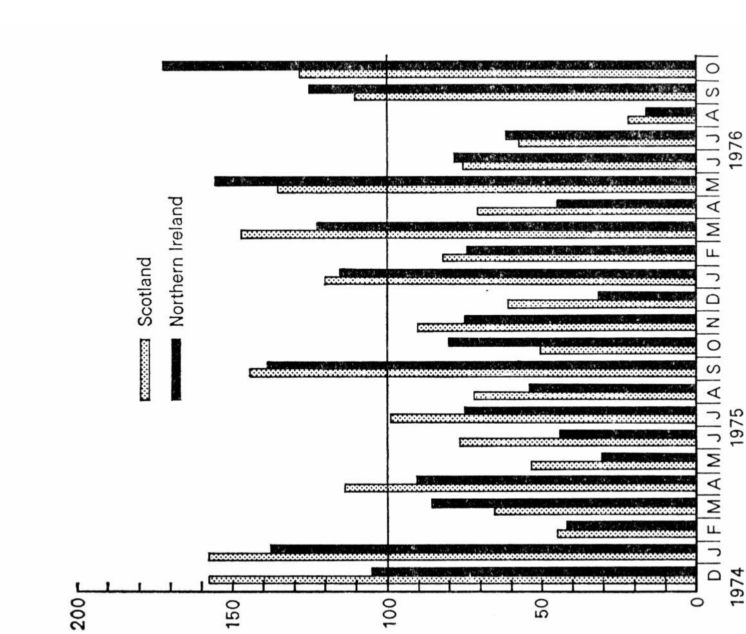

FIGURE 2—MONTHLY RAINFALL, AS PERCENTAGE OF AVERAGE (1916–50), FROM DECEMBER 1974 TO OCTOBER 1976 OVER SCOTLAND AND NORTHERN IRELAND

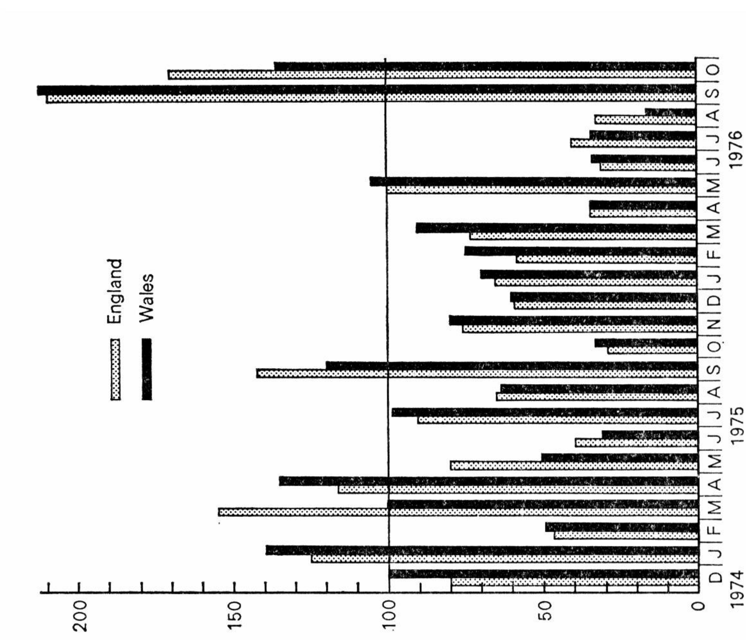

FIGURE 1—MONTHLY RAINFALL, AS PERCENTAGE OF AVERAGE (1916–50), FROM DECEMBER 1974 TO OCTOBER 1976 OVER ENGLAND AND WALES

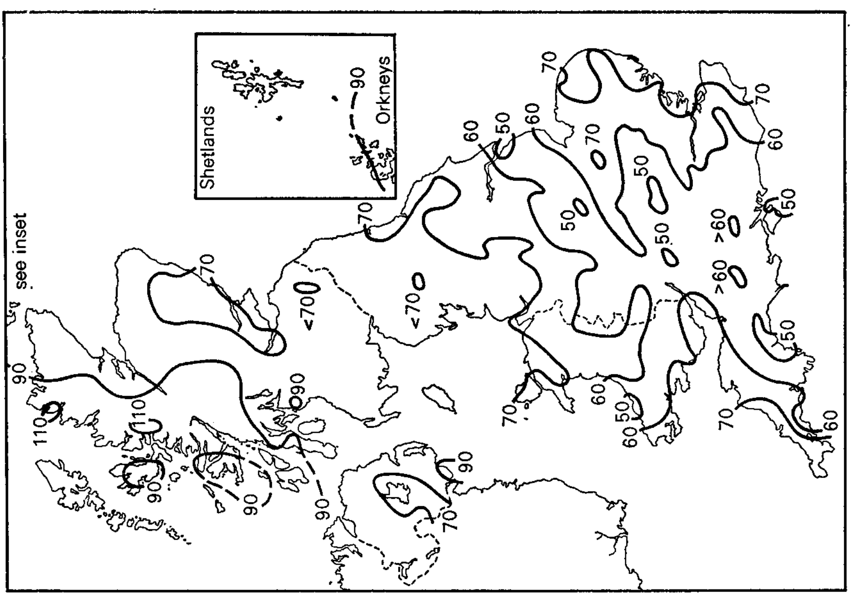

FIGURE 3—RAINFALL, AS PERCENTAGE OF AVERAGE (1916–50), FOR THE 16 MONTH PERIOD FROM MAY 1975 TO AUGUST 1976 OVER THE UNITED KINGDOM

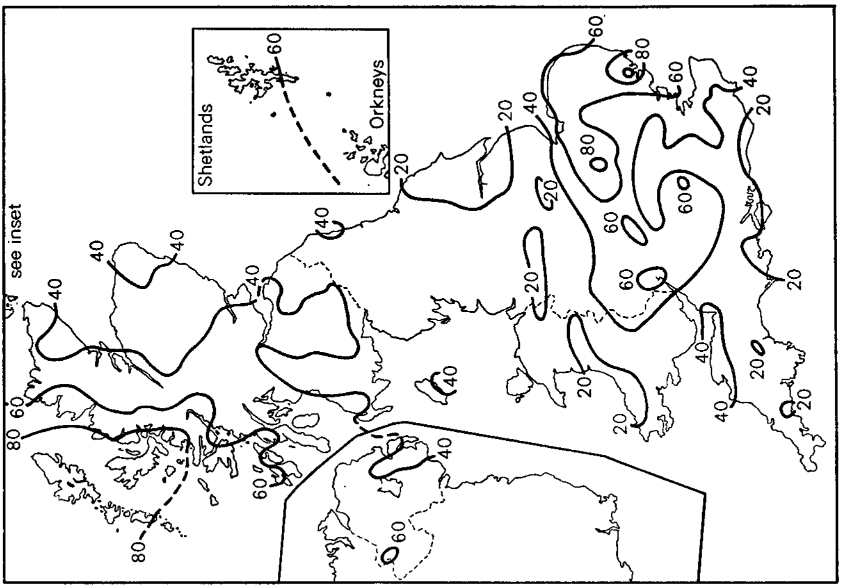

FIGURE 4—RAINFALL, AS PERCENTAGE OF AVERAGE (1916–50), FOR SUMMER (JUNE TO AUGUST) 1976 OVER THE UNITED KINGDOM

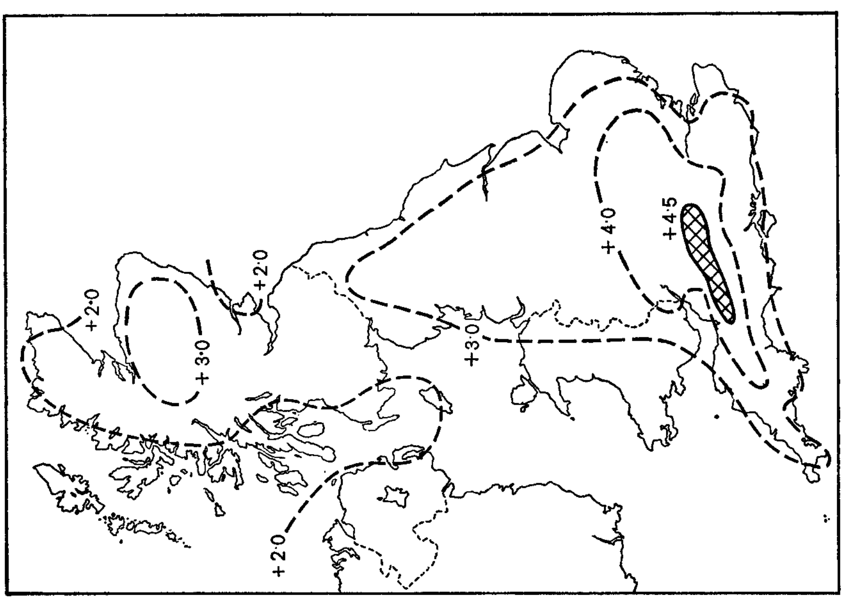

FIGURE 5—DEPARTURE FROM AVERAGE (1941–70) OF MEAN DAILY MAXIMUM TEMPERATURE FOR SUMMER (JUNE TO AUGUST) 1976 OVER THE UNITED KINGDOM

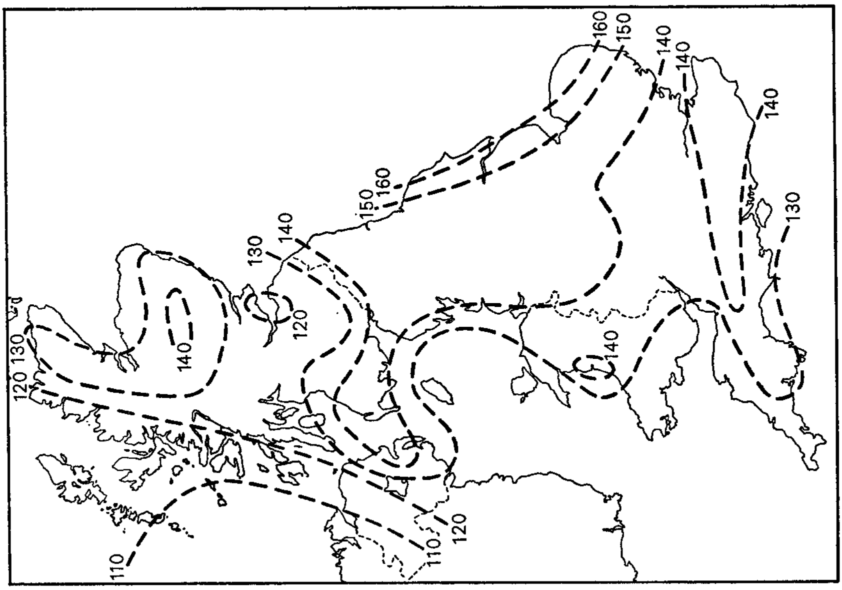

FIGURE 6—SUNSHINE DURATION AS PERCENTAGE OF AVERAGE (1941–70) FOR SUMMER (JUNE TO AUGUST) 1976 OVER THE UNITED KINGDOM

There were notable differences in the way in which soil moisture deficits* developed during the spring and summer months in 1975 and 1976. For instance, in the routine issue of the Meteorological Office SMD Bulletin for 23 April 1975 (not shown) the SMD estimates, using the grassland model as described by Grindley (1967), were small (0 to 12 mm) everywhere, largely because the preceding six months were somewhat wetter than usual. The warm dry weather which set in during May 1975 over much of England Wales, followed by a preponderance of warm dry and sunny weather in the summer, led to the development of large soil moisture deficits in England by the end of August, as may be seen in Figure 7, although deficits were mostly unremarkable in Scotland. In most years deficits generally disappear at some time during the autumn or early winter months, but following the fine summer of 1975, the autumn and winter were drier than usual and soil moisture deficits were slow to disappear, so that even by mid-February 1976 there were still small areas which were not yet at field capacity in eastern England (Figure 8). Largely as a result of the dry March and April, deficits soon began to increase again, much earlier than usual over England, so that deficits on 21 April 1976 (see Figure 9) were already larger than usual for the time of the year in much of the south, east and central parts of England, where they were mostly 25–50 mm in marked contrast with the very small deficits about the same time in April 1975. Even larger deficits built up in summer 1976 than in the previous summer; the deficits on 25 August 1976 (see Figure 10) were large everywhere in Britain, and they were near the extreme values possible in most of England. Despite the large and extensive deficits which were in existence late in August 1976, the exceptionally wet September and October brought the soil to capacity over most of Britain before the end of October 1976, much earlier than usual.

The pattern of change in evaporation (including transpiration) and soil moisture deficit during the two summers will now be described in more detail for a few representative places, using a grassland model. Figure 11 shows the end-of-month estimates of actual and potential evaporation (including transpiration)—AE and PE—at Exeter in 1975 and 1976. PE estimates, based essentially on the theory of Penman (1948), assume that moisture is non-limiting. AE is frequently and typically less than PE in the summer, when soil moisture deficits have increased sufficiently. Figure 11 shows that by the end of June 1975 there was a large difference between PE and AE and this difference remained until September. In 1976 there was already a difference between PE and AE at the end of May, and in June, July and August the difference was near the maximum possible for the grassland model, and, moreover, AE was very small. Grass and other short-rooted vegetation became essentially desiccated during this period since there was virtually no moisture in the topsoil, and little or no transpiration was possible. The position changed abruptly by the end of September 1976. A similar diagram (Figure 12) for Wyton in Cambridgeshire shows essentially the same patterns in the time-sequence of PE and AE as at Exeter.

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* The soil is at field capacity when it holds the maximum amount of water by surface tension and capillary action against gravity. The maximum amount of water retained at field capacity and also the part of this water which can be extracted from the soil by vegetation is a function of both soil and crop type. A soil moisture deficit (SMD) develops where any extraction of water from the soil by evaporation or transpiration is not compensated by rainfall or irrigation. The soil moisture deficit is in effect the amount of water needed to restore the soil to field capacity (i.e. to zero deficit).

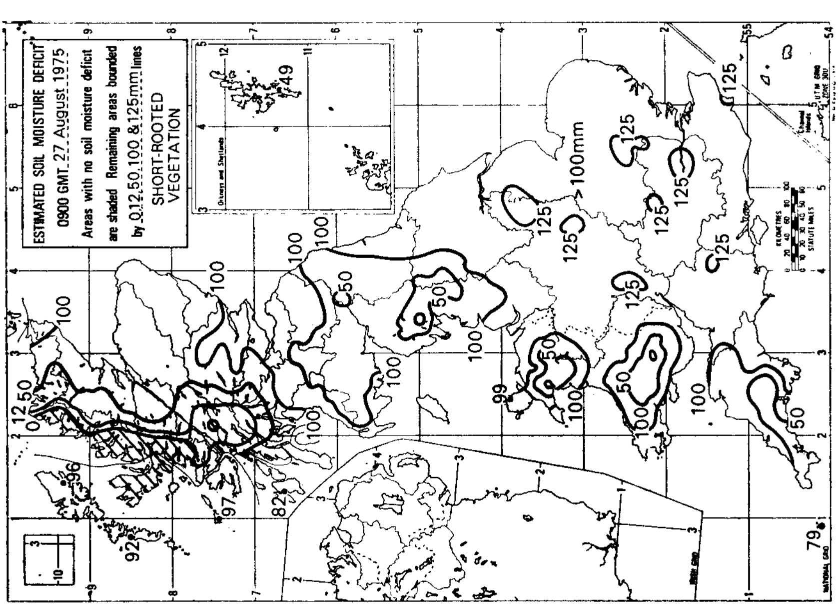

FIGURE 7—ESTIMATED SOIL MOISTURE DEFICIT (mm) (SHORT-ROOTED VEGETATION MODEL) ON 27 AUGUST 1975 IN BRITAIN

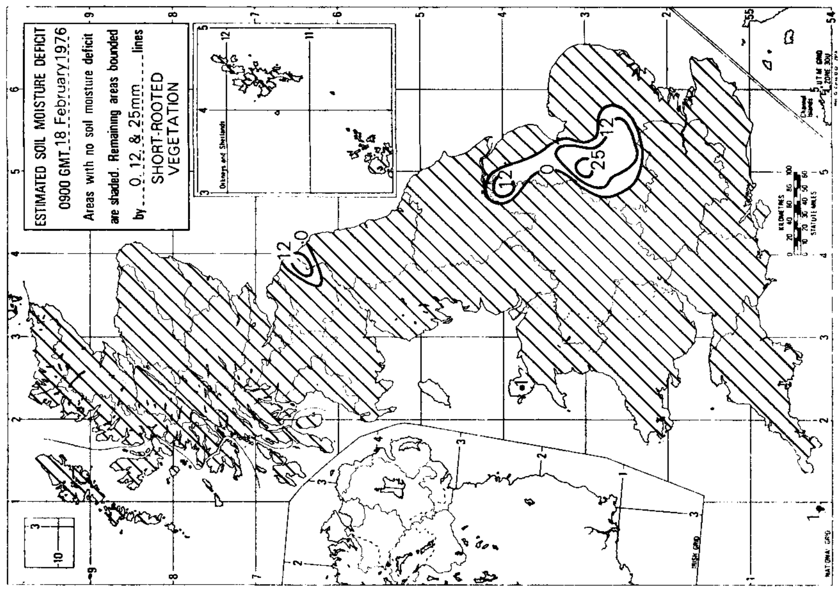

FIGURE 8—ESTIMATED SOIL MOISTURE DEFICIT (mm) (SHORT-ROOTED VEGETATION MODEL) ON 18 FEBRUARY 1976 IN BRITAIN

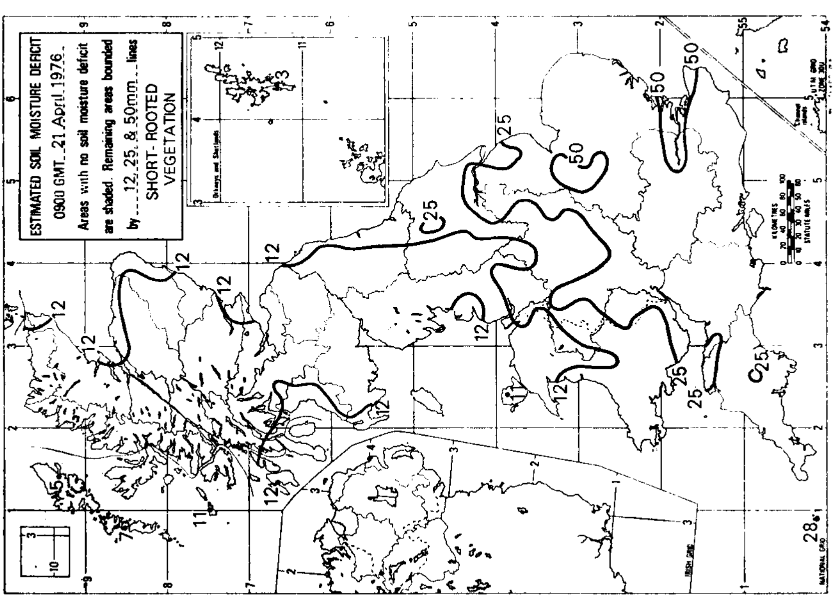

FIGURE 9—ESTIMATED SOIL MOISTURE DEFICIT (mm) (SHORT-ROOTED VEGETATION MODEL) ON 21 APRIL 1976 IN BRITAIN

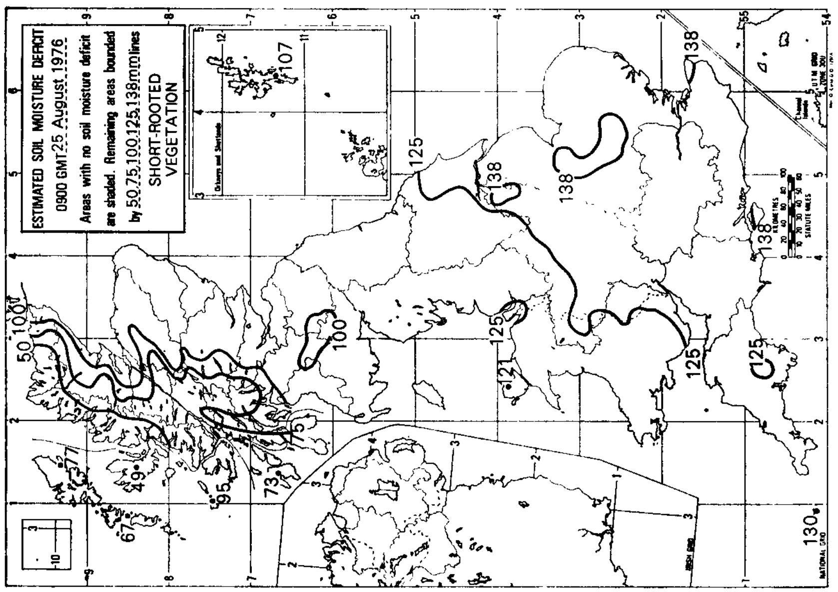

FIGURE 10—ESTIMATED SOIL MOISTURE DEFICIT (mm) (SHORT-ROOTED VEGETATION MODEL) ON 25 AUGUST 1976 IN BRITAIN

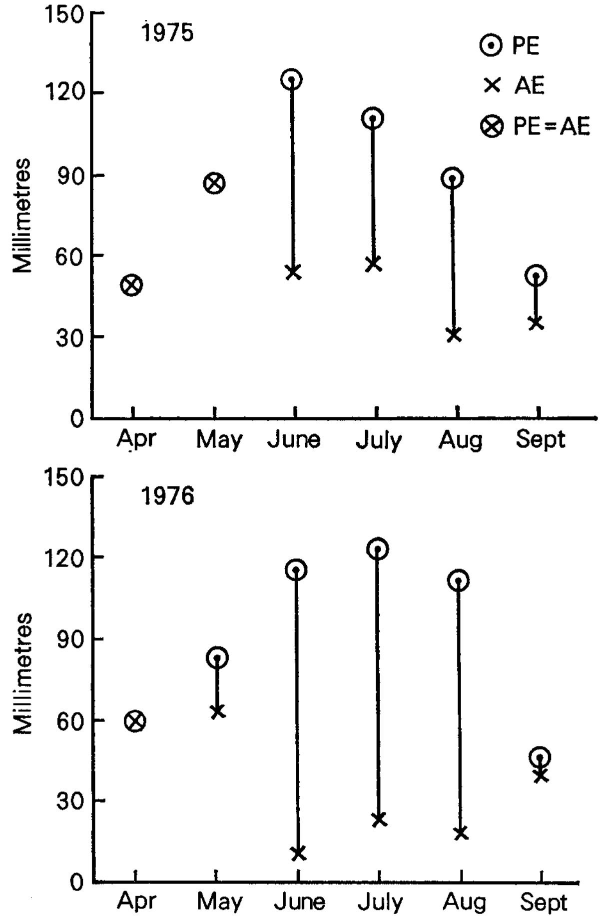

FIGURE 11—MONTHLY TOTALS (mm) OF POTENTIAL AND ACTUAL EVAPORATION (PE AND AE) (SHORT-ROOTED VEGETATION MODEL) AT EXETER FROM APRIL TO SEPTEMBER IN 1975 AND 1976

The contrast between the behaviour pattern of evaporation (including transpiration) at Plymouth and Carlisle may be seen readily in Figures 13 and 14 for 1975 and 1976 respectively. The histograms show weekly totals of PE and AE from April to September. The picture in 1976 (Figure 14) shows a very striking contrast between the two places. At Carlisle AE was clearly not seriously restricted until late July and August. On the other hand at Plymouth AE was already noticeably less than PE in May and the difference between them was pronounced from May to August. AE from short-rooted vegetation is estimated to have been almost negligible for five weeks from late July to near the end of August.

For the same stations (Plymouth and Carlisle) the soil moisture deficits, both actual SMD and potential SMD, varied throughout 1975 as shown in Figure 15. At Plymouth both types of SMD were greater than at Carlisle. This was also true in 1976, but there were other notable features (see Figure 16). At Plymouth

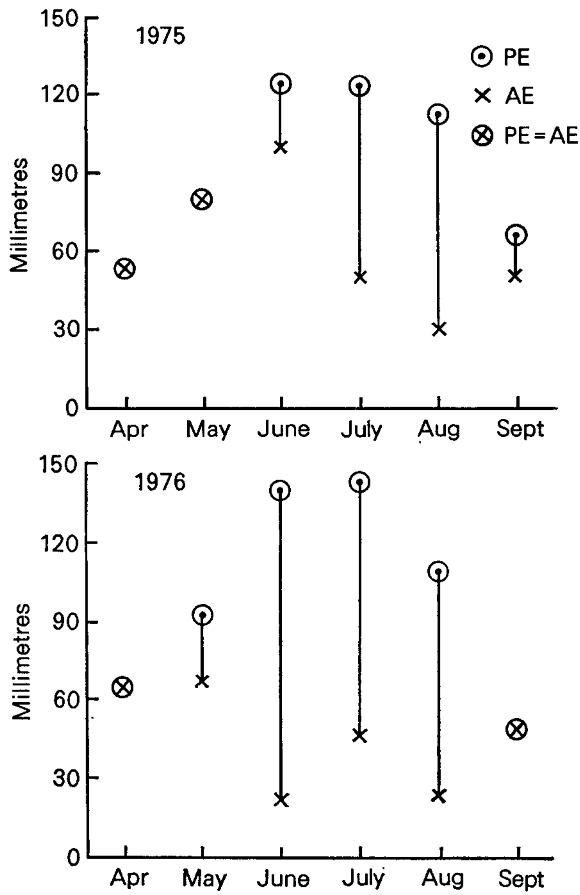

FIGURE 12—MONTHLY TOTALS (mm) OF POTENTIAL AND ACTUAL EVAPORATION (PE AND AE) (SHORT-ROOTED VEGETATION MODEL) AT WYTON FROM APRIL TO SEPTEMBER IN 1975 AND 1976

in 1976 actual SMD was between 100 mm and 130 mm from the beginning of June to mid-September and potential SMD increased to a maximum of nearly 400 mm at the end of August. At Carlisle actual and potential SMD did not markedly diverge until late July. The agricultural drought in 1976 was clearly neither as intense nor as prolonged at Carlisle as at Plymouth.

4. GENERAL

The beginning and ending of a drought are not often clear-cut and depend on the definitions used. In this article it is not possible, and probably not profitable, to attempt to pin-point the beginning, temporary interruption and the ending of the meteorological, agricultural and hydrological droughts in great detail in different parts of the United Kingdom. It is sufficient to give some broad indications. In this instance it is evident that the various types of drought were

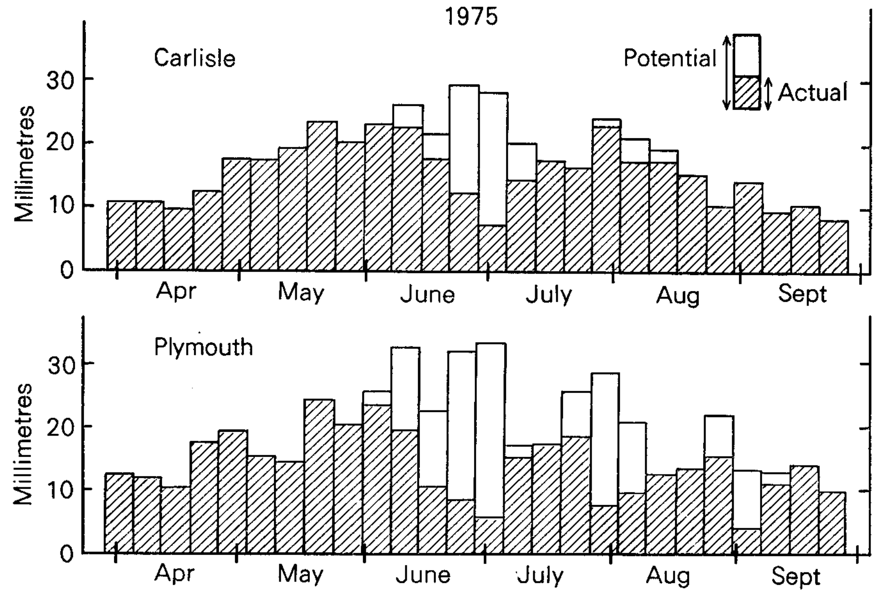

FIGURE 13—WEEKLY TOTALS (mm) OF POTENTIAL AND ACTUAL EVAPORATION (GRASSLAND MODEL) AT PLYMOUTH AND AT CARLISLE FROM APRIL TO SEPTEMBER 1975

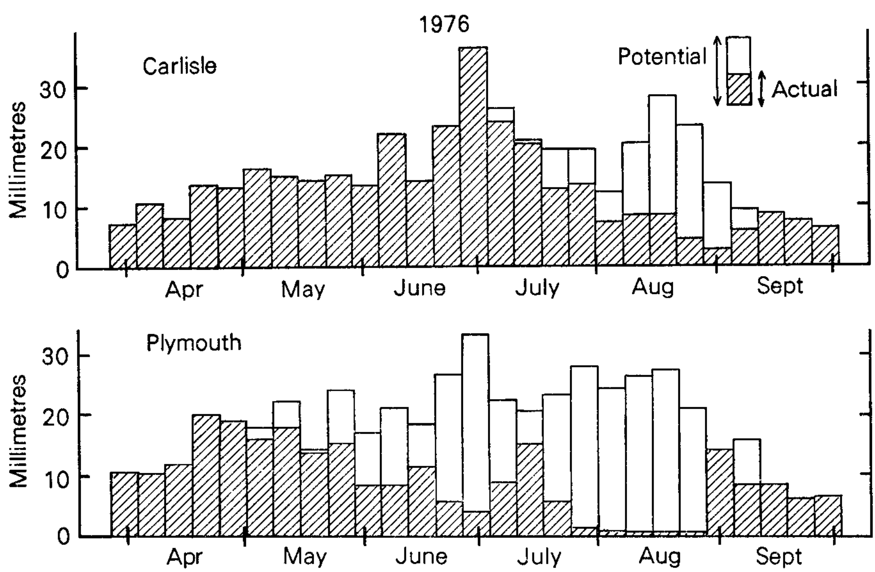

FIGURE 14—WEEKLY TOTALS (mm) OF POTENTIAL AND ACTUAL EVAPORATION (GRASSLAND MODEL) AT PLYMOUTH AND AT CARLISLE FROM APRIL TO SEPTEMBER 1976

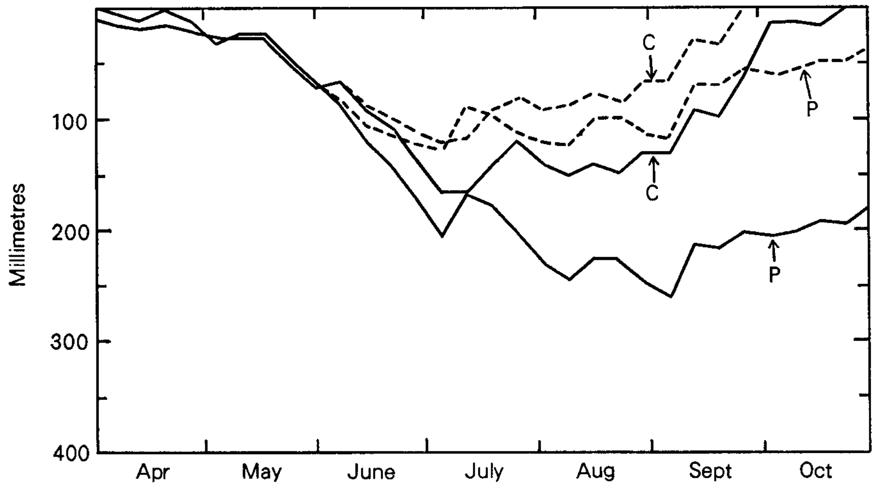

FIGURE 15—ACCUMULATED POTENTIAL AND ACTUAL SOIL MOISTURE DEFICITS (GRASSLAND MODEL) AT PLYMOUTH AND AT CARLISLE FROM APRIL TO OCTOBER 1975

P ——— Plymouth potential
P – – – – Plymouth actual
C ——— Carlisle potential
C – – – – Carlisle actual

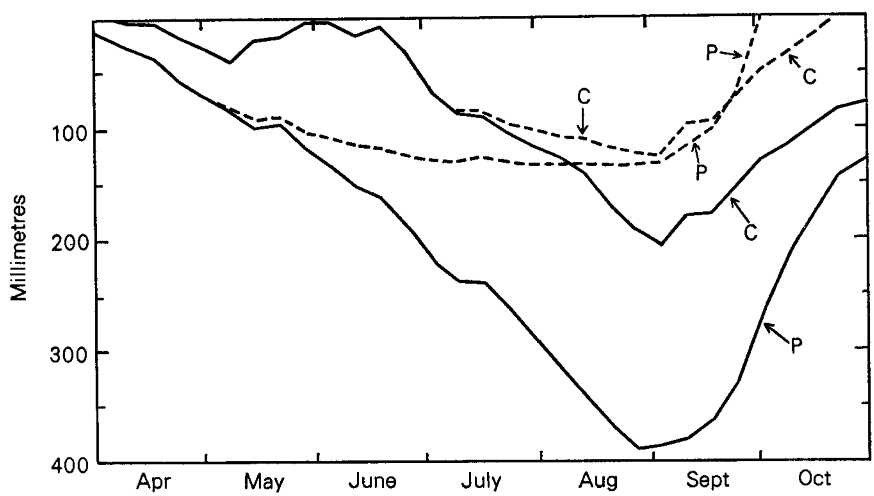

FIGURE 16—ACCUMULATED POTENTIAL AND ACTUAL SOIL MOISTURE DEFICITS (GRASSLAND MODEL) AT PLYMOUTH AND AT CARLISLE FROM APRIL TO OCTOBER 1976

P ——— Plymouth potential
P – – – – Plymouth actual
C ——— Carlisle potential
C – – – – Carlisle actual

certainly over, on the monthly time-scale and nation-wide, in September 1976, as clearly indicated by the rainfall patterns shown in Figures 1 and 2.

The ending of the main meteorological drought of the summer of 1976 occurred in the last few days of August in most parts of the United Kingdom. It was in fact rainless over much of England and Wales for several weeks in the latter part of July and most of August. In particular it was dry in many parts of South Wales, south-west and southern England for 35 to 42 days until rain was recorded on 27, 28 or 29 August. For instance, a remakable run of 42 dry days at Thorney Island (Hampshire) and Newhaven (East Sussex) ended with rain on the 27th, although the rainless spells were broken at most other places one or two days later. It again became dry nearly everywhere for about a week from 2 September, but the main meteorological drought can, with hindsight, be said to have ended in most parts in the last five days of August.

For hydrological purposes the Meteorological Office prepares soil moisture deficit maps on the basis of composite land-use in which it is assumed that any unit area consists of 50 per cent short-rooted vegetation, 30 per cent long-rooted vegetation and 20 per cent riparian. This over-simplified land-use assumption is expected to be superseded by more realistic land-use information in the near future. However, using the composite model currently in operational use, estimates of the first dates on which significant rainfall became effective for hydrological purposes were made by taking the difference between rainfall and estimated evaporation, after soil moisture deficit had been eliminated. The end of the hydrological drought is here taken arbitrarily as the dates when 5 mm of hydrologically effective rainfall (as defined) were computed to have occurred. Figure 17 shows the estimated dates of the ending of hydrological drought. The heavy rains near the end of August may be said to have broken the hydrological drought on 28–29 August over a band from south-east Wales to Norfolk, but most other places did not have significant hydrologically effective rainfall until around 10 September and a few places lasted out until early October.

The estimated accumulations of hydrologically effective rainfall (on the basis of the composite 3 tier land-use model) are shown in Figure 18. It is evident that there were large accumulations of hydrologically effective rainfall at the end of October 1976 over northern England, Wales and south-west England, with estimates of over 300 mm in some hilly areas. Meteorologists are well aware of the complexity of the hydrological problem in relation to the crudity of the existing operational soil moisture deficit model and the paucity of data, so that the details in Figure 18 have considerable uncertainty, although the broad picture is unlikely to be far from the truth. It is not surprising, in the light of the estimates in Figure 18, that the very low water levels in reservoirs in most drought-stricken areas late in August 1976 rose rapidly, particularly in Wales, south-west and north England, and also that flooding followed so closely on the heels of the drought in many places.

The effect of drought on agriculture depends in a complex way on many factors, including plant-type, state of crop, root-depth, soil-type, etc: the effectiveness of rainfall in ending agricultural drought also depends on many factors. Breaks in a long agricultural drought can occur fairly easily, especially with some short-rooted vegetation which may benefit almost immediately after the onset of significant rainfall. However, late in the growing season, when transpired moisture normally decreases, drought can be considered to have come

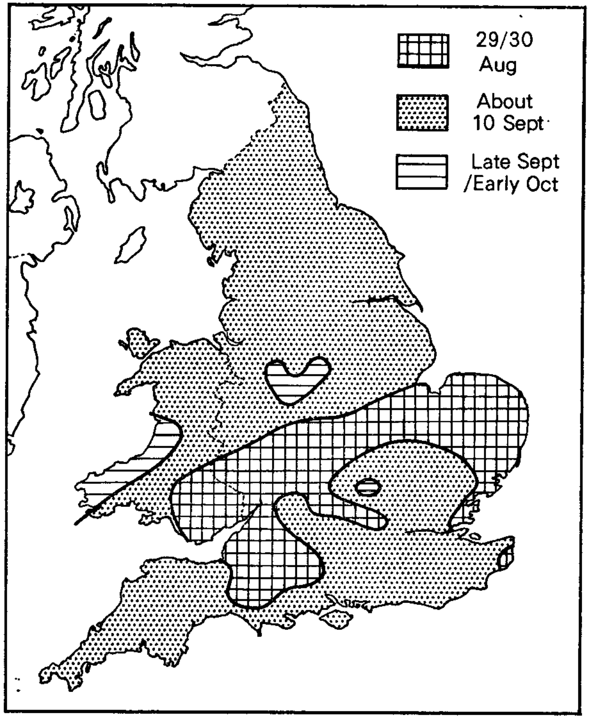

FIGURE 17—ESTIMATED DATE OF END OF 1975/76 DROUGHT IN ENGLAND AND WALES: DATE BY WHICH EFFECTIVE RAINFALL ACCUMULATED TO 5 mm (COMPOSITE LAND-USE MODEL)

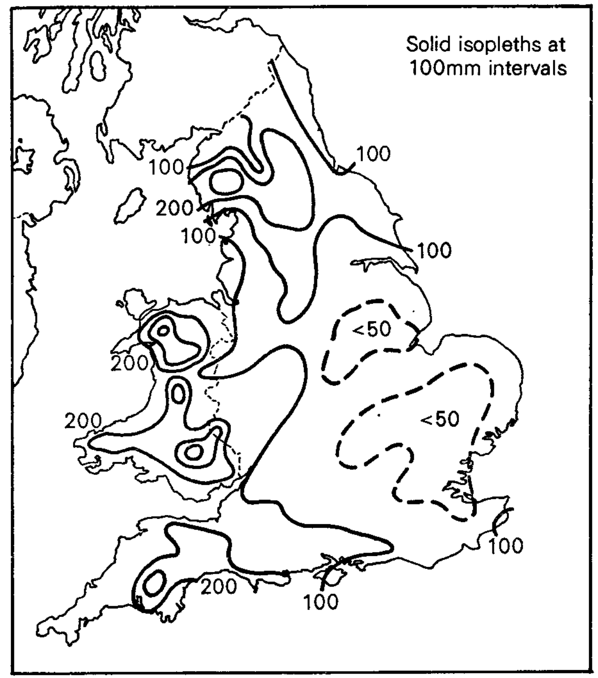

FIGURE 18—ACCUMULATED EFFECTIVE RAINFALL (mm) FROM AUGUST TO OCTOBER 1976 OVER ENGLAND AND WALES (COMPOSITE LAND-USE MODEL): ISOPLETHS AT 100 mm INTERVALS

to an end on the date following which accumulated rainfall becomes and remains greater than accumulated transpiration. The dates of ending of the agricultural drought of 1976 in different parts of the country were not later than the dates for the ending of the hydrological drought which are estimated in Figure 17; the dates were probably about 28 August in the areas from south-east Wales to Norfolk shown in Figure 17 and probably a few days before 10 September in most other parts of England and Wales. A complicated pattern of estimated dates for the ending of the agricultural drought in different places could be derived on the basis of various assumptions, but it would scarcely be justified in view of the great variability of rainfall in space and time, as well as other factors with large uncertainties.

ACKNOWLEDGEMENTS

I would like to thank colleagues who prepared the material and also Miss M. G. Roy and Mr J. Grindley for helpful discussions.

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A SYNOPTIC CLIMATOLOGIST'S VIEWPOINT OF THE 1975/76 DROUGHT

By R. A. S. RATCLIFFE

SUMMARY

The drought is shown to be related to a variety of factors including unusual coldness in the North Pacific Ocean and over Canada in the winter half-year, stronger than usual upper winds in the central Pacific and the quasi-biennial oscillation. Feedback reactions involving Atlantic sea temperatures and the drought itself helped to maintain the atmospheric mode which appeared to show considerable inertia. The final breakdown was initiated by strong arctic cooling in early autumn which precipitated a southward jump in the latitude of the main jet stream.

All meteorologists will be aware that it is not possible to indicate a definite cause for an event such as the 1975/76 drought. It arose as a result of many interrelated factors and the most that one can do is to draw attention to some important anomalies and perhaps suggest how they may have come together to produce the drought situation.

The first point to note is that the four winters 1971–74 were all mild, not only in Britain, but over most of Europe as far east as about Moscow. As a result the coldest air was displaced to the western side of the hemisphere and there were negative anomalies of 1000/500 mb thickness over Canada and the North Pacific during those winters compared to the 1951–70 averages (Painting, 1976).

The second interesting fact is that the jet stream in the east Atlantic/European sector was displaced between 5 and 10 degrees of latitude northwards over the 16 months' drought period compared to the same 1951–70 averaging period—see Figure 1. This northward movement occurred in the late autumn of 1974 and, on a monthly mean basis, was persistent with only short-period variations until September 1976, suggesting a good deal of inertia in the atmosphere over this 16 month period (Morris and Ratcliffe, 1976).

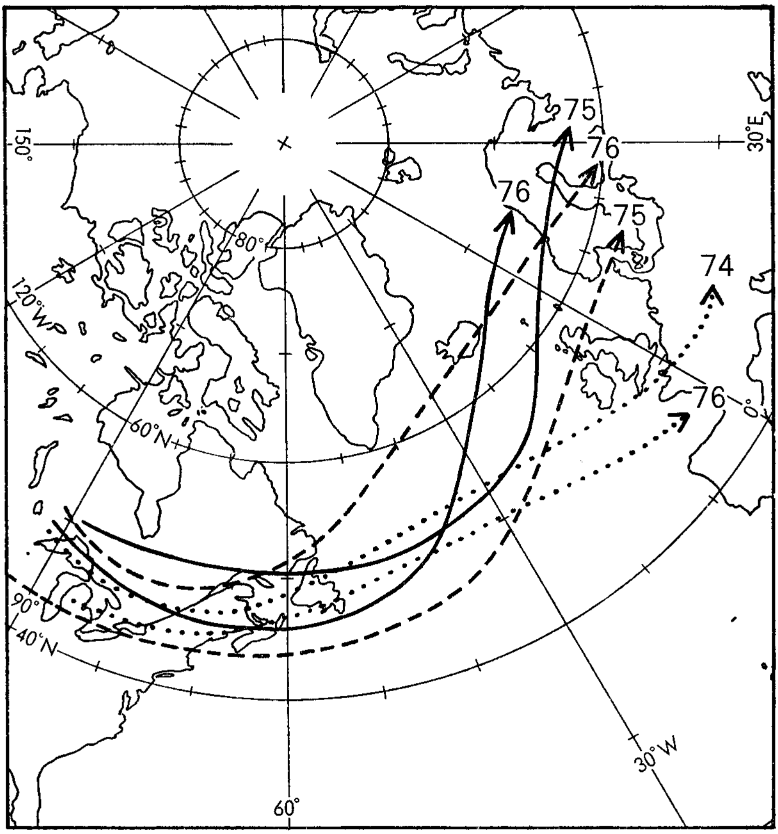

FIGURE 1—JET STREAM POSITIONS FOR SUMMER (1975 AND 1976), WINTER (1975 AND 1976) AND AUTUMN (1974 AND 1976)

Summer ——— Winter - - - - Autumn . . . . . .

Thirdly it is noticeable that the Pacific Ocean north of 40°N was continuously colder than usual, especially from spring 1975 to summer 1976 inclusive. Figure 2 shows the mean anomaly of sea temperature per 5° × 5° latitude/longitude quadrangle over the whole North Pacific north of 40°N since the summer of 1974. It is probable that the coldness of the ocean was partly due to the coldness of the winters of the early 1970s in that sector of the hemisphere: in particular ice was excessive in the North Pacific in late winter 1975 and 1976 and its melting may well have been partly responsible for the sharp increase of negative sea temperature anomalies in the springs and summers of those years.

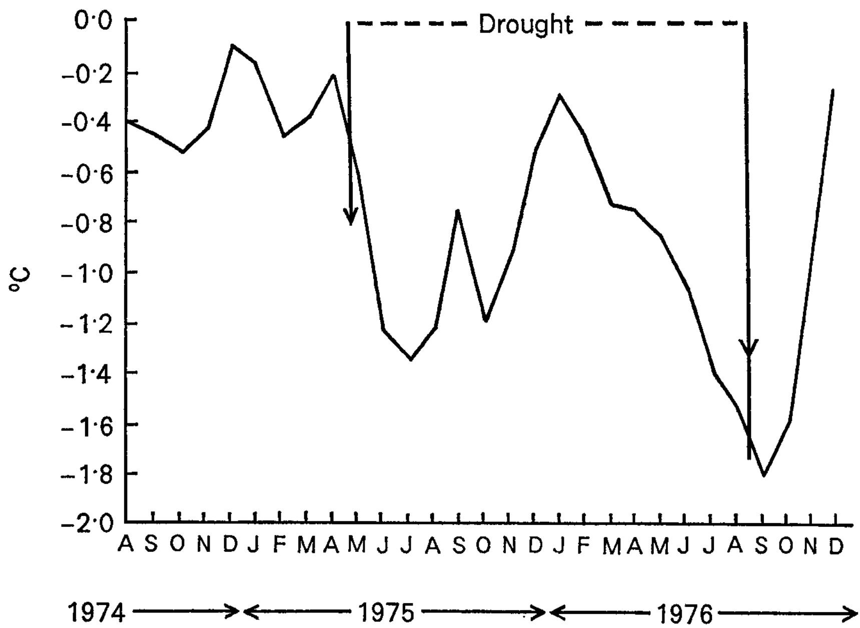

FIGURE 2—NORTH PACIFIC SEA TEMPERATURE ANOMALIES—MEAN ANOMALY NORTH OF 40°N AND FROM 150°E TO AMERICAN COAST, RELATIVE TO LONG-PERIOD NORMAL

Normal values from US Oceanographic Office (1969)

The 500 mb flow was computed for the drought period over the hemisphere north of 15°N and compared with the average at each grid point on the standard grid. There were three areas where the flow was significantly different (at the 5 per cent level using 'Student's' *t*-test) from average. Two of these were, as one would expect, in regions to the north and south of the British Isles where the flow was significantly stronger and weaker respectively, reflecting the northward displacement of the jet stream. The third area was at 45°N in the east central Pacific between 150 and 180°W: here the mean flow was 4 m s^{-1} stronger than the average of 17 m s^{-1}, an enhancement of the flow by more than 20 per cent over the 16 months as a whole. The time series of the anomalous flow at the mid point of the area is shown in Figure 3. Since there was also considerable enhancement of the 1000/500 mb thickness gradient from north to south in the Pacific during the drought, it seems highly probable that the cold water north of 40°N was a factor contributing strongly to the enhanced flow especially as sea temperatures south of 40°N were not in general colder than usual. The relationship between strong flow in the central Pacific near 45°N and weather over Britain was examined more closely by selecting the 14 summers since 1873 when surface flow between 35 and 55°N and 150/180°W was noticeably enhanced, and comparing with the 8 summers when flow was noticeably decreased in the same area. The mean summer rainfall over England and Wales for the 'enhanced' sample was 196 mm while that for the 'decreased' sample was 265 mm, a difference significant at the 5 per cent level. The 'enhanced' sample mean was significantly more anticyclonic than the 'decreased' sample while 12 of the 14 'enhanced' sample years had good summers over Britain compared with only one good summer in the 'decreased' sample, as measured by the index of cyclonicity (see Murray and Lewis, 1966).

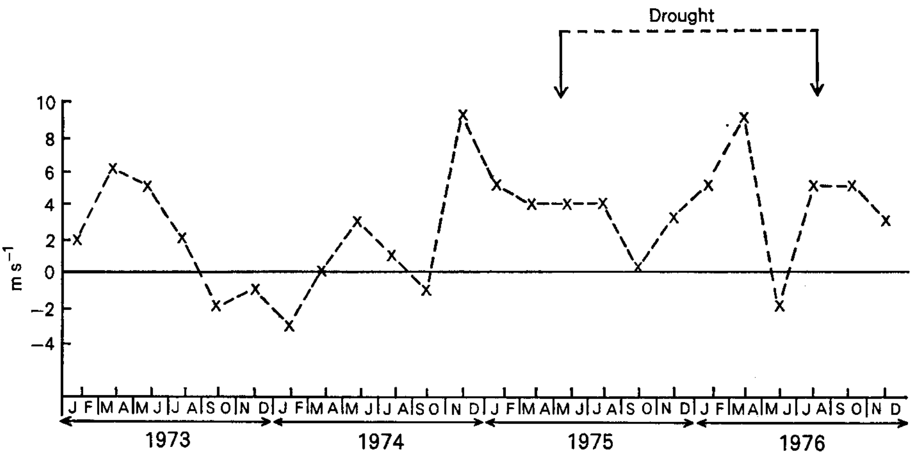

FIGURE 3—ANOMALIES OF THE 500 mb ZONAL COMPONENT OF GEOSTROPHIC WIND AT 45°N 170°W RELATIVE TO 1951–70 NORMAL (17 m s^{-1})

Two-month seasonal values

The enhanced Pacific flow and the winter coldness over Canada appear to have been important factors in the drought situation. The hemispheric 500 mb flow pattern can be resolved into its major orthogonal component patterns by eigenvector methods. One can then select the component patterns which represent enhanced Pacific flow and enhanced flow around the east Canadian trough and compound them to see what are the normal downstream consequences. For the two month season January–February the resulting 500 mb anomaly pattern is shown in Figure 4 which may be compared with the actual anomaly pattern for January–February 1976 (Figure 5). There is clearly a good deal of similarity indicating a connection between the enhanced Pacific and Canadian flow and the anomalous ridge over western Europe. In fact the technique is able to show that what happened over Europe in the winter half-year 1975/76 was the normal concomitant of stronger than usual flow in the Pacific and over eastern Canada. In summer, when wave lengths are shorter, a 500 mb ridge developed over east Canada in both 1975 and 1976 so that the east Canadian flow was decreased. Figure 6 shows the 500 mb anomaly pattern which results from adding together those flow patterns which represent this state of affairs, which compares closely with the actual anomaly pattern for summer 1976 (Figure 7). The anomaly pattern for summer 1975 was also very similar.

In addition to the factors already mentioned, there were almost certainly feedback reactions acting on the atmosphere through the Atlantic sea temperature anomaly patterns during the drought. In the summers of both 1975 and 1976, ocean temperatures to the east and south-east of Newfoundland were in general colder than usual. Ratcliffe and Murray (1970) showed that such patterns of sea temperature are normally followed by rather blocked anticyclonic situations over Britain. The cold ocean itself may well have owed its origin to the unusual winter and spring coldness over east Canada which, with the normal prevailing westerly circulation, would be likely to cool the adjacent ocean gradually. In the winter half-year 1975/76 the Atlantic was colder than usual north of about 55°N owing perhaps to the excessive cyclonic activity south of Iceland. Such a sea temperature anomaly pattern has been shown to favour an anomalous ridge extending towards Britain from the Azores anti-cyclone much as actually happened in the winter of 1975/76.

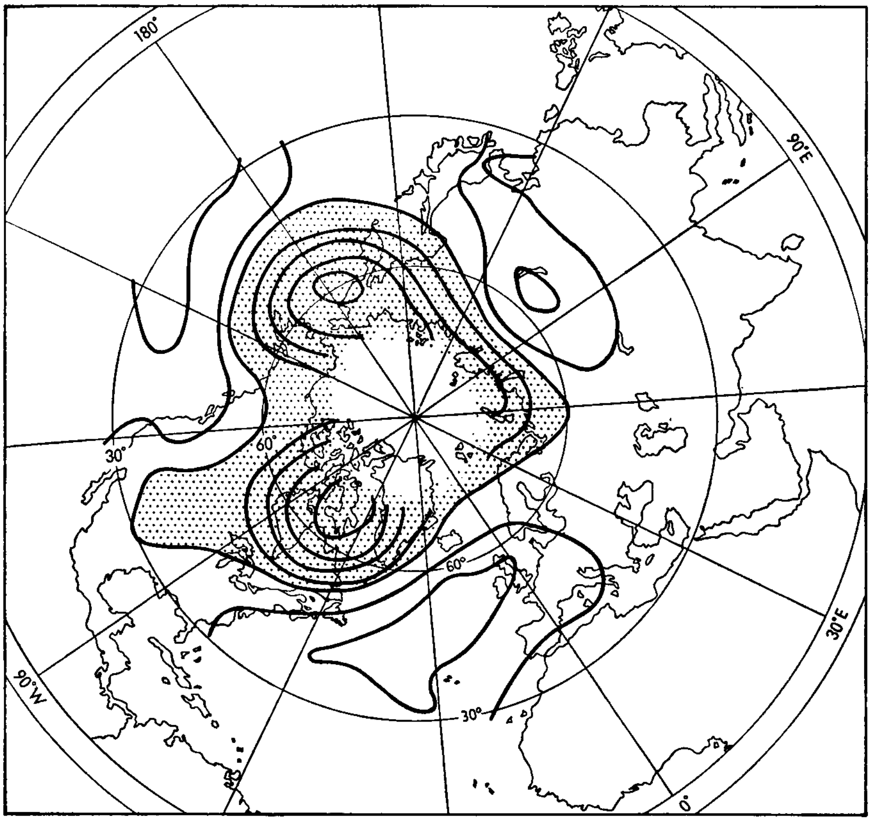

FIGURE 4—COMPOUND OF 500 mb EIGENVECTOR PATTERNS SHOWING ENHANCED PACIFIC AND ENHANCED CANADIAN TROUGH: TWO-MONTH SEASON, JANUARY–FEBRUARY

(arbitrary units) (negative values shaded)

Yet another interesting fact is that most of the drought period was associated with the westerly phase of tropical stratospheric winds (QBO). This phase started in spring 1975 and continued until early summer 1976. Ebdon (1975) has shown that the Atlantic jet stream is usually further north (see Figure 1) in westerly compared to easterly QBO phases.

About late spring 1976 the broad-scale meteorological situation, which had shown considerable inertia and persistence for over a year, was showing signs of a change. Extra baroclinicity became apparent in the upper flow in mid Atlantic near 50°N and the main jet stream had reached an extremely far north

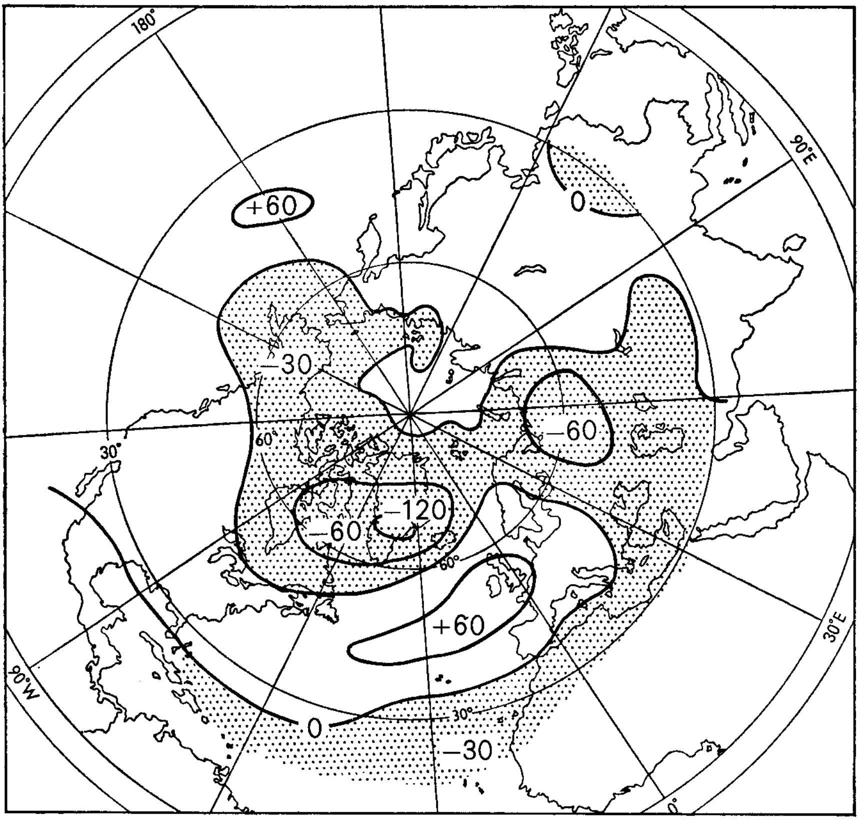

FIGURE 5—ANOMALIES OF 500 mb GEOPOTENTIAL SURFACE (gpm) RELATIVE TO 1951–70 NORMAL: TWO-MONTH SEASON JANUARY–FEBRUARY 1976

(negative values shaded)

position near Iceland. The westerly phase of the QBO was also about to end and indeed all seemed set for a breakdown of the long-standing regime and a transfer of the jet stream to near 50°N. The upper flow in the Pacific at 45°N had also weakened (see Figure 3). All the statistical evidence, on which the experimental summer forecast for 1976 prepared in the Synoptic Climatology Branch of the Meteorological Office was based, suggested a breakdown to a normal unsettled summer pattern. Why did this not happen?

It is my view that the weather did not break at this stage primarily because of the drought itself (perhaps aided by the resurgence of Pacific flow—see Figure 3). It has been demonstrated (Ratcliffe, 1976) that the excessive dryness of the ground in the late spring and early summer resulted in something like 80–90 per cent of incoming solar radiation being available for heating the ground and hence the air, compared with about 50 per cent in the normal year (the other 50 per cent is used in evaporation and transpiration). The favourable anticyclonic

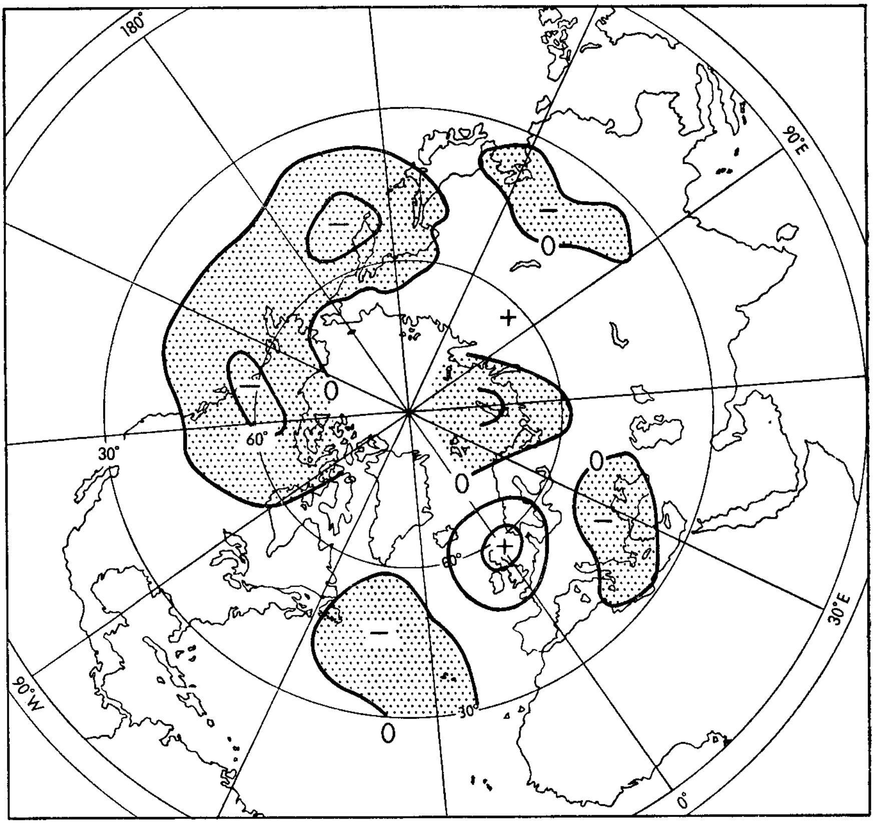

FIGURE 6—COMPOUND OF 500 mb EIGENVECTOR PATTERNS SHOWING ENHANCED PACIFIC AND WEAK CANADIAN TROUGH: TWO-MONTH SEASON, JULY–AUGUST

(arbitrary units) (negative values shaded)

situation which developed around 20 June thus resulted in very high temperatures and also exceptionally high 1000/500 mb thicknesses being built up over Britain and western Europe. The thickness anomaly over Britain for mid-June to mid-July was in fact about twice that in any other comparable period since the war. This factor may have played a part in keeping Britain on the warm side of the main baroclinic zone and this caused frontal systems to slide away northwards just to the west of Ireland, effectively maintaining the fine weather and drought until the end of August.

With the imminent onset of arctic cooling, the extreme northern position of the jet stream near Iceland could not be maintained much longer. The intensification of thermal gradient noted in the early summer in mid Atlantic around

50°N had, if anything, increased and the most likely event appeared to be a discontinuous evolution so that the main flow would be transferred from the latitude of Iceland to about 50°N across the Atlantic. This change was initiated

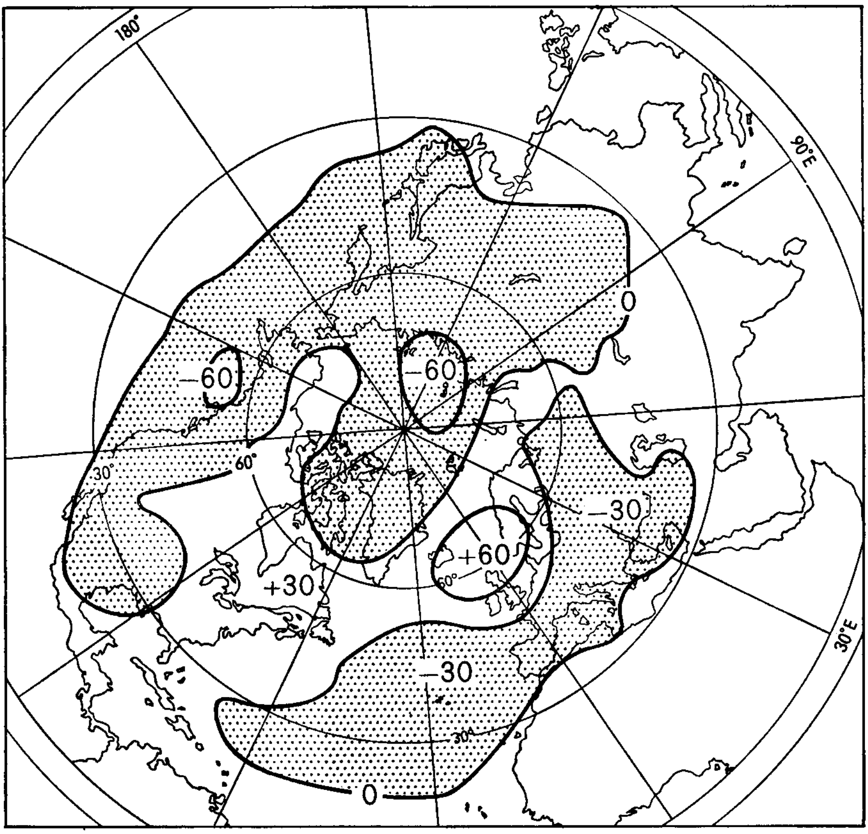

FIGURE 7—ANOMALIES OF 500 mb GEOPOTENTIAL SURFACE (gpm) RELATIVE TO 1951–70 NORMAL: TWO-MONTH SEASON, JULY–AUGUST 1976

(negatives values shaded)

by an outbreak of cold air from the Arctic into northern Canada in late August which started a major retrogression of the arctic flow pattern and precipitated a cold plunge down the North Sea which eventually formed a cold trough west of Biscay and resulted in the main upper flow becoming established across the Atlantic near 50°N (Ratcliffe, 1977). This development was unusual and against the normal climatology since there is often strong persistence of weather in Britain from August to September: in fact an increase of wave length is normal as the general circulation begins its seasonal strengthening. The change of regime resulted in a shortening of wave length and hence was unusual for the season. Once this major change in the circulation had taken place, the excessive rains of September and October followed. One reason for their exceptional nature was undoubtedly the high sea temperature (up to 2°C above average) which existed to the south-west of the British Isles owing to the long hot summer (Figure 8). Such high ocean temperatures enabled more moisture and more sensible heat to be transferred to the atmosphere than is usual and, given the favourable synoptic situation provided by the upper trough, greatly enhanced the rain-producing process. The abnormal gradient of sea temperature existing between about 40°N 30°W and 35°N 20°W (see Figure 8) is also believed to be a factor aiding cyclonic development to the south-west of Britain. To some extent at least, therefore, it would appear that the exceptional autumn rains of 1976 had their origin in the exceptional summer.

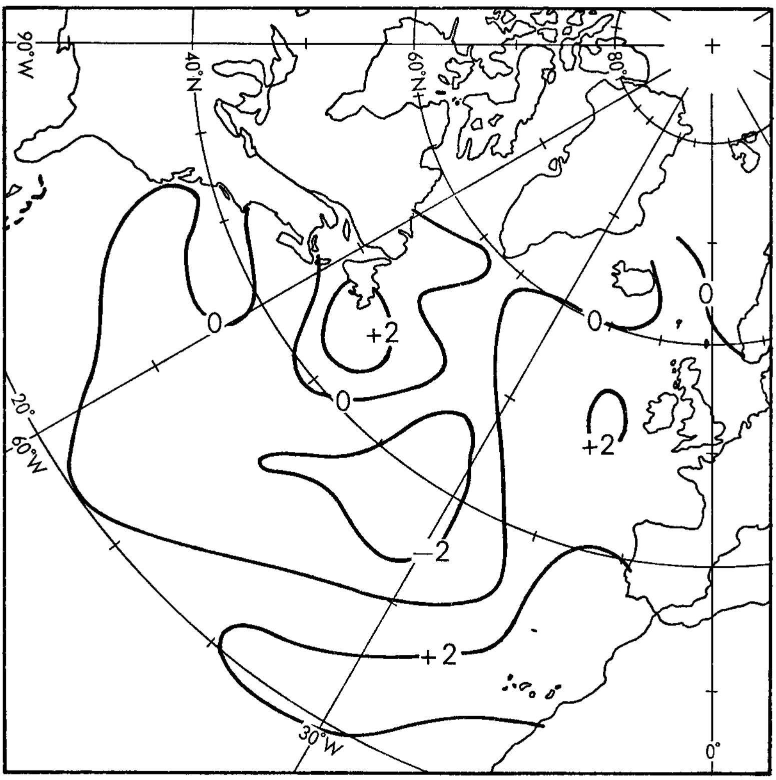

FIGURE 8—NORTH ATLANTIC SEA TEMPERATURE ANOMALY (°C) 3–7 SEPTEMBER 1976 RELATIVE TO LONG-PERIOD NORMAL

(US Hydrographic Office (1967))

CONCLUSION

The drought is seen as part of a continuous evolution of the hemispheric circulation over a period of at least the two years from autumn 1974 to autumn 1976. After the succession of mild European winters of the early 1970s with the main hemispheric coldness transferred to Canada and the North Pacific, the east Atlantic jet stream moved north and its apparent inertia aided by feedbacks from the Atlantic sea temperature and perhaps also the excess ice cover in the North Pacific, maintained the situation. Another exceptional feedback may have arisen because of the extra sensible heating available to the atmosphere in the summer due to the greatly decreased evaporation and transpiration. The eventual break came with strong seasonal cooling in the Arctic initiating a discontinuous southward jump of the jet stream.

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ATMOSPHERIC CIRCULATION DURING THE SEVERE DROUGHT OF 1975/76

By M. K. MILES

SUMMARY

The anomalies of the northern hemisphere circulation at the surface and 500 mb for the 16 months of the drought (i.e. May 1975 to August 1976) are shown and discussed. It appears that the marked absence of rain was due primarily to a deficiency of cyclonic types over the British Isles. The association of the anomalous circulation over the British Isles with conditions over the North Pacific Ocean is discussed.

1. INTRODUCTION

The 5 years 1971–75 are the driest over England and Wales since 1898–1902 but the 16 months from May 1975 are the driest in the record of England and Wales rainfall back to 1727. Table I shows the nearest approaches to this for 12 month and 16 month periods back to 1820.

TABLE I—RAINFALL TOTALS FOR ENGLAND AND WALES FOR THE 12 MONTH PERIOD BEGINNING SEPTEMBER 1975 AND FOR THE 16 MONTH PERIOD BEGINNING MAY 1975 WITH SOME EARLIER DRY 12 AND 16 MONTH PERIODS

	12 months			16 months	
Year	1st month	Rainfall	Year	1st month	Rainfall
		mm			*mm*
1975/76	Sept.	571	1975/76	May	757
1854/55	Feb.	618	1933/34	Feb.	811
1920/21	Nov.	618	1933/34	Apr.	855
1887/88	Feb.	624	1887/88	Feb.	857
1963/64	Dec.	637	1920/21	Aug.	880

The 16 month drought included two summers, which perhaps makes it of unusual interest to agriculturists.

This article examines the atmospheric circulation over most of the northern hemisphere for the 16 month period from May 1975 to August 1976 during which there was only 64 per cent of the 1916–50 average rainfall over England and Wales.

2. THE HEMISPHERIC GEOSTROPHIC CIRCULATION

Figure 1 shows the surface pressure distribution and the anomalies from the 1951–70 average and Figure 2 shows the geopotential of the 500 mb surface and anomalies from the 1951–70 average. In each case the largest anomaly is over the British Isles. Even for a 12 month period these anomalies are greater than three standard deviations from the mean so for a 16 month period they represent an occurrence with an expectation of something less than about 1 in 500.

Departures of three standard deviations occur somewhere on annual maps about once each year but at any given grid point this means once in 300 years. The negative anomalies over Greenland are also just about over three standard deviations from the mean. They are probably a dynamical consequence of the circulation pattern which led to the positive anomalies over the British Isles.

The mean strength of the 500 mb zonal flow for the hemisphere in the latitude band 35–55°N where it is on average strongest was very little different from average. It was above average over the Pacific and below average in all other sectors. The zonal speed in the latitude band 55–75°N was about 15 per cent above the average. It was near average in the Pacific sector and above average in all other sectors. This means that the cyclonic shear of the 500 mb circumpolar circulation was generally below average north of the belt of maximum flow.

The meridional index of the surface flow as described by Miles (1976) was below average for the latitude band 35–55°N and about the same amount above average for the band 55–75°N. For annual means these anomalies would represent quite small deviations.

The latitude of the circumpolar flow at 500 mb was very near the average for all sectors except that between 30°W and 30°E. Here it was north of the average position reaching a maximum displacement of over 10° latitude near the Greenwich meridian. The mean meridional profile of the west–east component of the flow is shown in Figure 3 for longitudes 20°W to 10°E inclusive. Instead of a maximum near 50°N there is a rather broad one near 60°N leading to a reversal of the usual cyclonic shear over the British Isles.

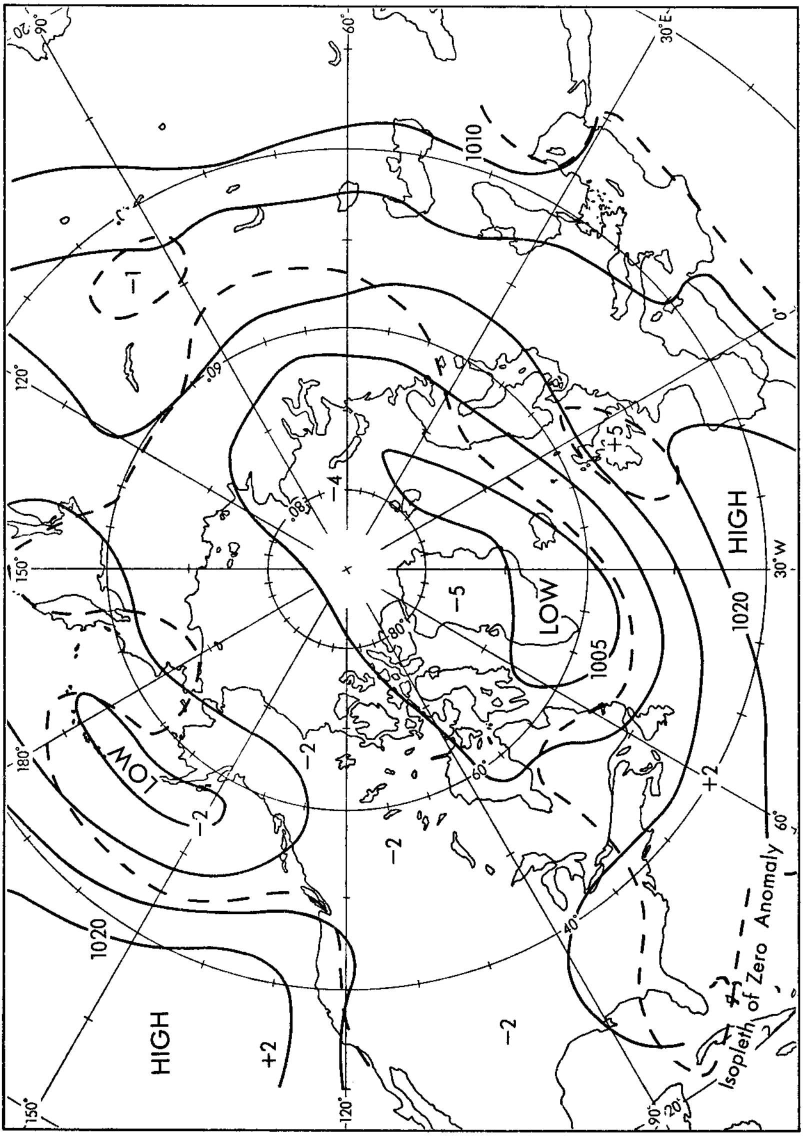

FIGURE 1—ISOPLETHS OF SURFACE PRESSURE AND ANOMALIES FROM THE 1951–70 AVERAGE IN MILLIBARS DURING THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE

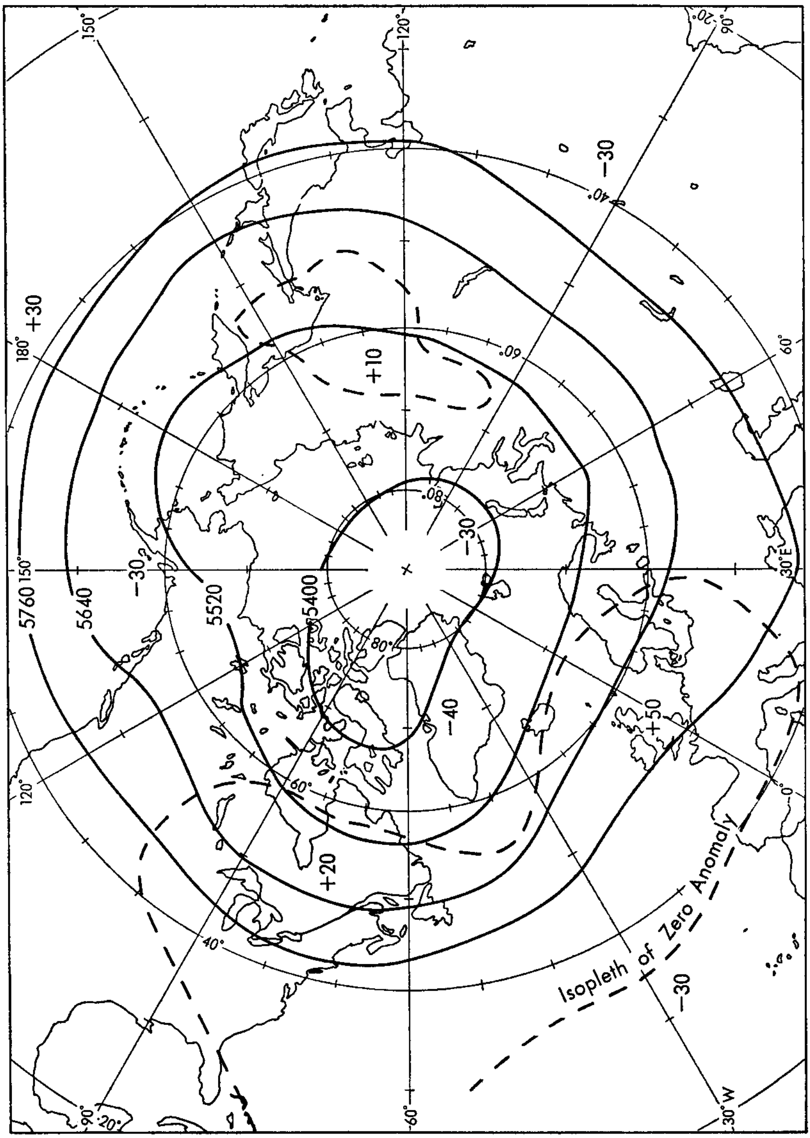

FIGURE 2—GEOPOTENTIAL OF THE 500 mb SURFACE AND ANOMALIES FROM THE 1951–70 AVERAGE DURING THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE (gpm)

This northward displacement of the maximum flow at 500 mb is an indicator that Atlantic cyclonic systems, of which there was no shortage during this period were turning left more markedly than usual as they approached the British Isles. The cyclonicity index described by Murray and Lewis (1966)

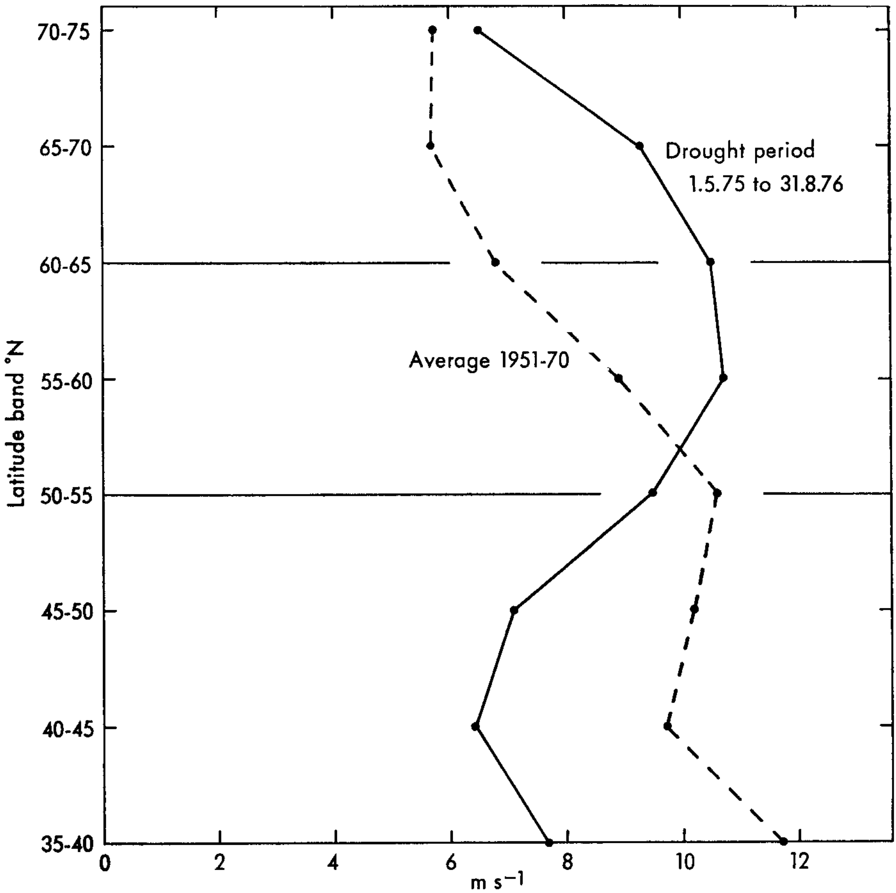

FIGURE 3—MERIDIONAL PROFILE OF WEST–EAST COMPONENT OF GEOSTROPHIC WIND AT 500 mb BETWEEN 20°W AND 10°E FOR THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE

shows that cyclonic types were much below average frequency over the British Isles. The index was, as Figure 4 shows, below the long-period average in 13 of the 16 months which is an event which should not occur by chance more often than once every few hundred years. This index is strongly correlated with England and Wales rainfall and its low value suggests that the large rainfall deficit during the drought is mainly to be ascribed to the lack of cyclonic types over the British Isles. Whether the increasing dryness of the ground as the drought continued was a further factor is a matter perhaps deserving of special study.

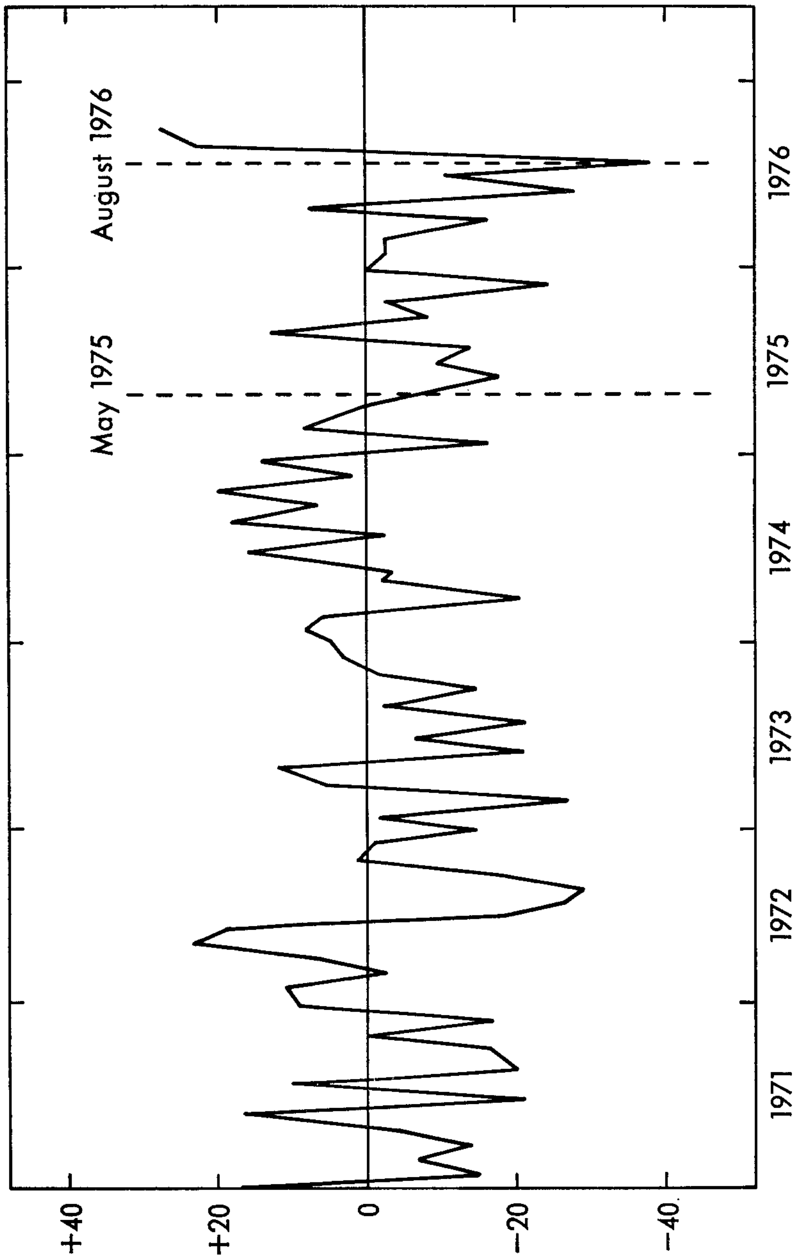

FIGURE 4—MONTHLY ANOMALIES OF THE CYCLONICITY INDEX FOR THE BRITISH ISLES

During the last three months of the drought when this effect would have been at its strongest the rainfall over England and Wales was about 20 mm less than that indicated by the regression line of rainfall on cyclonicity index. This is well within the statistical expectation and does not require or preclude the invocation of additional or unusual factors.

Figure 5 shows the distribution of the 1000/500 mb thickness and the anomalies from the 1951–70 average. The distribution is quite near average over the British Isles. The most unusual zone is in the west Pacific where the occurrence of anomaly centres of +30 gpm and −30 gpm on almost the same meridian indicates a 20 per cent increase in thermal wind. The Pacific was the only sector where the thermal wind in the latitude band 35–55°N was above average: the hemispheric mean was about 0·1 m s^{-1} below average. The surface westerly component in this band was about 0·1 m s^{-1} above the average—hence the near-average 500 mb westerly component in this band.

3. The location and intensity of the mean troughs and ridges at 500 mb

Figure 6 allows us to see how the mean location of the main troughs and ridges during the 16 month period differs from the 1951–70 average at two latitudes. At 60°N the broad trough usually located over north-east Asia was displaced into the eastern Pacific. The ridge usually near the Rockies was less intense and displaced a little east. The trough over eastern Canada was slightly more intense and geopotentials were lower than usual east of the axis. The most marked intensification was of the ridge normally over southern Norway. It was also located nearly 10° longitude west of the average position. There was thus a small reduction in the usual spacing between the Rockies ridge and that near the British Isles. This is apparently inconsistent with the enhanced zonal flow (about 20 per cent above average) at this latitude in this sector and indicates that there was probably a considerable departure from the implied assumption of constant absolute vorticity.

At 45°N the east Asian trough was a little more intense but in about the average position. The Rockies ridge and Canadian trough are also not far from their average location, but again the east Atlantic ridge is more intense and so also is the east European trough.

Generally one could summarize the wave pattern at 500 mb during the period in the statement that most features tended to be a little east of their average location (determined for the 20 years 1951–70) and there was exceptional intensification of the ridge near the British Isles.

4. Other persistent features during the drought

The average sea surface temperature of the North Pacific for the past two or three years has been below the long-term average. Figure 7 shows the distribution of sea surface temperature in both North Atlantic and North Pacific for the 16 months of the drought. It may not be coincidence that the thermal wind over the Pacific has been above average during most seasons since 1973 as can be seen from Figure 8. An examination of the association of these features with the drought is contained in an article by Ratcliffe (1977).

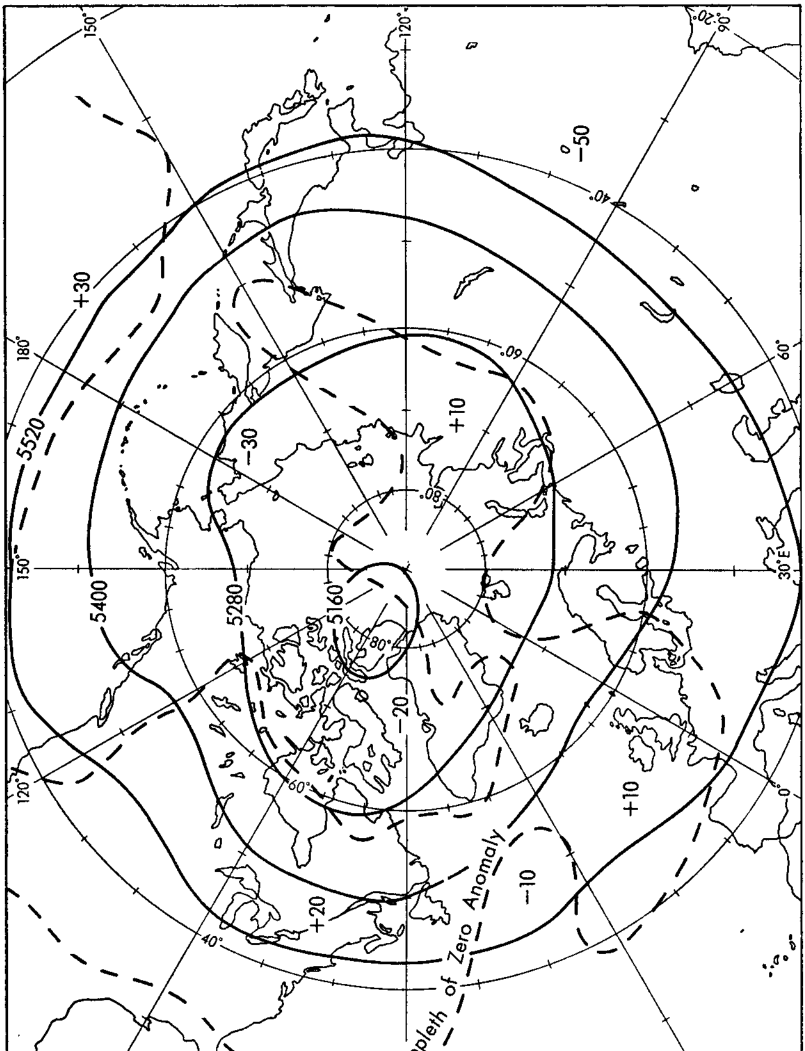

FIGURE 5—THE 1000–500 mb THICKNESS AND ANOMALIES FROM THE 1951–70 AVERAGE DURING THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE (gpm)

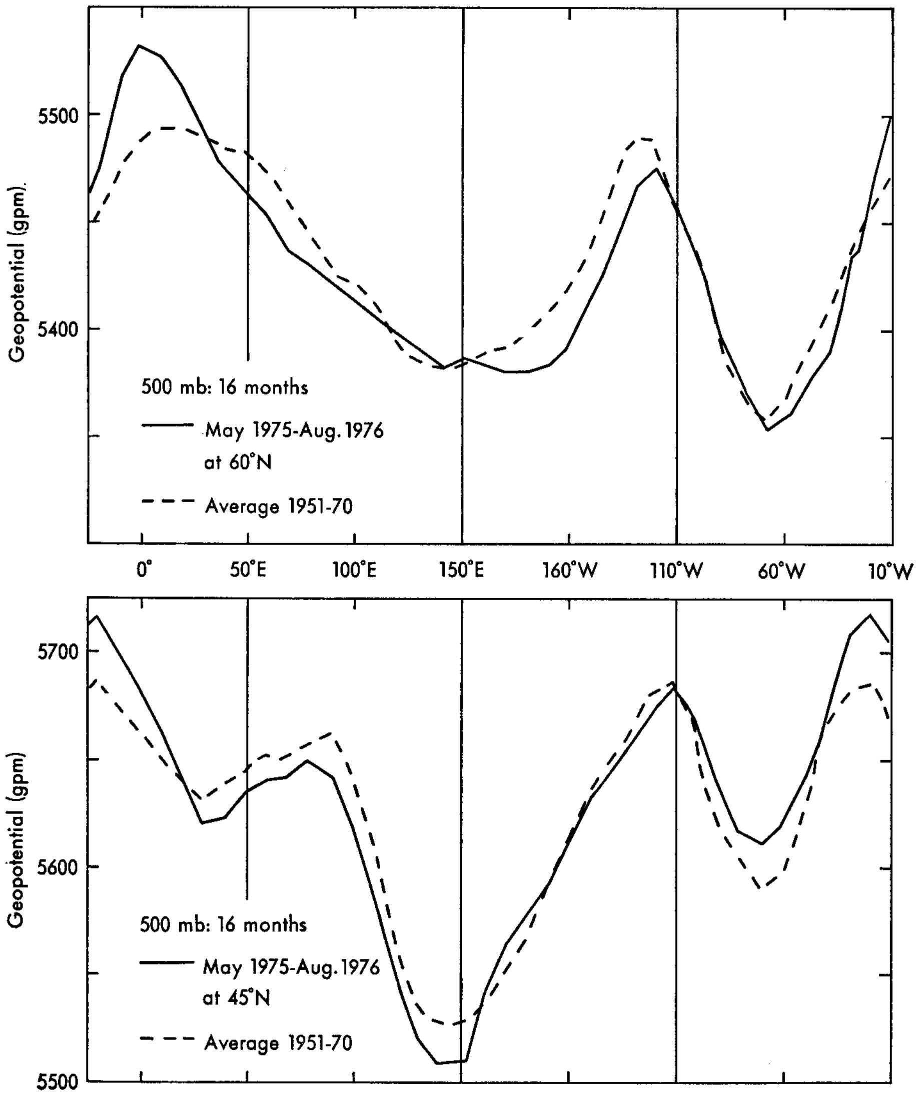

FIGURE 6—PROFILE OF THE 500 mb GEOPOTENTIAL AROUND TWO LATITUDE CIRCLES FOR THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE

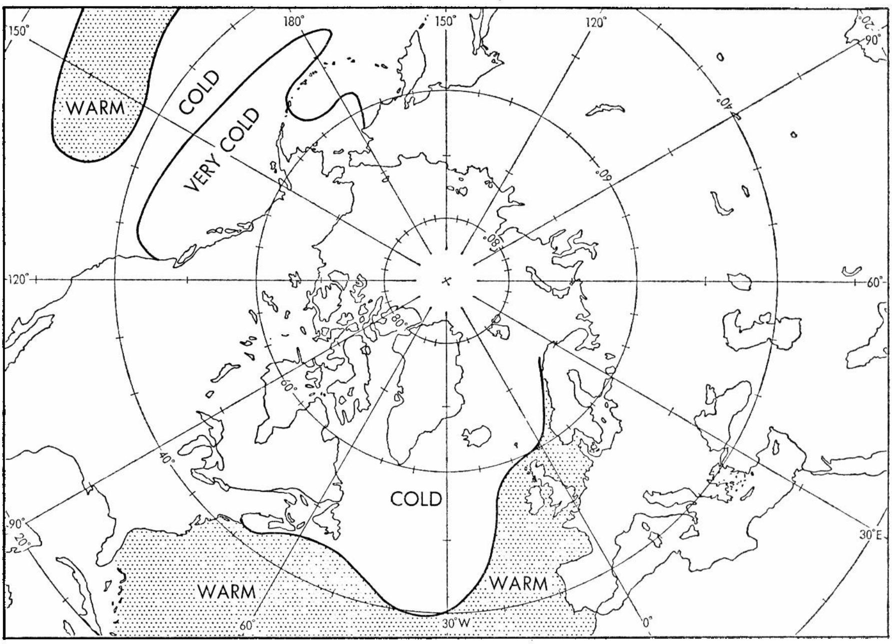

FIGURE 7—ANOMALIES OF SEA SURFACE TEMPERATURE FOR THE PERIOD MAY 1975 TO AUGUST 1976 INCLUSIVE

Isopleths are at intervals of 1·0°C. Stippling denotes areas warmer than average.

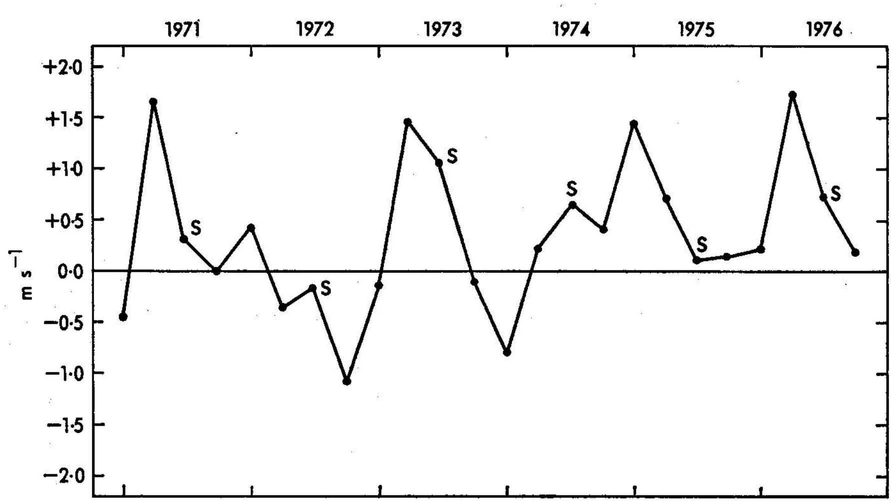

FIGURE 8—ANOMALIES OF THE THERMAL WIND 35–55°N BY SEASONS OVER THE NORTH PACIFIC

Period of average is 1966–76. The summer seasons are denoted by S.

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HONOUR

We note with pleasure that Dr F. Pasquill was elected a Fellow of the Royal Society on 17 March for studies of turbulence and diffusion processes in the atmospheric boundary layer and their application to the transport of pollutants. Dr Pasquill retired from the Meteorological Office on 7 September 1974 as a Special Merit Deputy Chief Scientific Officer. An account of his career and his outstanding research work is given in the *Meteorological Magazine* Vol. 103, pp. 274–275.

NOTES AND NEWS

Upper-air observations at St Helena

The last of the series of new upper-air stations established overseas by the United Kingdom for the global network of the World Weather Watch was opened at Bottom Woods, St Helena on 27 October 1976 by the Governor of St Helena, Sir Thomas Oates, C.M.G., O.B.E.

During January 1977 Mr J. H. Convery of the High Atmosphere Branch visited the station and brought the Dobson Ozone Spectrophotometer into operation; routine daily observations of total ozone, made by staff of the upper-air station, began on 20 January. This station fills a major gap in the global ozone observational network.

North Atlantic Ocean Stations

The WMO agreement for Joint Financing of North Atlantic Ocean Stations, negotiated in November 1974 (*Met Mag*, **104**, 1975, pp. 90–91 and 311) entered into force on 1 December 1976. The First Session of the Board to administer the NAOS agreement was convened at WMO Headquarters, Geneva on 13–16 December 1976. Delegations from 14 contracting parties attended, including the United Kingdom, and seven other states were represented by observers. The estimated cost of the network for 1977 is just over £7 million.

Dr R. Berggren of Sweden was elected President of the Board and M. R. du Chaxel of France was elected Vice-President and both will serve in these capacities until the end of 1977.

Two UK weather ships being refurbished to maintain Station 'L' will be renamed *Admiral FitzRoy* and *Admiral Beaufort*.

THE METEOROLOGICAL MAGAZINE

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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