LONG RANGE FORECASTING IN THE METEOROLOGICAL OFFICE PART 1

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1. INTRODUCTION

In these two lectures, long range forecasting will be taken to mean forecasting for periods ranging from several weeks to a season ahead. It is distinguished from shorter range forecasting by being concerned with periods which extend beyond the limit of 'deterministic predictability' as this term is generally understood i.e. the time it takes for initial state errors, consistent with observational accuracies, to grow to saturation values in a forecasting model. This limit is recognised to be around 2-3 weeks when a 'perfect' model is used. In practice, successful forecasts can be made for a fraction of this time, perhaps to about 3-4 days on most occasions but sometimes, depending on the synoptic situation, for considerably longer. And it is distinguished from longer period forecasting by being still an initial value problem for the atmosphere. For a short period ahead the internal dynamics of the atmosphere clearly dominate the forecasting problem but as the period of interest is extended the effect of forcing external to the atmosphere (but usually interacting with it) becomes increasingly important and it is not at present clear at what period ahead the initial state of the atmosphere may confidently be ignored. The estimate of a season suggested above is convenient and based upon subjective interpretation of data, but it has no firmly established basis.

There are indications that at low latitudes the effect of forcing may become important more rapidly than in middle latitudes. The considerations noted here apply mainly to middle latitudes, and there may be a need for amendment in a global view.

Within the Meteorological Office, long range forecasts are prepared for a period of a month ahead twice monthly at the beginning and middle of each calendar month. Forecasts for a season ahead have also been prepared at the beginning of each season. For the most part, my remarks will be concerned with the monthly forecasts. They were issued to the general public on a semi-operational basis for about 17 years, the service having been terminated at the end of 1980. It is well-known that the accuracy of the forecasts was low though not negligible. When the service was initiated there was optimism that increasing familiarity with the problem and the development of methods based on the statistical interpretation of the historical record would produce a consistent but modest improvement which would gradually raise the level of attainment. In practice, it became clear that the shortness of the historical record was a major limitation to the development of statistical techniques. Methods which appeared to be successful when applied to past data failed in practice, or methods which were successful in the shorter term ceased to be so later. It appeared that variations in climate such as may be detected in the differences between the decades of the present century were such as to remove much of the success expected.

It was accepted from the first however that statistical methods were unlikely to make substantial inroads into the scientific problem and that in the longer term it was necessary to look towards more physically based techniques. At about the same time as long range forecasts were made public, the Dynamical Climatology Branch was set up, with the principal long term aim of developing models suitable for long range forecasting. For over a decade the effort was concentrated on developing general circulation models and investigating the sensitivity of the simulations to changes in model formulations or in forcing functions. In the last few years the problem of long range forecasting has been considered more directly.

In this first lecture I shall be dealing primarily with the basis for long range forecasting, at least as perceived by the practitioner, about some of the practical problems and finally very briefly about the methods used in the Meteorological Office. The second lecture will be concerned with long range forecasting by dynamically based methods.

2. THE BASIS FOR LONG RANGE FORECASTING

The Central England temperature series constructed by Manley (1974) has formed a valuable data set for the study of climate and its variations and for examining the statistical properties to detect potentially predictable features. In order to maintain and extend the series, Central England temperatures at daily intervals have been derived from individual station records the aim being to maintain as far as possible the average properties of the original. Figure 1(a) and (b) show the stations which have been used over the last 100 years. Changes were necessary in the early 1970's to replace stations which ceased making observations; the use of six values at the present time is intended to reduce the impact of further closures in the future. A daily temperature is obtained by averaging the maximum and minimum values for all stations.

Figure 2(a) shows the Central England temperatures during 1980 as 5-day running averages. The use of running averages eliminates short period variations and tends to alter the amplitude of variations on time scales out to 10–15 days. However, for present purposes, where the main interest lies in the lengths of

Stations used for Central England Daily Temperatures

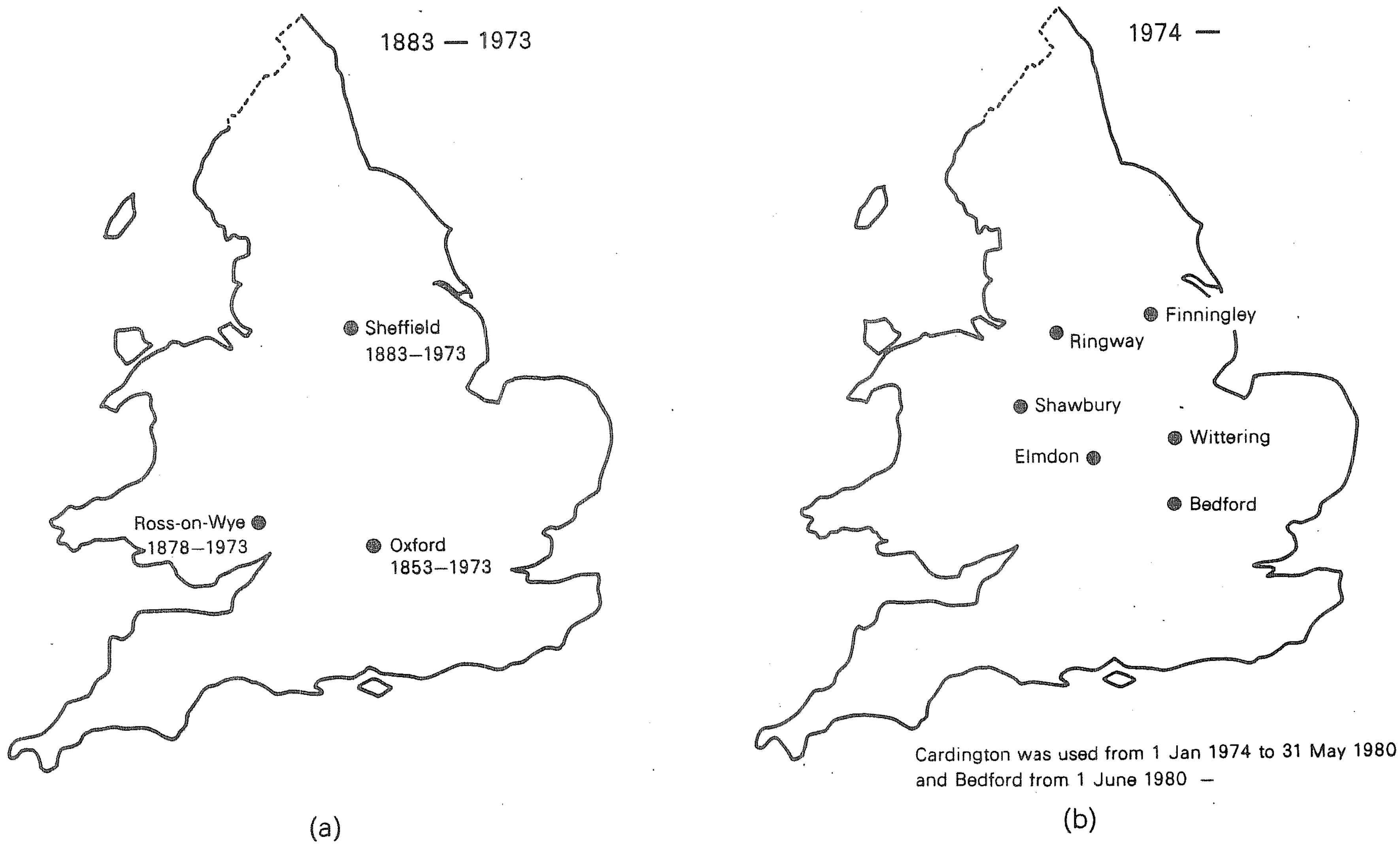


Fig. 1 Stations used in calculating Central England temperatures for the periods shown.

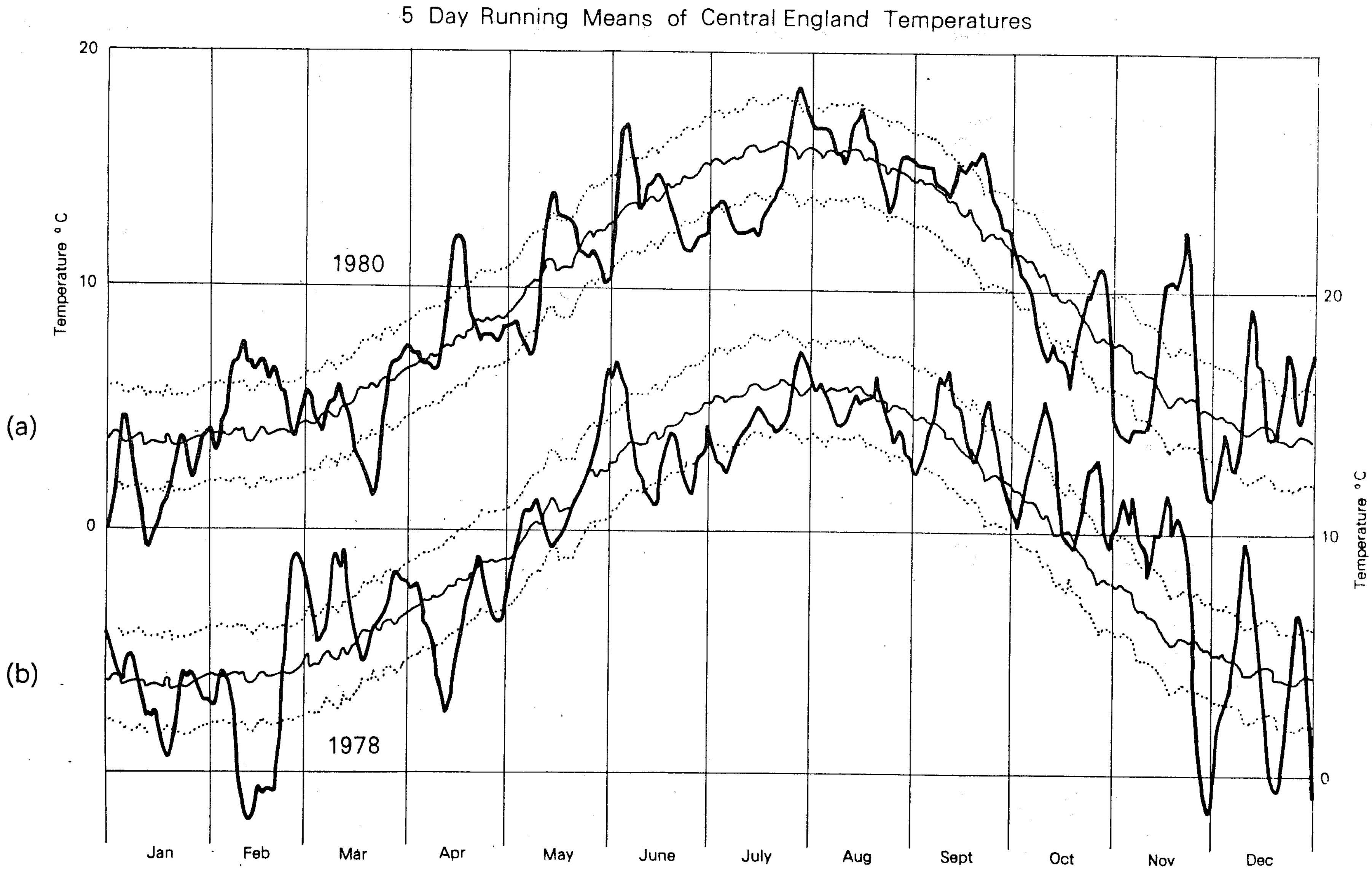


Fig. 2 5-day running mean values of Central England temperature for particular years (heavy continuous line). Also shown are the appropriate long term average temperatures, from 105 years of data, 1871-1975 (thin continuous line) and the ± 2°C deviations from this (dotted lines). (a) 1980, (b) 1978.

5 Day Running Means of Central England Temperatures

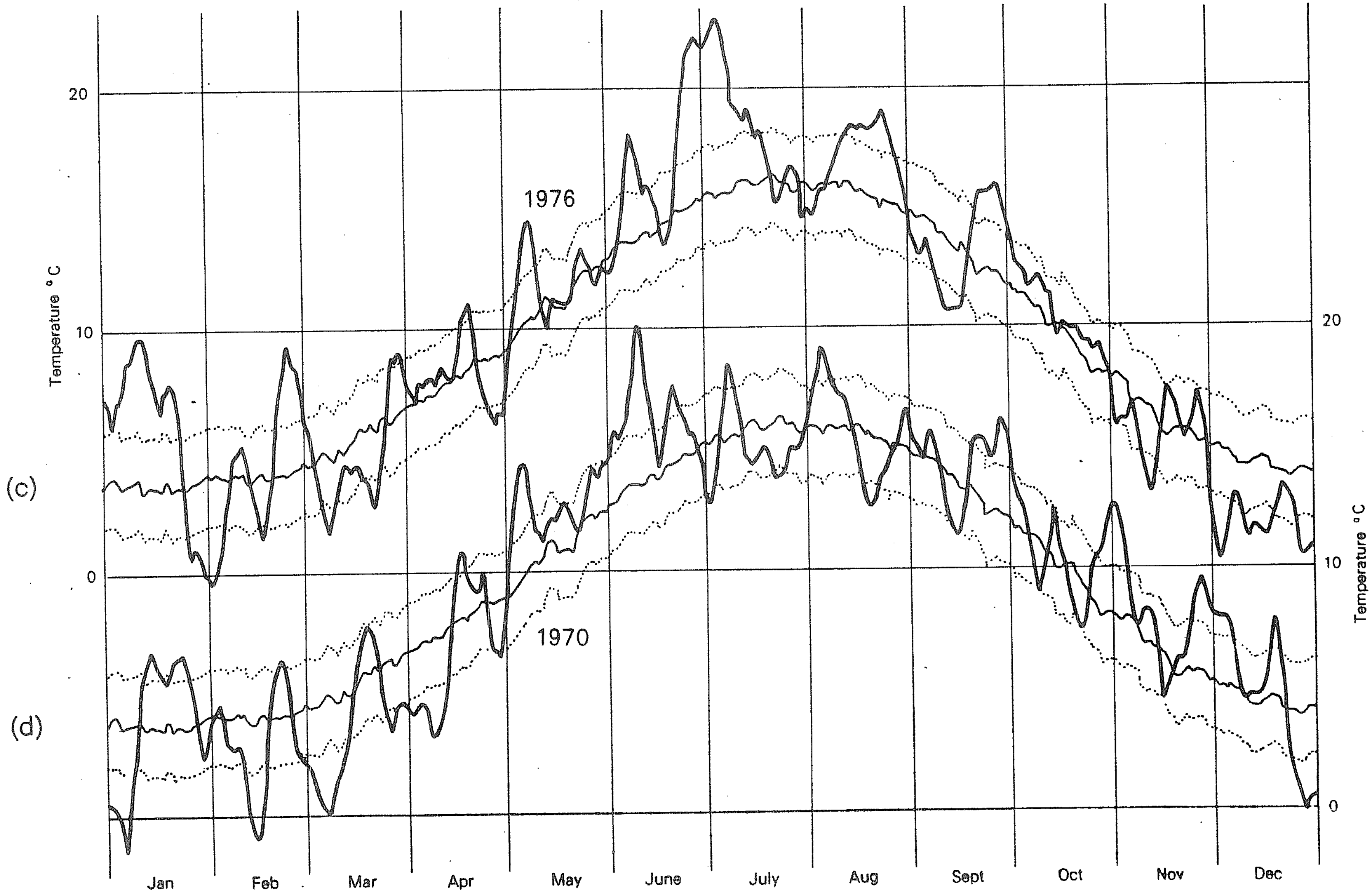


Fig. 2 (contd.) (c) 1976, (d) 1970.

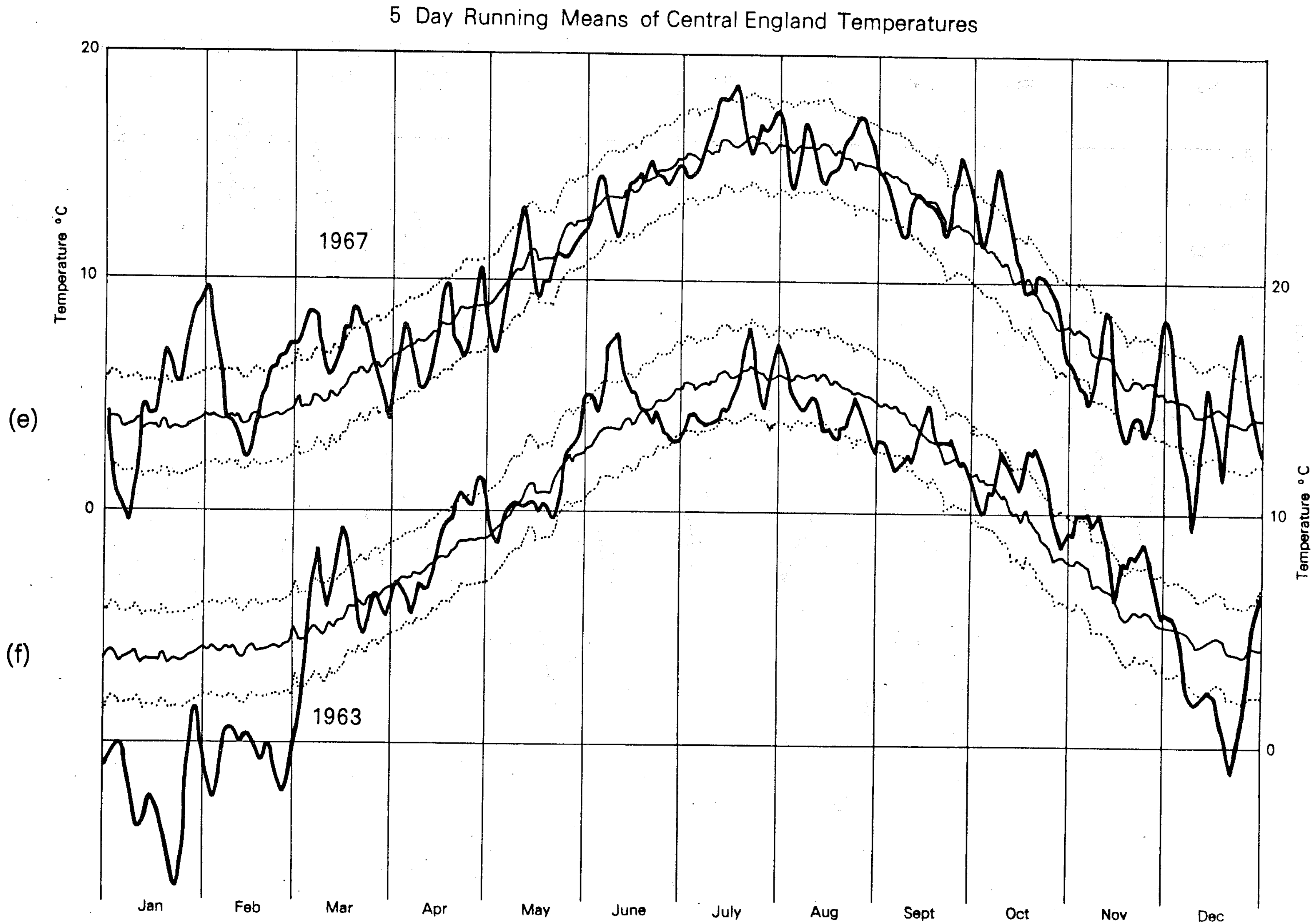


Fig. 2 (contd.) (e) 1967), (f) 1963.

longer spells of above or below average values, the effect of the running average technique is unlikely to affect the conclusions significantly. Also shown is the average daily temperature through the year calculated from 105 years of data 1871–1975 and curves at ± 2°C from it.

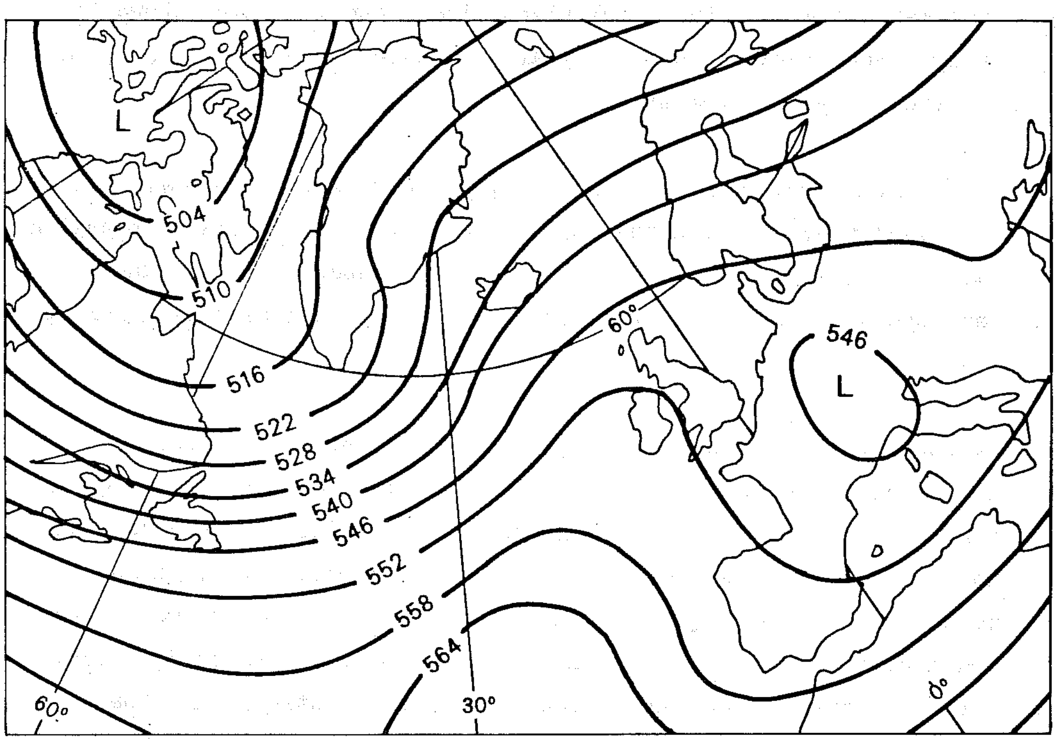
The data indicate clearly that there are fairly long spells of above or below normal temperatures; indeed they dominate the series confirming the general impression that the variation of weather is not dominated by the passage of individual cyclones and anticyclones, but by longer period variations corresponding perhaps to weather types.

There is great variability in the kinds and lengths of spells from year to year, a feature that is demonstrated in Figure 2. Figure 2(f) indicates that 1963 was a year in which the length of spells was unusually long. This applied not only to the very long winter but also to cold and warm spells which affected much of the summer and autumn respectively. In contrast, 1967 (Figure 2(e)) was a year with few marked deviations from normal and spells of generally short duration. 1970 (Figure 2(d)) is similar to 1980 in general characteristics, but shows a tendency for positive peaks to occur in a quasiregular sequence. In 1976 (Figure 2(c)), persistence scored highly as a method of forecasting the monthly mean temperature (see Table III and discussion of it); there were long periods in which the temperature was predominantly above normal during spring summer and autumn. 1978 (Figure 2(b)), which proved especially difficult for the long range forecasters (see Table   ) had an unusual variation with few warm spells in the first half of the year, balanced by an autumn in which mild weather continued well into November.

Spells of relatively warm or cold weather are caused by the surface wind direction remaining predominantly in one quarter for substantial periods. To illustrate these persistent flow patterns Figures 3 show the surface pressure and 500 mb contours near the British Isles for four spells in 1980, averaged over the period during which Central England Temperature was continuously either above or below the long term normal.

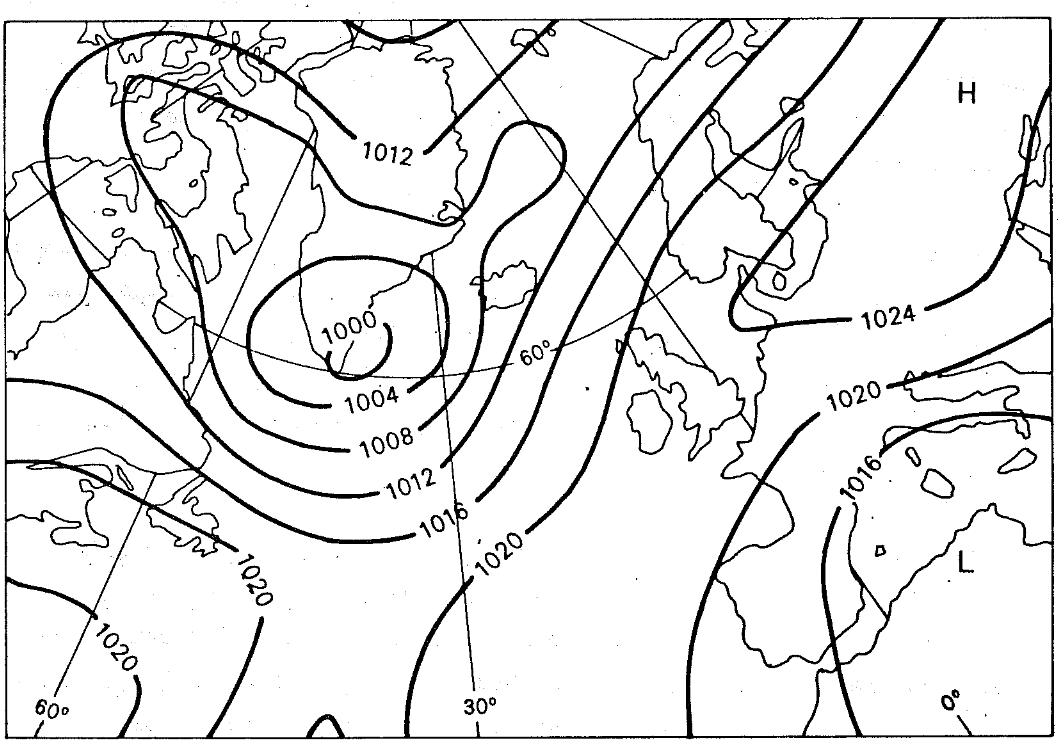
The cold spell 6–19 January (Figures 3(a), (b)) was associated with easterly winds on the southern side of a ridge extending westwards across Europe. The situation has some of the features of a blocked pattern viz. a split upper flow and relatively low pressure over the western Mediterranean but it is by no means a typical example of the genre. The mild spell which lasted for most of February (Figures 3(c), (d)) was caused by a persistent trough in mid-Atlantic which gave south to south-west winds at low levels over England. The cold spell in April–May (Figures 3(e), (f)) resulted from north-easterly winds blowing

Cold Spell 6 – 19 Jan 1980



500 mb

(a)

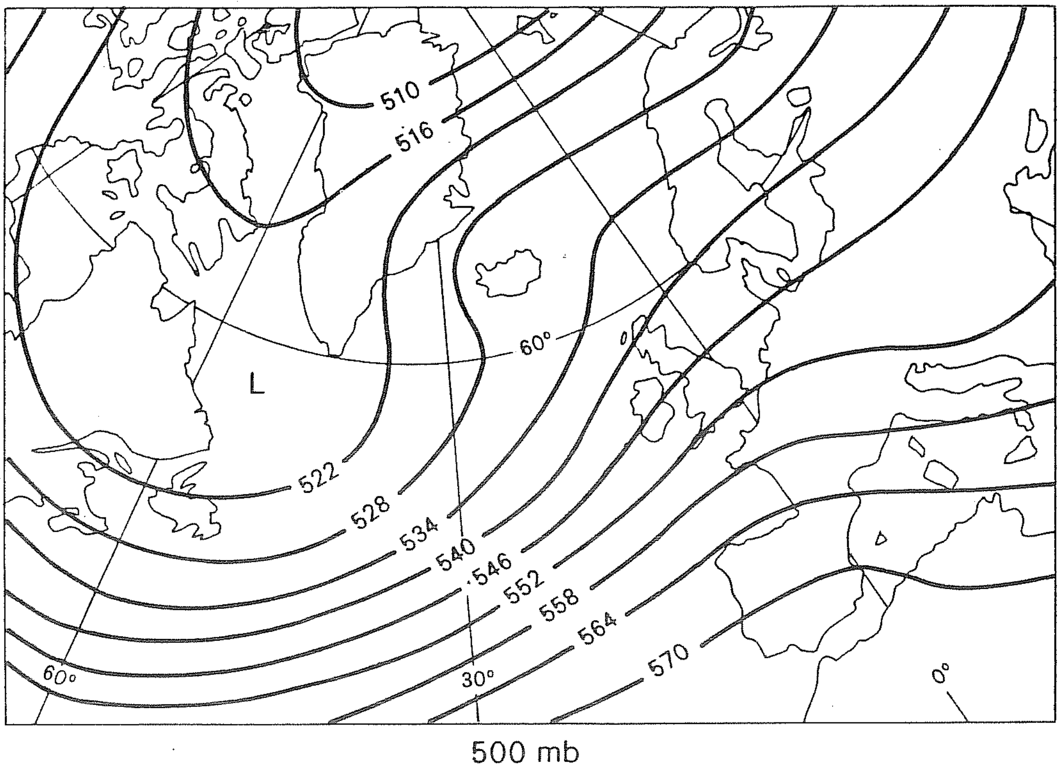


Surface

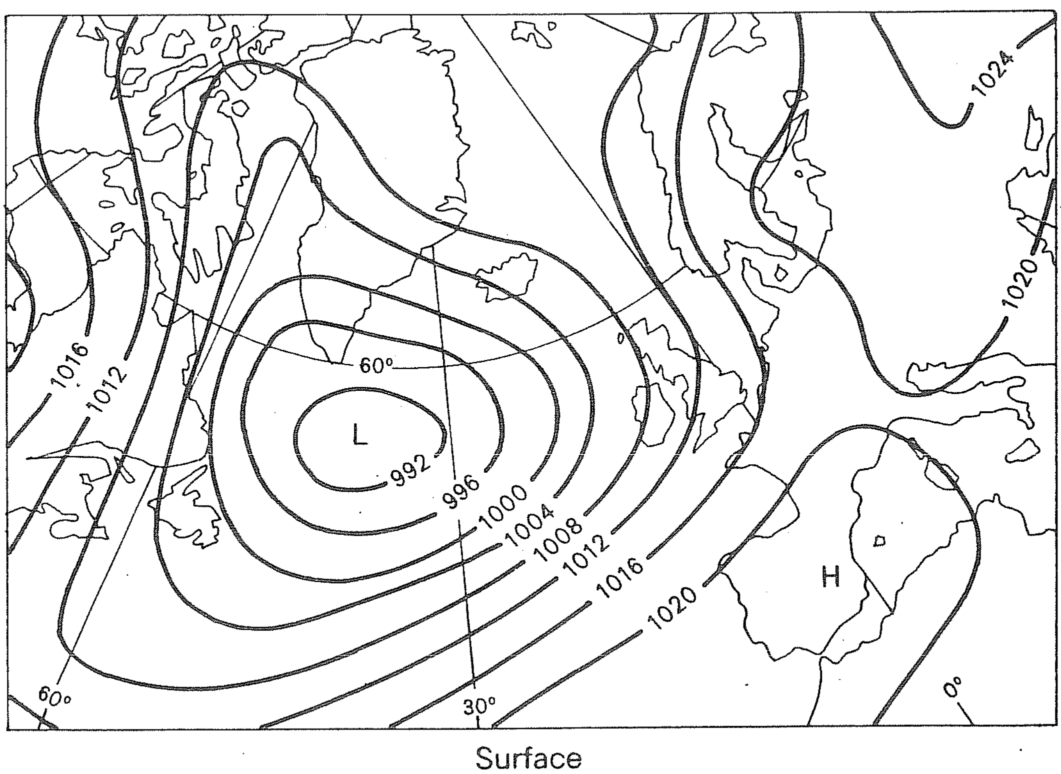
(b)

Fig. 3 500 mb contour charts and mean sea-level pressure charts for warm and cold spells in Central England during 1980.
(a) and (b) 500 mb and PMSL charts for cold spell 6-19 January.

Warm Spell 2 — 22 Feb 1980



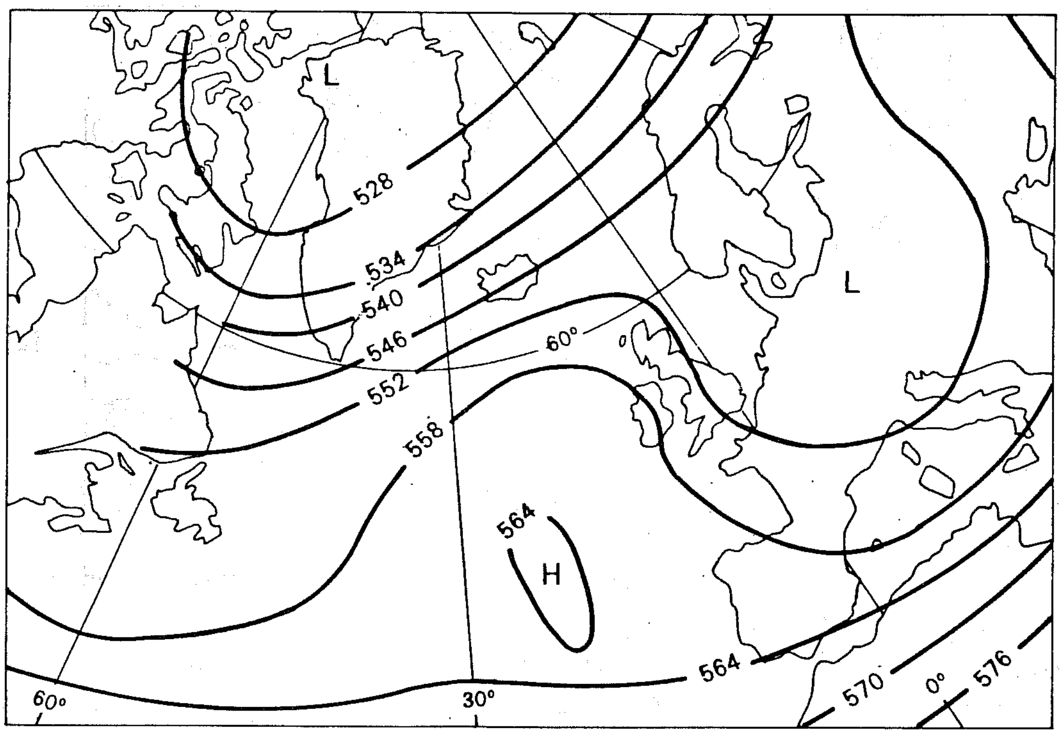
(c)



(d)

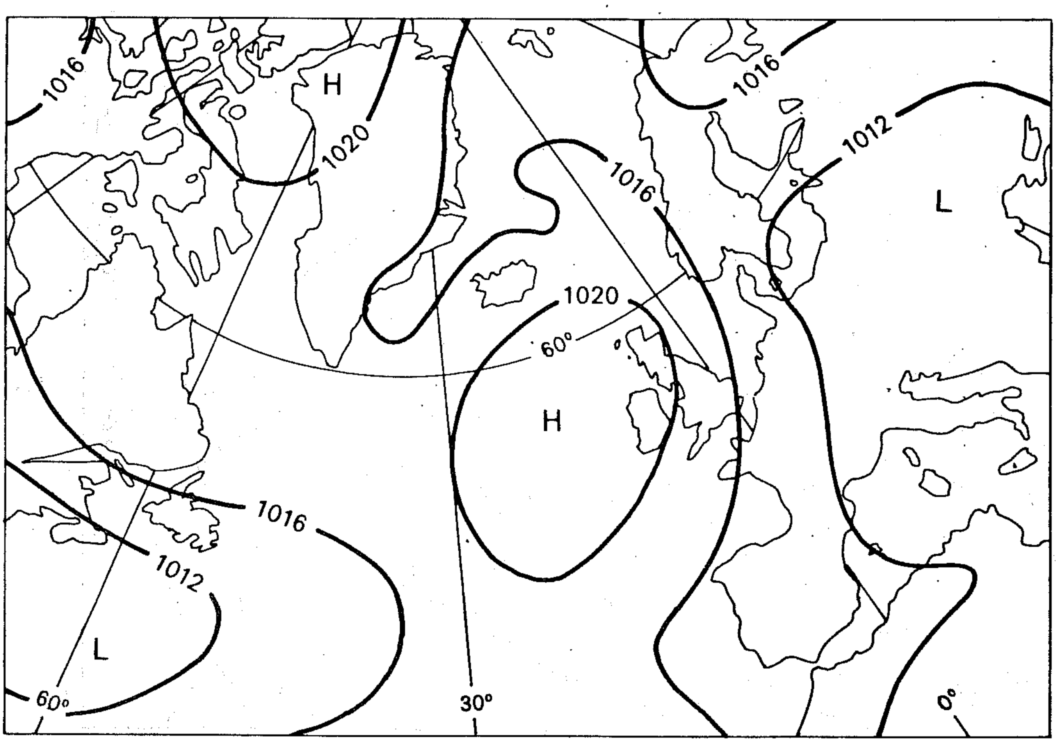
Fig. 3 (contd.) (c) and (d) for warm spell 2-22 February.

Cold Spell 17 April — 8 May 1980



(e)

500 mb

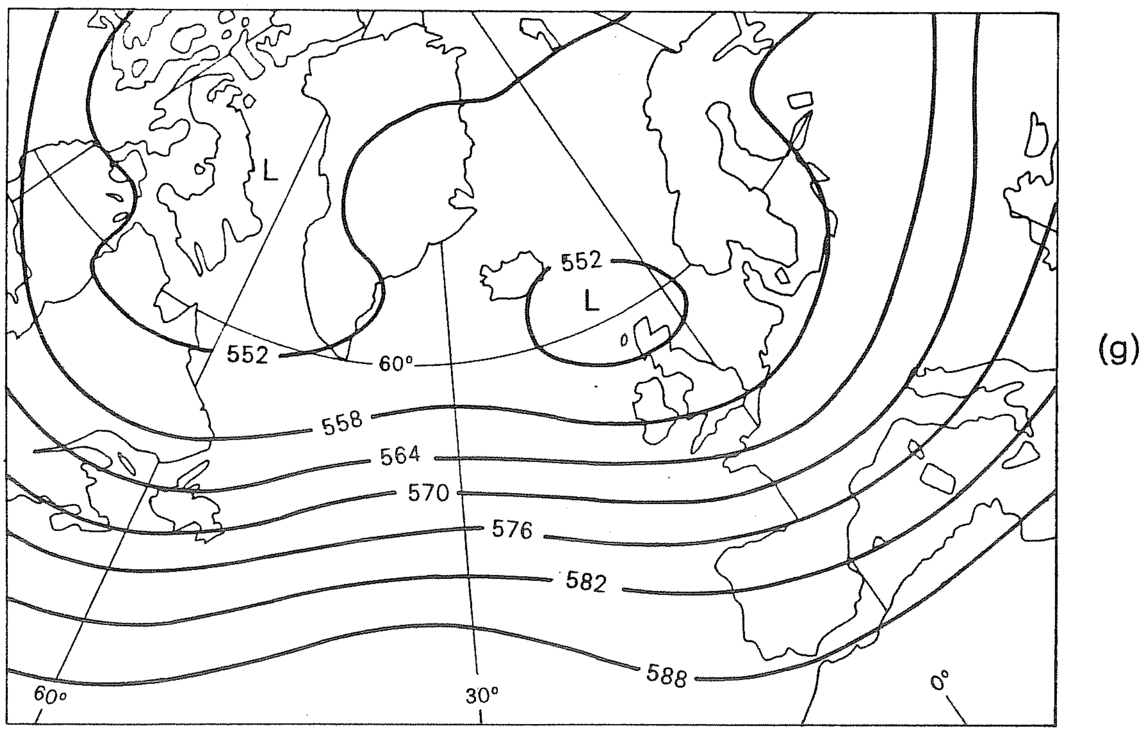


(f)

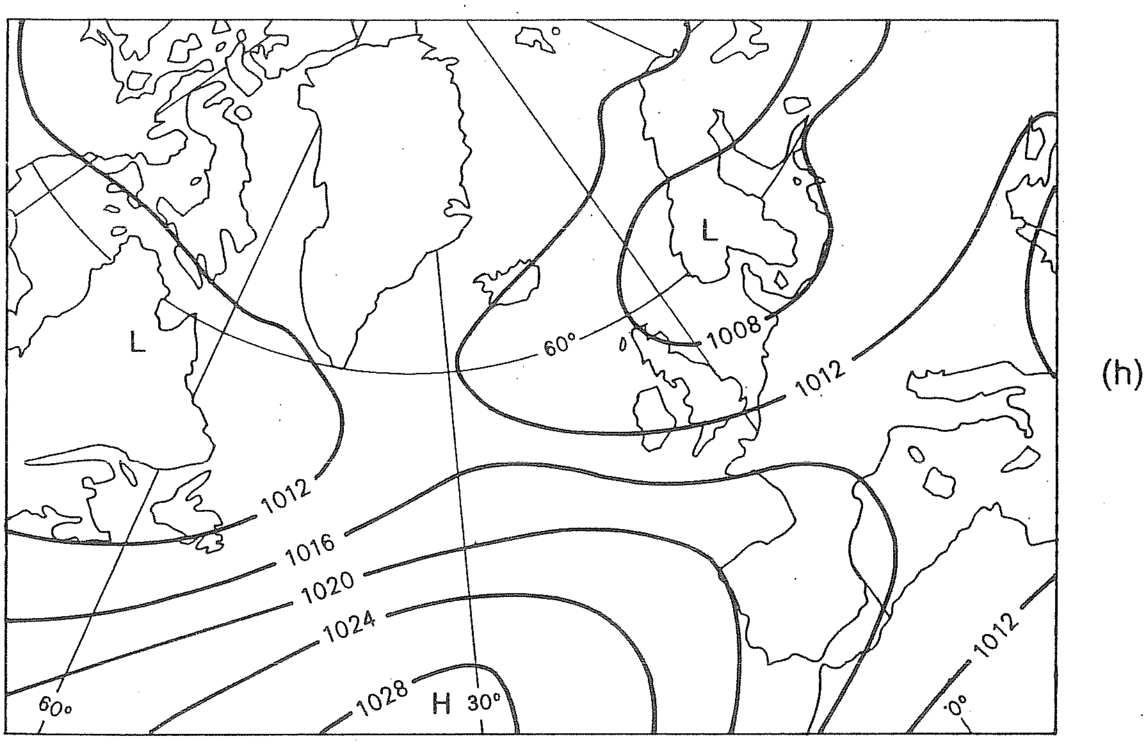
Surface

Fig. 3 (contd.) (e) and (f) for cold spell 17 April-8 May.

Cold Spell 15 June — 21 July 1980



500 mb



Surface

Fig. 3 (contd.) (g) and (h) for cold spell 15 June-21 July.

around a high latitude blocking high, fairly typical of spring blocking patterns though on this occasion low pressure features south of the high were relatively weak. The cold spell which affected a large part of the summer (Figures 3(g),(h)) was associated with a persistent ridge in mid-Atlantic and generally north-westerly winds over the British Isles. With low pressure near England, the weather was persistently cool and wet.

While the spell lengths of Central England temperatures show no preferred periodicities, they give the subjective impression that there are periods within which the spells tend to be either relatively long or relatively short. Further investigation of this aspect seems worthwhile.

In order to determine the characteristics of spells the data for the twenty years 1960–1979 have been used to construct a histogram of the lengths of spells. Figure 4 shows the lengths of warm and cold spells taken together. Also shown are the lengths to be expected from a single Markov chain process with values of the correlation coefficient set at .9 and .8. The latter value gives a reasonable fit to the frequency of spells in the range 5 to 15 days but clearly tends to underestimate frequencies of longer spells.

In Table I, the number of days which belong to spells with a duration in the ranges specified, are shown:

TABLE I

Total number of days occurring within spells of a given duration

Length of spell	$\not< 10$	10–20	20–30	30– days
Warm	1269	1144	601	595
Cold	1214	1332	506	644
Combined	2483	←	4822	→

The probability of a day chosen at random belonging to a spell greater than 10 days is approximately 2:1.

Spectral analysis of the data, although more difficult to interpret and use, is in general a more satisfactory approach to the problem of describing time series. Figure 5 (a), (b), (c) and (d) show the results of such an analysis (using the maximum entropy technique) carried out on the four 5-year periods making up the twenty years 1960–79. The Central England temperatures have been used directly, without averaging over a time period. The spectra confirm that most of the

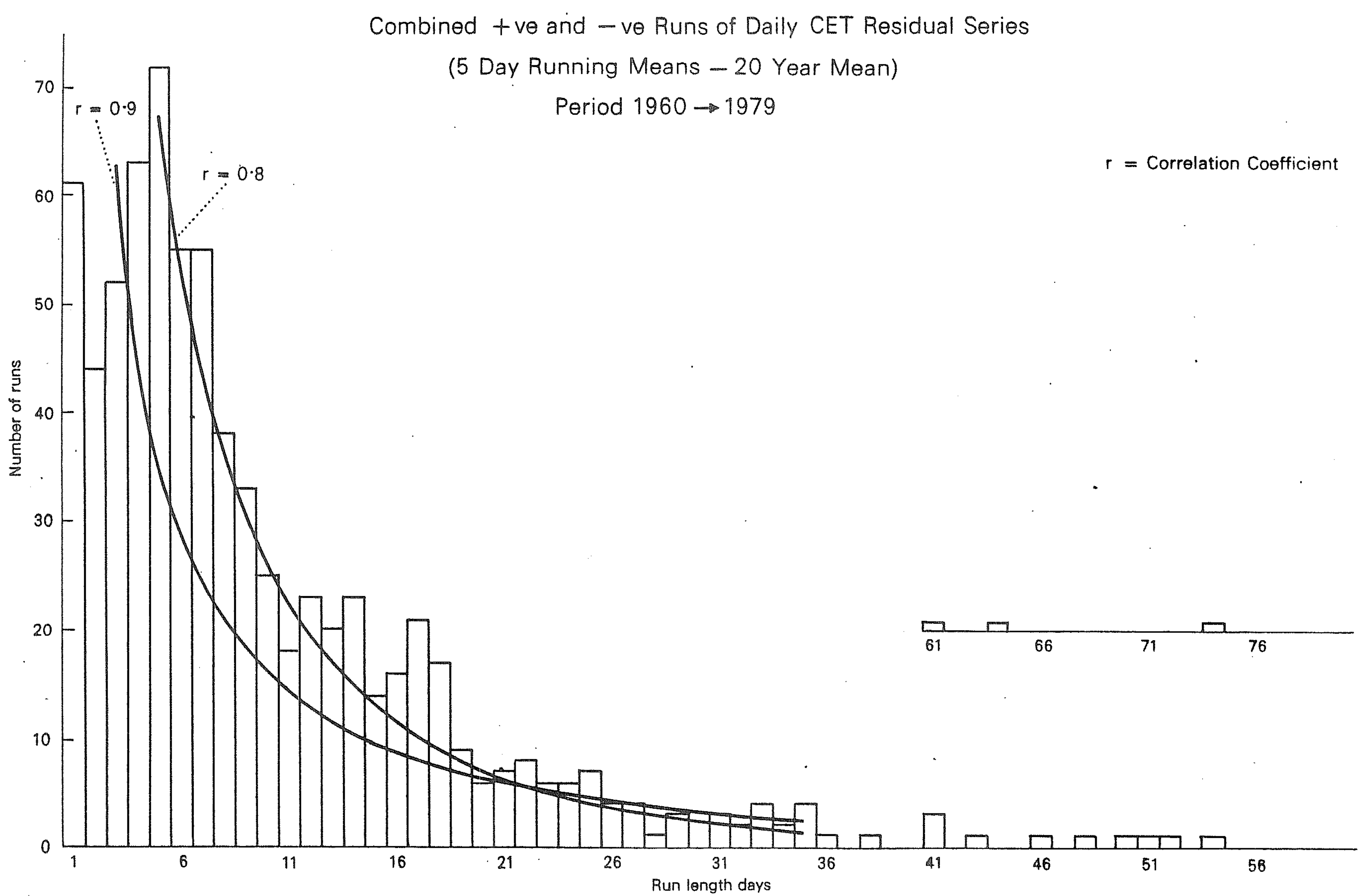


Fig. 4 Histogram showing of frequency against length of above and below normal spells (combined) of Central England temperature, from 5-day running mean values for the period 1960-1979.

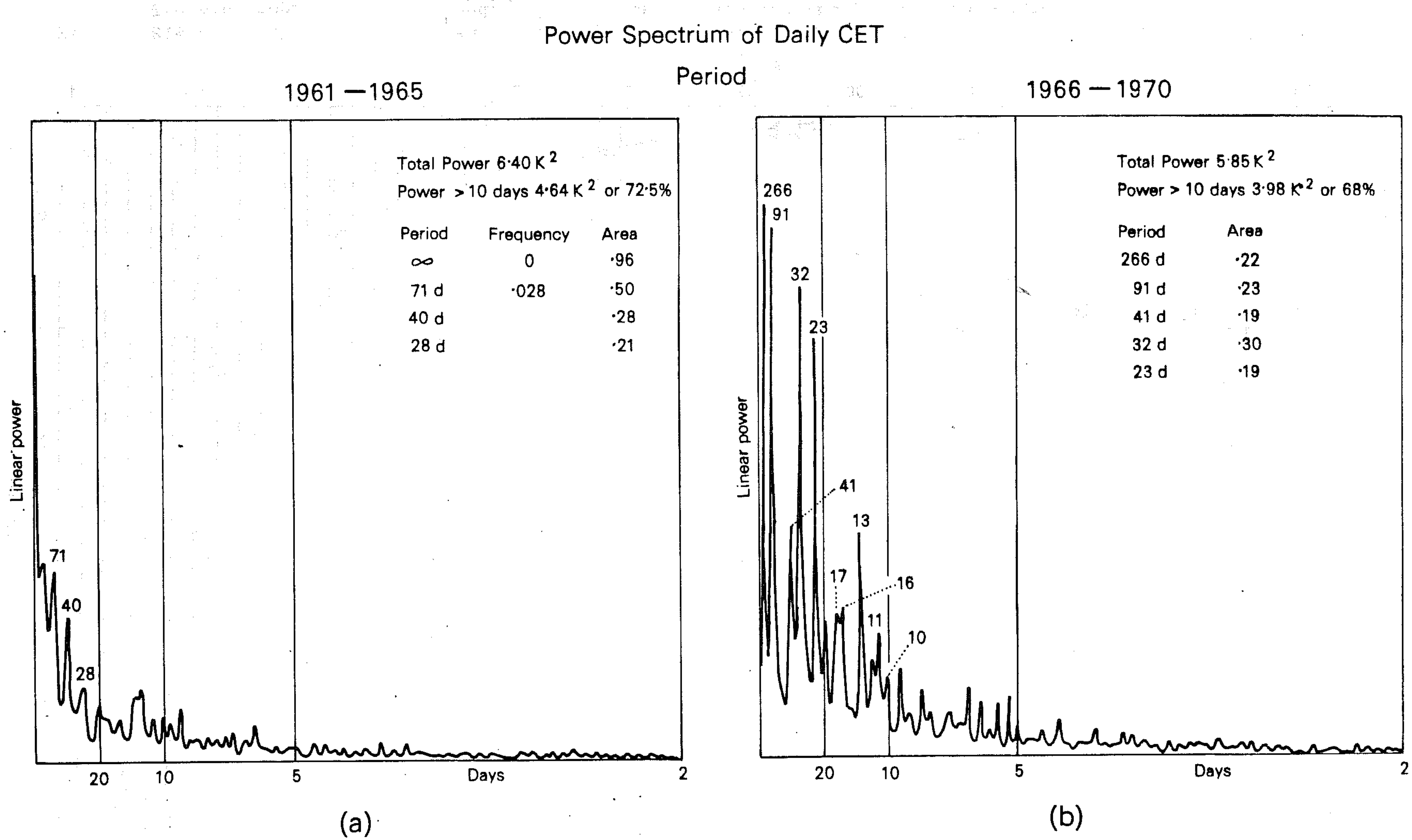


Fig. 5 Power spectrum analyses of daily Central England temperatures for 5-year periods.

(a) for period 1961-65 (b) for period 1966-70

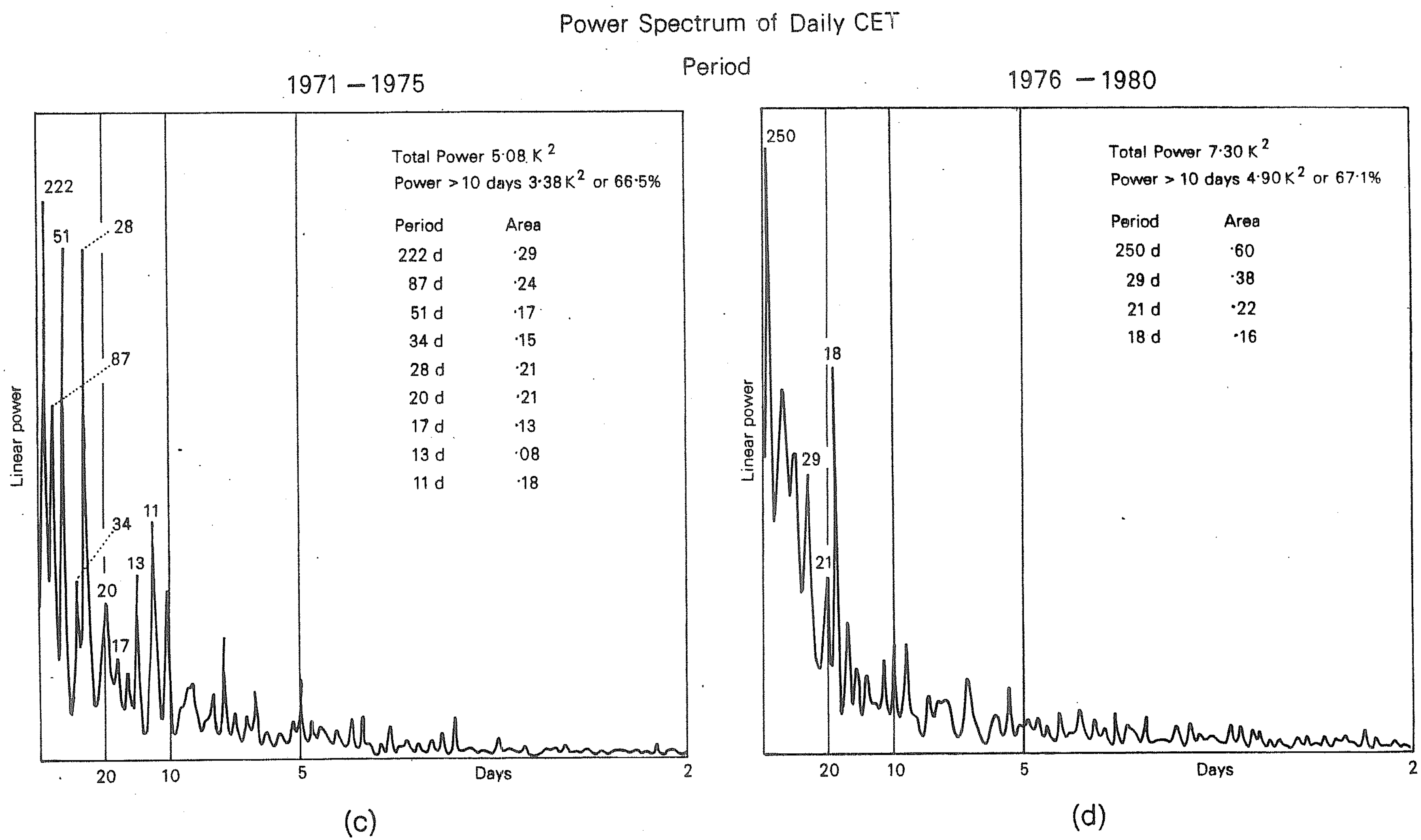


Fig. 5 (contd.) (c) for period 1971-75 (d) for period 1976-80 variance, about two-thirds, lies in periods greater than 10-days and that the largest peaks in the spectrum lie in this range. It should be noted that the area under a particular peak depends on the breadth of the peak. To determine it, the programme fits a Gaussian curve to the peak and the area is measured to the half-power distance.

By its nature, rainfall is a more difficult variable to deal with than temperature, and considering its physical causes, it is unlikely to occur in such marked spells as temperature anomalies. In long-range forecasting in the Meteorological Office it has been usual to consider an England and Wales Rainfall (EWR) variable. It is based on many rainfall recording stations (over 400 at the present time) in the two countries, each station being normalised before averaging. A time series is maintained over a long period, though for obvious reasons it is not as long as the Central England temperature series. Examples of the series are shown in Figure 6. Here, the 40-year averages for each day of the year have been smoothed by taking a 31-day running average; this is shown by the dotted curve. The variation through the year is not large, though there is a clear tendency for low values to occur in spring; and for high values to occur in October-November, and in January-February. Also shown on the diagrams are the 5-day running average values of the EWR expressed as a percentage of the annual average value It is quite clear again that there are identifiable spells which can be prolonged. Dry spells however are more likely to be longer lasting than wet spells. For example, in the winter of 1963, spring 1974, summer of 1975 and 1976 there were dry spells of at least a month in length. Though wet spells tend to be shorter-lived, there were notable wet periods in the years illustrated in November 1963 and in September-October 1976.

As for temperature, histograms of spell lengths have been drawn. Figure 7 shows them for wet and dry spells combined. As before, the period considered is the twenty years 1960-79. In this case, the runs refer to periods when EWR values (smoothed by taking 5-day running averages) were above or below .03% of the annual average value. Frequencies to be expected with a first order correlation of .8 and .7 for spells longer than 5 days are indicated. Although there tend to be fewer long spells than for temperature, there are nevertheless some very extended periods all of them dry. In Table II the information shown in Table I for temperature is shown for rainfall:

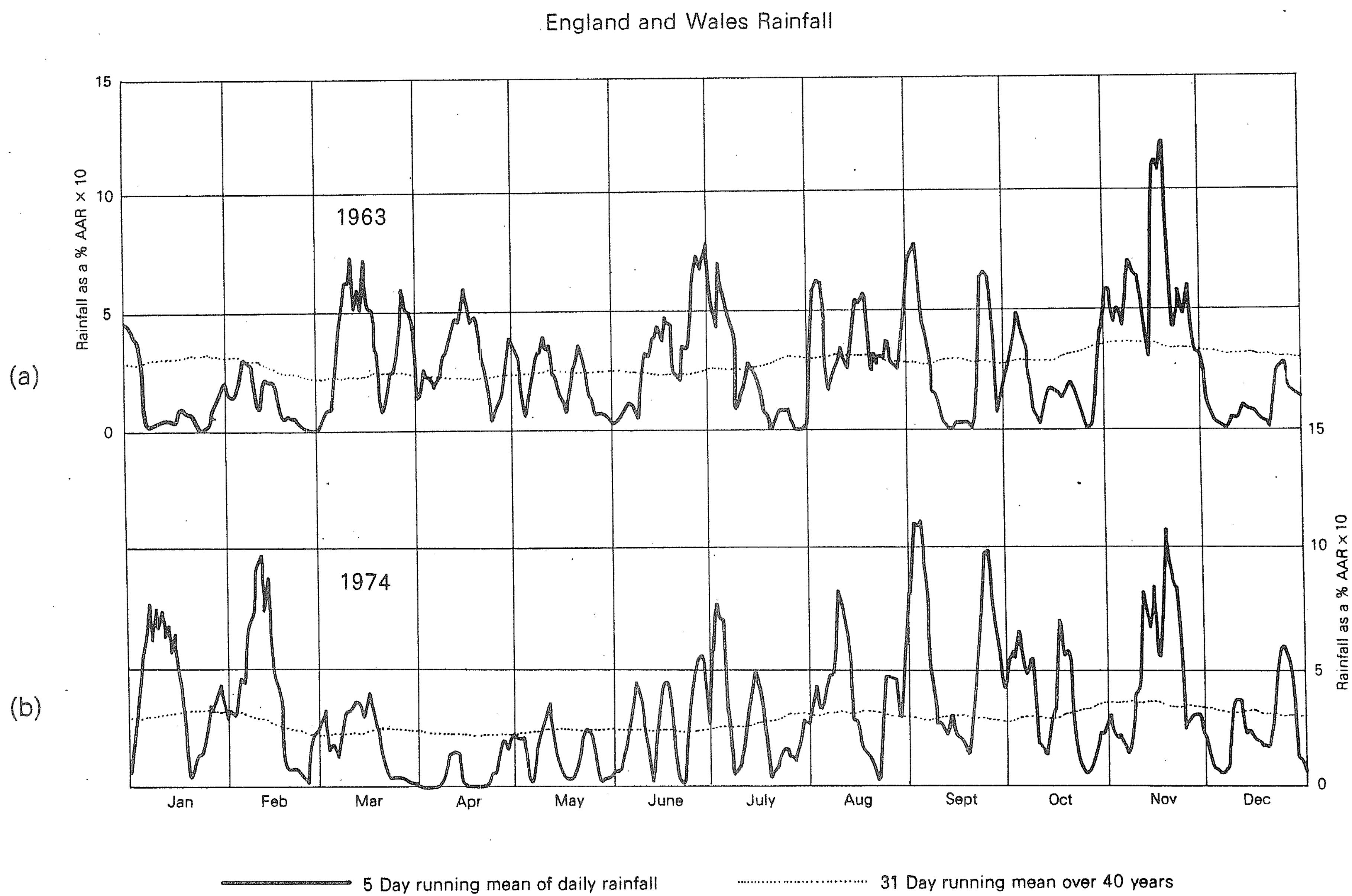


Fig. 6 5-day running mean values of England and Wales rainfall for particular years (heavy continuous line) and the 31-day running mean averaged for 40 years. (a) 1963, (b) 1974.

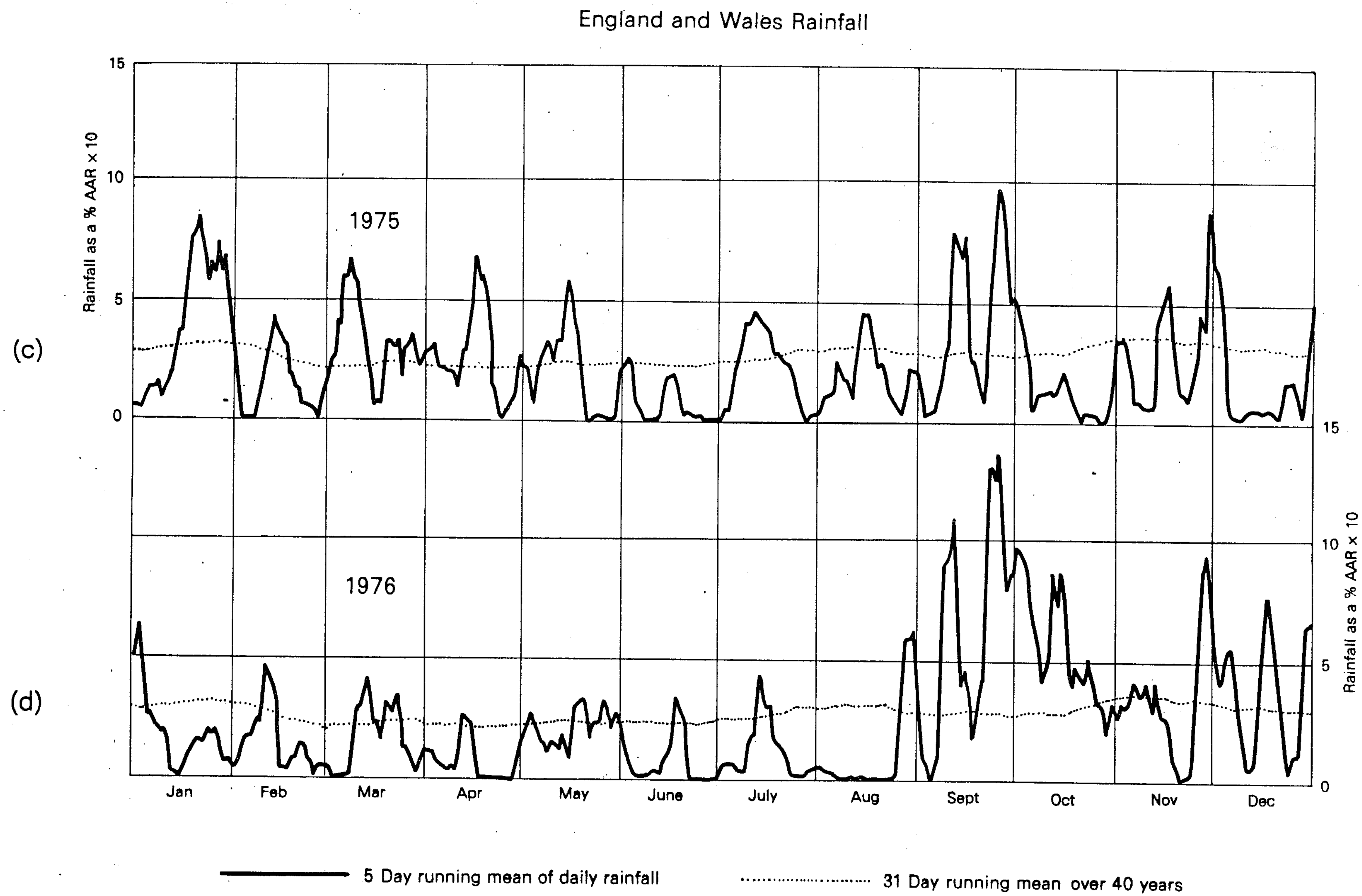


Fig. 6 (contd.) (c) 1975 (d) 1976

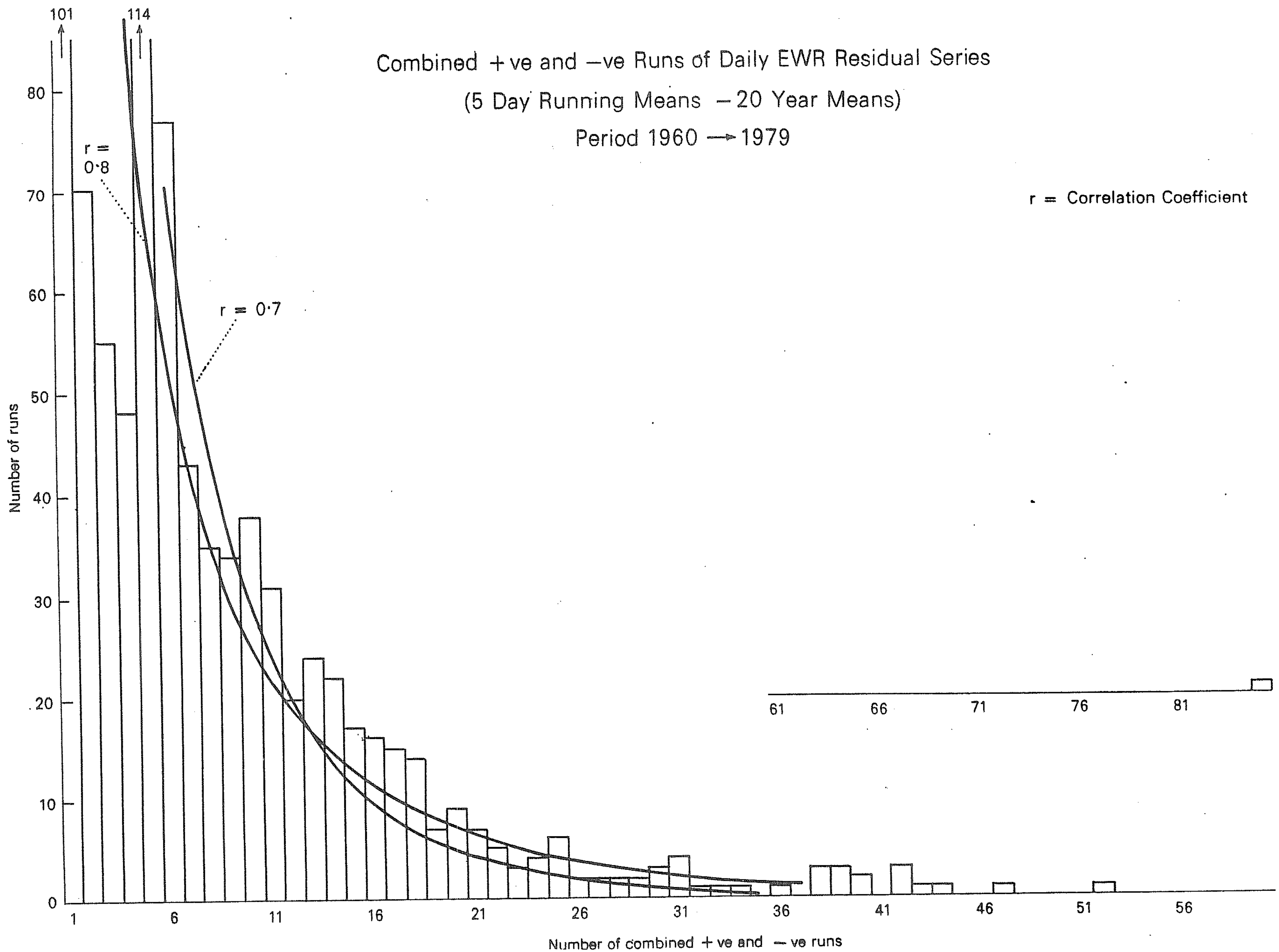


Fig. 7 Histogram showing frequency against length of above and below normal spells (combined) of England and Wales rainfall, from 5-day running mean values for the period 1960-1979.

TABLE II

Total number of days occurring within spells of a given duration

Length of spell	< 10	10–20	20–30	30–	Total
Dry	1242	1364	673	897	4176
Wet	1682	1168	209	70	3129
Combined	2924	←	4381	→	7305

The table indicates that a relatively dry day chosen at random is almost 2.5 times more likely to be within a dry spell longer than 10 days than shorter than 10 days. On the other hand a relatively wet day chosen at random is slightly less likely to be in a spell longer than 10 days. We note however that the predominance of the influence of spells on the general behaviour of the rainfall series makes it essential for that to be a central theme in a consideration of long range forecasting.

I have dwelt on these records of temperatures and rainfall representing conditions over a substantial part of the British Isles because I believe it is records of this kind which provide the most encouraging evidence that long range forecasts, over periods considerably more than the normally recognised period of deterministic predictability, might be possible. Even the knowledge of the average properties of the series should enable forecasts based on the persistence of spells to contain a modest amount of useful information; some degree of skill in forecasting the influence of the initial atmospheric situation on the likely persistence of a spell should improve the forecast.

At present we have no real assurance that the length of spells can be forecast with useful accuracy, but numerical models provide the means to investigate the problems involved. This is a matter for the next lecture.

A secondary reason for considering temperature at the earth's surface and rainfall in particular is to stress the importance of these variables in long range forecasting. It was the demand from aviation which led to the growth of forecasting services during and immediately after World War II, and it was a fortunate circumstance that it was for upper winds that it was found possible to attain the highest forecast accuracy. The demand was for the most easily provided quantity. On the other hand, the accuracy of forecasts of rainfall and temperature at the earth's surface is still rather low and forecast skill decreases quickly with time. Hard though it is, it is with these difficult variables that the long range forecaster is concerned to the virtual exclusion of all others; there is little interest in an operational sense with upper winds or temperatures averaged over a month.

3. THE CONTENT OF LONG RANGE FORECASTS

At this point I would like to divert to consider a matter which is less scientific than practical in its content and yet is extremely important in its implications for practical long range forecasting. It is "who can use long range forecasts?" and the allied question "what parameters should we be trying to forecast?".

Forecasts for a month ahead must at least on the great majority of occasions in middle latitudes be probability statements, either explicitly or implicitly. Our experience with models leads us to believe further that on many occasions the bias of probability in favour of one particular development will not be much different from that of other apparently possible developments. Stated more succinctly, we have to accept that on many occasions forecasts stated in definitive terms will be incorrect; for those stated in probability terms, the solution of highest probability will on many occasion not be the one which eventuates.

It has frequently been assumed in attempting to assess the market for long range forecasts that it was right to include "potential" users ie those who could make use of them if they reached an adequate, usually rather high level of success. This of course provides a very wide range of users from members of the general public, through many industries right on to national and international planning. However, this can be a very misleading assessment. When the fact or what we believe to be fact, - namely that forecasts can never be highly accurate - is taken into account, the number of possible serious users slumps dramatically. (I do not of course mean to rule out general interest in the forecasts or certain particular occasions when a higher accuracy may be possible and larger groups of users could be involved.)

In general, users of forecasts for a month ahead have to be found among those who are

(a) interested in conditions over a large area.

(b) not crucially affected by the outcome of any particular forecast but are concerned with a sufficiently long series that they can benefit from a small amount of skill in the series as a whole.

On this basis, it is unlikely that some of the large obvious groups - the general public and farmers for example - can realistically expect to make use of monthly forecasts on a regular basis, though there may of course be individual occasions such as the continuation of severe winter or summer drought conditions when forecasts can be made with sufficient confidence to satisfy their more exacting requirements.

Overwhelmingly, I believe the regular users of monthly forecasts, at least in a European context, come down to two groups: the energy and water industries, with interests primarily in temperature and rainfall respectively. Wind and solar radiation could become significant parameters if wind and solar power generation became important, but at present not only are they of less interest, but the prospects for forecasting them with useful accuracy are much less.

Energy producers are likely to be the most important customers for long range forecasts. International oil companies wish to buy and distribute their products economically and it therefore helps to forecast demand regionally; on the other hand the many other factors which cause variations in demand for energy far outweigh those of weather and climate so that decisions can be improved by taking account of forecasts, but they are not crucially dependent on the forecasts being correct. Power stations have to be closed down and refurbished at times coinciding with minimum demand and at minimum cost in terms of the standby alternative means of generation. As long as sufficient standby generators are available, (and this is usually the case, at least in UK) wrong decisions as regards weather conditions do not lead to a breakdown in supplies, but over long periods the economics of the exercise can be improved by long range forecasts which have a reasonable accuracy. The control of water resources can similarly benefit from forecasts for fairly large areas, and economic decisions concerning the use of water supplies can be improved by forecasts which over a long series show some skill, but it is only on rare occasions of severe drought that dependence on the forecasts may become crucial.

Long range forecasts, if they are to be useful, have to be produced to meet the needs of their (realistically) potential customers. It follows from the considerations above that, at least for the British Isles and countries similarly placed, they have to contain rather specific kinds of information and be produced to a regular schedule dictated by the planning requirements of the customers. If forecasts are produced at irregular intervals when it happens to suit meteorologists to do so, they lose most of their potential value.

In dealing with this matter of potential customers, I have digressed from my scientific theme because I believe it to be important that scientists involved in investigations on long range forecasting should not paint too rosy a picture of the possible benefits from their work. In the end that can only lead to disillusionment and to the disbenefit of the science of meteorology. While it is right to be optimistic at this time about the prospects for finding a significant proportion of occasions when useful predictions can be made beyond the "limit of deterministic predictability" (to their credit, many of those engaged in long range forecasting never took the pessimistic view implied by theories of predictability at their face value in any case), the general concept of predictability being limited by error growth and with it the corollary that long range forecasts can with few exceptions only indicate probabilities seems unassailable.

4. LONG RANGE FORECASTS AND CLIMATIC VARIABILITY

Probably the single most useful variable which can be provided by a long range forecast is the average temperature for the month ahead given at a variety of localities over a fairly wide area. The period appears to suit planners concerned with energy use, and the monthly average correlates well with the weather-dependent component of energy consumption variability. It is of course helpful if some indication of the variability through the month can also be given, but it is less obvious how these shorter period variations can be brought into the planning process.

In attempting to produce forecasts for a month ahead, it soon becomes clear that the variability of climate from one period to another is an important ingredient which has to be taken into account. This is illustrated in Figure 8 which shows the Central England temperatures averaged for each April and October for the period 1930-1980. Also shown are the quintiles which divide the frequencies into five approximately equal parts; three sets are shown for each month, referring to the thirty year periods 1930-59, 1940-69, 1950-79 respectively. In the long range forecasts produced by the Meteorological Office, the quintiles are used to delineate average, above or below average, and much above and much below average.

In the 1940s, only one April fell below the long term average, and the quintiles based on frequencies containing that unusual decade differ very markedly from those which do not. For October, the decadal average temperature (indicated on Figure 8 by the triangle) has been above average since 1940, so that the quintiles based on frequencies containing the 1930s (ie 1930-59) are notably at variance with those which do not. The solution might at first sight appear to be to use a longer period on which to base the quintile definitions, but this might make things easier for the forecaster while removing much of the potential benefit from the forecasts. On the other hand the period of thirty years is a reasonable approximation to what might generally be considered as 'within living memory', and as such is probably the best period to use for this purpose. A better

Central England Temperatures

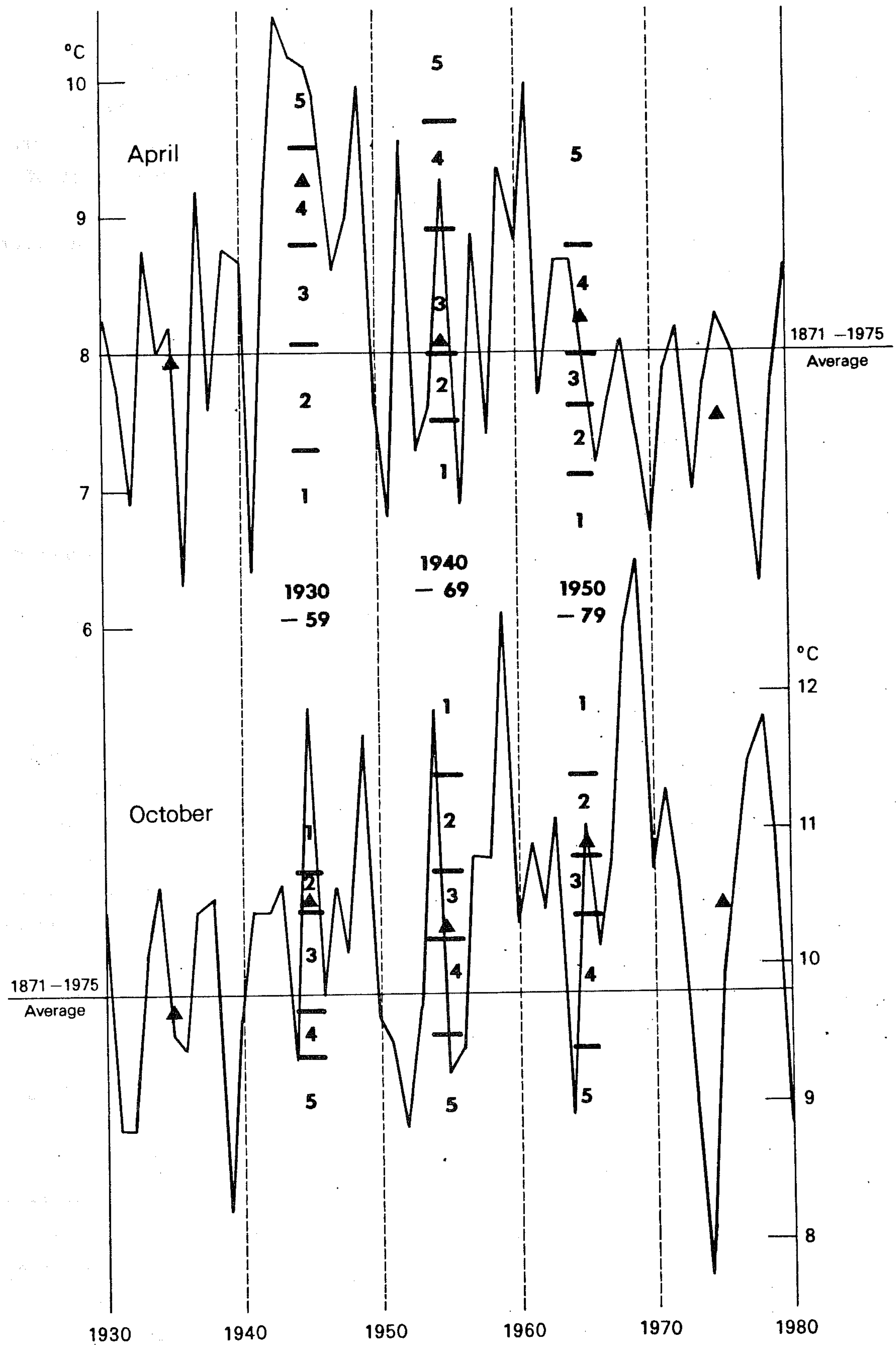


Fig. 8 Central England temperatures for April and October for the years 1930 to 1980, shown with reference to the 1871-1975 average. Triangles indicate the decadal mean temperatures. Short horizontal lines indicate quintiles separating classes with approximately equal frequency in the 30-year periods 1930-59, 1940-69, 1950-79.

solution could be to retain the use of thirty years to define the average, while basing the quintiles on the variation about a moving average over a much longer period.

The effects of climatic variability are also evident in the success markings for the Meteorological Office long range forecasts, shown in Table III:

TABLE III

Meteorological Office long range forecast scores for temperature using the Sutcliffe marking system.

Year	F	P	C	R
1965	205	235	−19	−11
6	107	−16	51	19
7	165	162	178	67
8	113	20	121	43
9	235	68	−157	−59
1970	293	143	21	10
1	29	59	168	61
2	87	202	163	49
3	55	98	215	81
4	173	214	−51	−19
5	142	50	3	7
6	154	297	45	12
7	−34	−19	−54	−8
8	−146	−100	−89	−29
9	78	101	−104	−35
1980	73	−65	134	56

F – Score for the long range forecasts.

P – Score for persistence ie assuming that the temperature in the forecast month will lie between the same quintiles as that in the previous month.

C – Score for climatology ie assuming that the temperature in the forecast month always lies between the second and third quintiles.

R – Score for a random choice, with an equal probability of forecasts lying in the five possible categories.

The scoring system, set out by Sutcliffe in the early days of the public issue of forecasts is shown in Table IV:

TABLE IV

	ACTUAL				
F/C	1	2	3	4	5
1	4	2	0	-2	-4
2	1	4	1	-2	-4
3	-3	1	4	1	-3
4	-4	-2	1	4	1
5	-4	-2	0	2	4

Alternative scoring systems are of course possible and some of them have desirable properties which the Sutcliffe system does not and vice versa. For general purposes this system is considered to be the most suitable. It is applied twice monthly to the forecasts for 10 regions of the British Isles for which quintiles have been established independently so that the maximum possible score for the year is 960.

The figures in Table III indicate surprisingly large changes from one year to the next, from one decade to the next. The forecasts were less successful in the 1970s even though the score for persistence was generally higher. 1978 was a particularly bad year for the forecasters and it coincided with the worst score for persistence.

From Table III it appears that forecasts may have to be produced for a protracted period before it is possible to assess their general level of skill accurately; and that the success rate may be different in different types of climatic situation - in the forecast series dealt with here, there is some evidence that the 1960s may have been easier for forecasting because reasonable analogues, particularly from the 1890s, seemed more relevant than those available for the 1970s.

The assessment of the success rate for long range forecasts given above is incomplete in that only one measure of success has been shown and it is universally recognised that any one measure may be, and frequently is, misleading. Despite their obvious limitations, subjective assessments, if carried out in an unbiased way, have significant advantages in that they have the flexibility to recognise, and give due credit to, aspects of the forecasts which provide useful information; for example, the forecast category may give a very good indication of general conditions for the month despite being in the wrong category because of a few extreme days. For the Meteorological Office forecasts the subjective assessments carried out independently of the long range forecasters indicated a higher level of success than the Sutcliffe scores above.

5. COMMENTS ON LONG RANGE FORECASTING TECHNIQUES USED IN THE METEOROLOGICAL OFFICE

For the most part the methods used to produce long range forecasts in the Meteorological Office have depended on the recognition of analogues in the historical data. Many variations of the basic technique have been tried (see for example Murray (1970)). Initially they were based on monthly mean temperatures at the surface over a fairly limited area of the globe, and the choices were made subjectively. Later, methods were introduced which gave weight to the sequence of synoptic types in the month or which made the choice of analogues on the basis of squared differences between eigenvector amplitudes, or which relied in part also on ideas akin to those of cluster analysis to select the best analogues. The success achieved by the methods was variable leading to periods of optimism or pessimism about their usefulness. It became clear however that the variations were not leading to an upward trend in the level of success; furthermore the methods led to no improved understanding of the reasons for success or failure. While such methods may provide a fall-back technique which can be applied in all situations to achieve some measure of guidance, further improvement of long range forecasts depends on the introduction of more physically-based ideas.

A relationship between sea-surface temperature and atmospheric developments is one possibility that has been considered by the long range forecasting group over a number of years. The variable quality, questionable representativeness and uneven distribution in space of sea-surface temperatures give rise to uncertainties in the analyses which are unlikely to be wholly resolved until more reliable and homogeneous measurements are available. It may be hoped that they will come from a satellite system, but formidable problems concerning the accuracy of the retrieved temperatures remain to be solved.

In the Meteorological Office the first investigations in this topic were reported by Ratcliffe and Murray (1970). Some of the problems raised in using sea-surface temperature can be seen by examining Figures 7 and 8 of that paper. Years with notable cold and warm sea temperature anomalies near Newfoundland were selected as in Table V.

TABLE V

JANUARY

Cold	1890 > 2°C 1891 > 2°C 1895 1–2°C 1896 1–2°C 1898 > 2°C	1910 1–2°C		1956 ?	1965 ?
Warm	1892 1–2°C	1915 > 2°C	1921 > 2°C 1924 > 2°C 1925 1–2°C 1927 > 2°C	1951 ? 1952 ? 1958 ?	

The years for which the anomaly is shown as ? are those of which Ratcliffe and Murray say "the position and intensity less certain". Values such as those shown obviously raise the possibility that what was being examined was a relationship which was not casual, but arose because sea temperatures and atmospheric variables both have large low frequency components in their variability.

Another example illustrating the difficulties associated with sea-surface temperatures may be taken from investigations undertaken to verify the results of a sea-surface temperature anomaly integration. Figures 9 and 10 summarize the results of a general circulation experiment using the model in its July configuration. The effect of inserting an anomaly of maximum value 2 K in a belt across the tropical Atlantic was to raise surface pressure to the north of the anomaly, by an amount which, judged against the variance of daily values, was highly significant. Figure 9 explains the experiment and the result. Figure 10 represents an attempt to verify the result against real data. Each plotted value on the latter diagram is a year in the period 1949-69. The abscissa is the average sea-surface temperature for July-August for an area of the tropical eastern Atlantic for which observations were relatively plentiful and the ordinate is the zonal component of the geostrophic wind derived from the surface pressure charts for an area which the experiment indicated should be sensitive to the sea surface temperature anomaly. The correlation coefficient of .61 is probably larger than could reasonably be expected from an experiment of this kind, partly accounted for by the fact that although the areas involved were selected objectively, the months were those which produced the highest correlation. However the greatest weakness of the attempt to verify the experimental result is that the sea-surface temperatures had to be estimated subjectively from observations which had a great deal of scatter.

A second attempt at verification was made when a more complete data set was available, and measures had been taken to control the observations for quality in a completely objective way. Figure 11 shows the result of correlating the sea-surface temperatures in the area indicated near the African coast (the area where observations are most dense) with the zonal geostrophic wind component derived from the August surface pressures for the area where the correlation is plotted. The results are in general accord with those of Figure 10, though as expected the correlations are somewhat lower. However, when the data set was extended to include additional years, the results of Figure 12 were obtained. Although the sign of the correlations remains the same, their level over the Atlantic is so reduced that they are probably not significant.

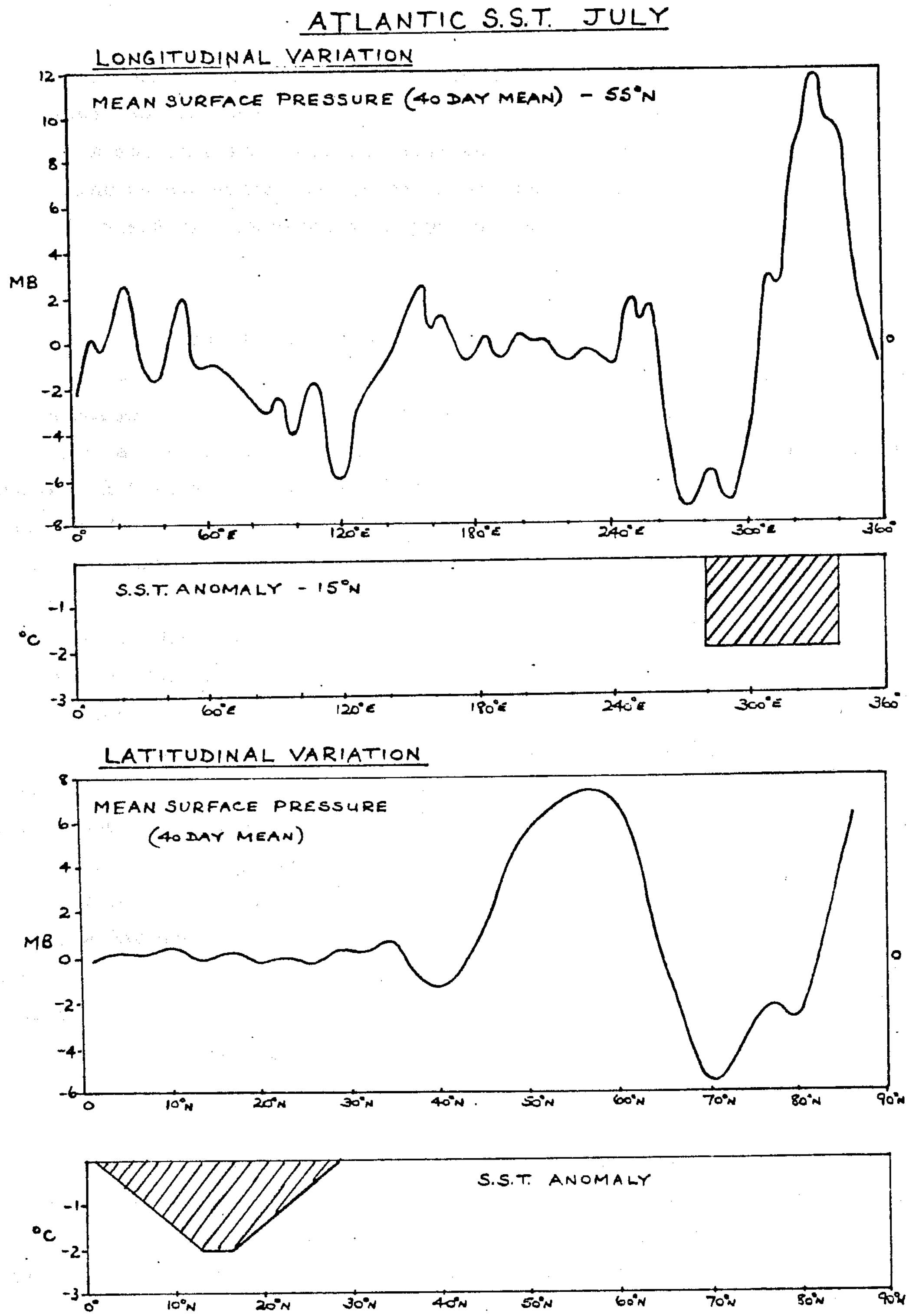


Fig. 9 A general circulation model response to an imposed sea-surface temperature anomaly across the tropical Atlantic.

First inset: anomaly minus control, 40-day mean surface pressure at 55°N.

Second inset: the longitudinal extent of the sea-surface temperature anomaly.

Third inset: anomaly minus control, 40-day mean surface pressure variation with latitude; averaged over the longitudes where the anomaly was imposed.

Fourth inset: the latitudinal variation of the imposed sea-surface temperature anomaly.

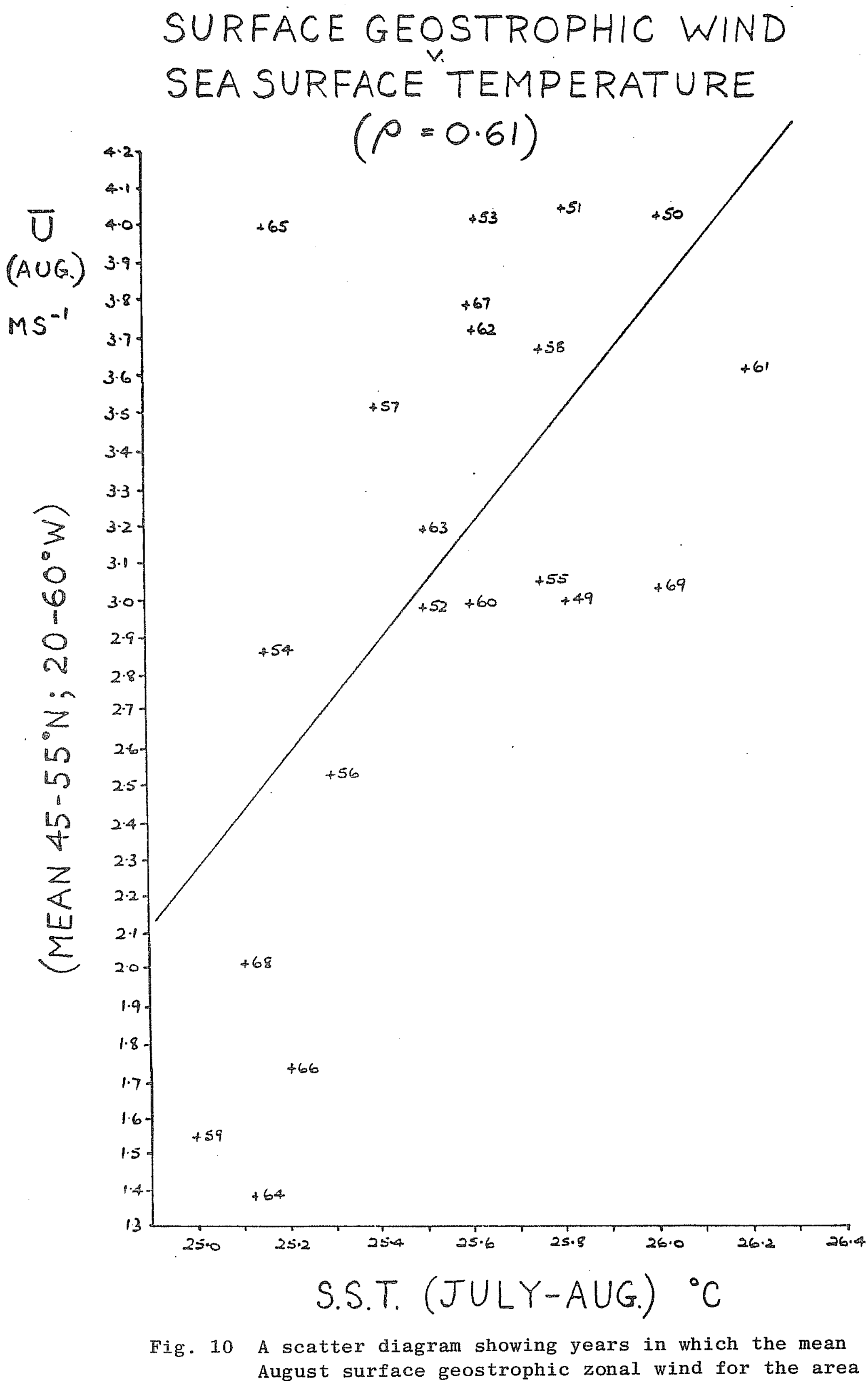
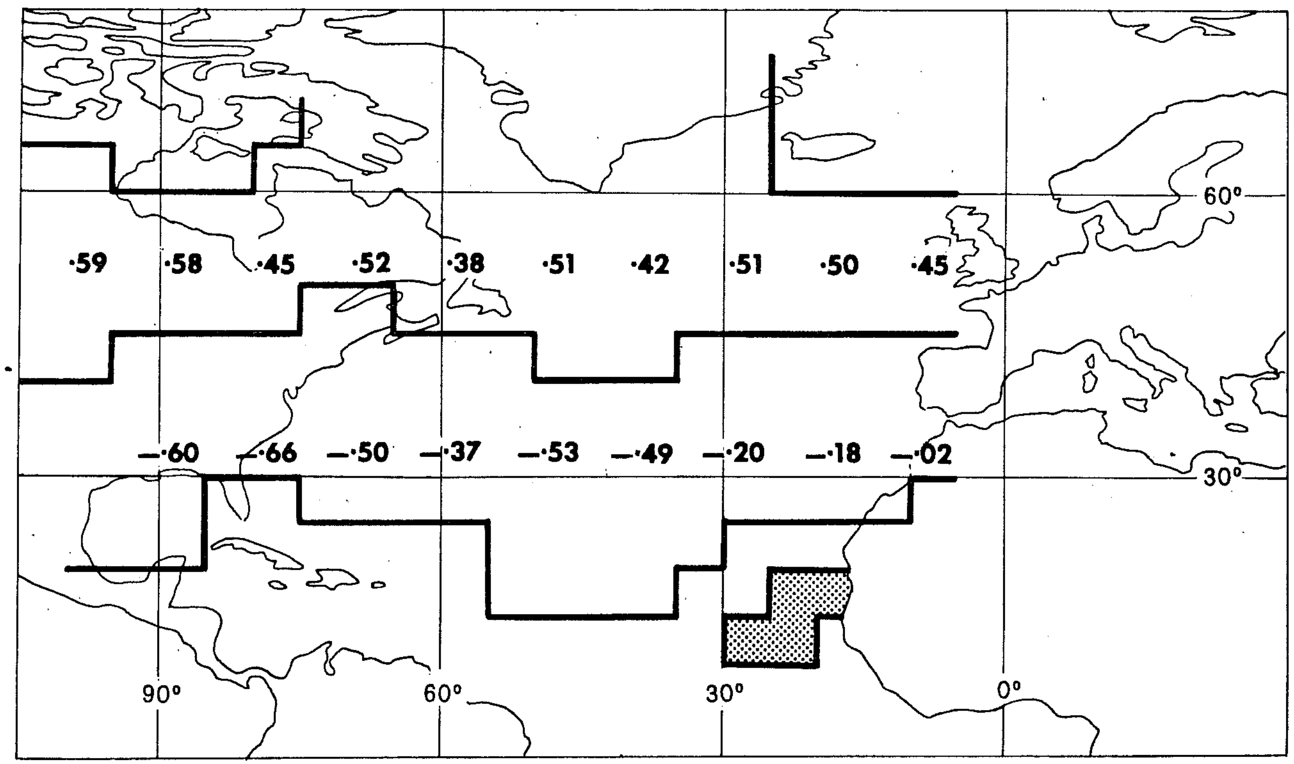


Fig. 10 A scatter diagram showing years in which the mean August surface geostrophic zonal wind for the area 45^{O}-55^{O}N, 20^{O}-60^{O}W was as shown on the ordinate and the average sea-surface temperature in an area off West Africa for July-August was as indicated on the abscissa. Years used - 1949-69.

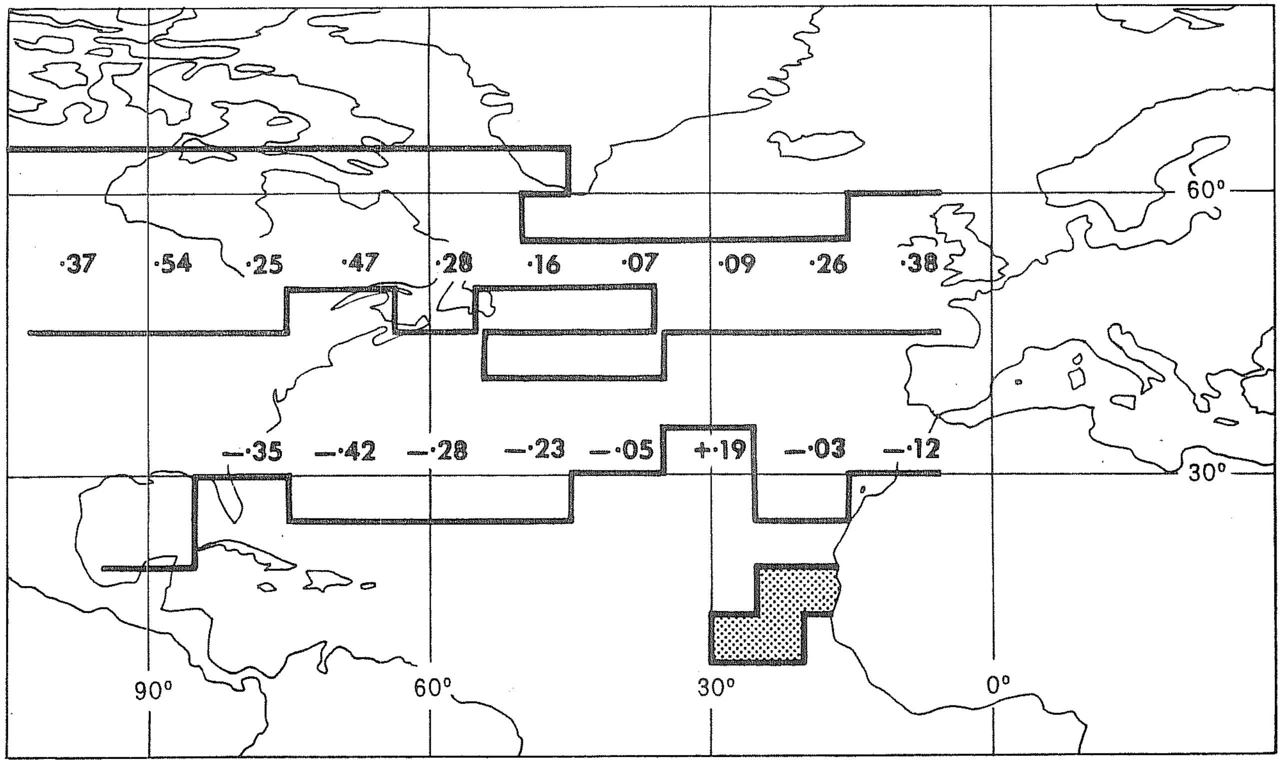
Correlations August 1949 – 69



$\bar{u}$ v SST in stippled area

Fig. 11 Correlation of mean August surface geostrophic zonal wind at the position where the correlation coefficients are plotted against the contemporaneous sea-surface temperatures for the stippled area off West Africa. Years used - 1949-69.

Correlations August 1951 — 80



$\bar{u}$ v SST in stippled area

Fig. 12 As Fig. 11, but using data for the years 1951-80.

The investigation of the effect of sea-surface temperatures on subsequent atmospheric developments is one of the most important areas for investigation in the field of long range forecasting. However, substantial effort needs to be devoted to it to overcome the many difficulties involved. It has benefitted very much from the use of numerical models but it is essential that whatever effort is committed to that aspect of the problem has to be matched by an equal effort to obtain and analyse reliable observational data.

6. CONCLUSIONS

1. From a purely pragmatic point of view, the possibility of useful long range forecasts rests upon the existence of significant spells of temperature and rainfall anomalies. Although this by no means guarantees that the forecasts are possible, it provides good grounds for hope that they are.

2. Practical long range forecasting is really about providing guidance for a relatively small number of important customers whose particular interests enable them to benefit from a series of forecasts in which the skill may be rather small. The forecasts for which there is real need are of surface temperatures and rainfall.

3. Methods of long range forecasting have so far been based on an interpretation of the historical record in some form or other. They have generally produced results which have had at best only moderate success, the main reason for this being that the historical record is not long enough to define and adequately test the methods.

7. REFERENCES

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