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The UK winter of 1989/90

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Temperature predictions for the UK winter

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Summary

The suggestion that the shape of the late autumn circumpolar vortex can be used to forecast UK winter temperatures is discussed and a simple mathematical predictor proposed. This predictor is assessed using correlation tests on a 44-year data set; investigating also the predictability of individual months and the value of different predictor periods. A simulation of real-time forecasts suggests that useful skill could have been achieved.

1. Introduction

Several articles appearing in *Weather* over the last 10 years have dealt specifically with long-range temperature predictions for the winter period in the United Kingdom. The prediction method used was essentially statistical and was based on upper-air patterns occurring across the higher latitudes of the northern hemisphere during October and November. It was first described by Davies and Reeve (1980). In Davies *et al.* (1986) a simple verification of the technique against 17 winters, although not conclusive, did give reason to believe that useful skill could be achieved. A similar but more quantitative approach used in Davies (1989) and Ratcliffe (1990) produced equally encouraging results. Again, though, the databases analysed were rather small, being 10 and 12 winters respectively.

In this investigation a quantitative adaptation of the prediction method described in Davies *et al.* (1986) is tested out on a 44-year data set. This begins in section 3, and included is an attempt to identify the best 'predictor' periods and also the 'most predictable' parts of the winter. In section 6, real-time predictions are simulated for the last 19 winters, by creating for each winter new regression equations based only on previous years. Section 2 gives a comprehensive description of the physical mechanisms underlying the statistics.

To put this study into some sort of context it is worthwhile considering which, to date, have been the most accurate long-range UK temperature predictions. Excluding the aforementioned leaves those of Murray (1972 and 1977) as perhaps the best. In a five-category system he achieved about 7 correct forecasts out of 24.

A major incentive for this work was that the financial worth of accurate long-range forecasts would be very great indeed.

2. Physical background

2.1 Link between autumn upper-air patterns and winter temperatures

Hughes (1981) investigated 'Central England' temperatures in 357 winter months. Of the 52 he classified as 'very cold', 48 were of a north-easterly, easterly or south-easterly type. This is clear evidence that winter temperatures in the United Kingdom are very closely related to wind direction. It is of course the atmospheric flow patterns which dictate the wind direction; these can be divided into two simple categories:

(a) a mobile westerly type giving above average temperatures, due to anticyclones to the south of the British Isles, and

(b) a blocked easterly type giving below average temperatures, due to anticyclones to the north of the British Isles.

As far as the predictive method is concerned the main factor affecting the probability of either (a) or (b) occurring is considered to be the forcing effect of 'boundary conditions' occurring at the earth's surface during the winter. Boundary conditions likely to be important are sea surface temperatures, snow cover and sea-ice cover; it is principally the forcing effect of sea ice which is being considered here. This is the same mechanism alluded to in Davies *et al.* (1986), and in earlier work. (Davies (1989) proposes a different mechanism, in which the ***high*** pressure present at high latitudes in cold winters is explained by net poleward *mass* transport 1–3 months earlier.)

Observational studies indicate that the sea-ice pattern sets itself for the winter late in the autumn (Davies *et al.* 1986). The shape of this pattern should depend largely on the distribution of cold air around the North Pole in October and November; a distribution which will be evident from upper-air patterns. Thus there should be a connection between upper-air patterns around the North Pole late in the autumn, and winter temperatures across the United Kingdom.

A good guide to the distribution of cold air around the North Pole on a given date can be gained from circumpolar 1000–500 mb thickness charts. Contour height charts for the lower stratosphere (e.g. 100, 200 mb) also provide a good guide, as low contour heights at such levels usually reflect the presence of deep, cold tropospheric air below. Most patterns on these charts can be approximated by an ellipse, such that the lowest thickness values or lowest contour heights (and hence coldest air) are in alignment with its major axis. It then seems reasonable to expect the most pronounced sea-ice development to be in that direction too.

The original prediction method entailed analysing one chart per day for (say) a 30-day period and identifying the direction of orientation of the major axis on each. Then from these 30 directions a polar diagram was constructed to represent the frequency of each direction of orientation. This diagram was the basis for the winter prediction, whereby a large east–west component on it pointed to a high probability of the cold flow pattern (b) occurring, whilst if other orientations were dominant the chances of getting mild type (a) conditions were increased.

2.2 The importance of the east–west component

To understand the significance of the 'east–west component' the following 'thought experiment' should prove helpful.

> During winter the higher latitudes of the northern hemisphere have to accommodate a certain amount of deep, cold, tropospheric air. For convenience consider 'higher latitudes' to be north of 50° N. The 'certain amount' can be represented by a domain of any shape whose area is equal to that bounded by a latitude circle at 65° N. What then will dictate the possible configurations of this domain? In other words how easily can different locations support the presence of very cold air above (see Fig. 1)?

Sea water rapidly modifies very cold air, warming it up through vigorous convection. Sea ice, snow and land have a much smaller modifying effect; mainly because their heat capacities are lower, but also because only in sea water is it possible to redistribute heat rapidly by advection and mixing. So the main restriction on the configuration of the cold air domain is that it cannot be allowed to encroach very far into sea areas ('seas open all year' in Fig. 1). Given a homogeneous planet the most likely configuration would be a circular one centred on

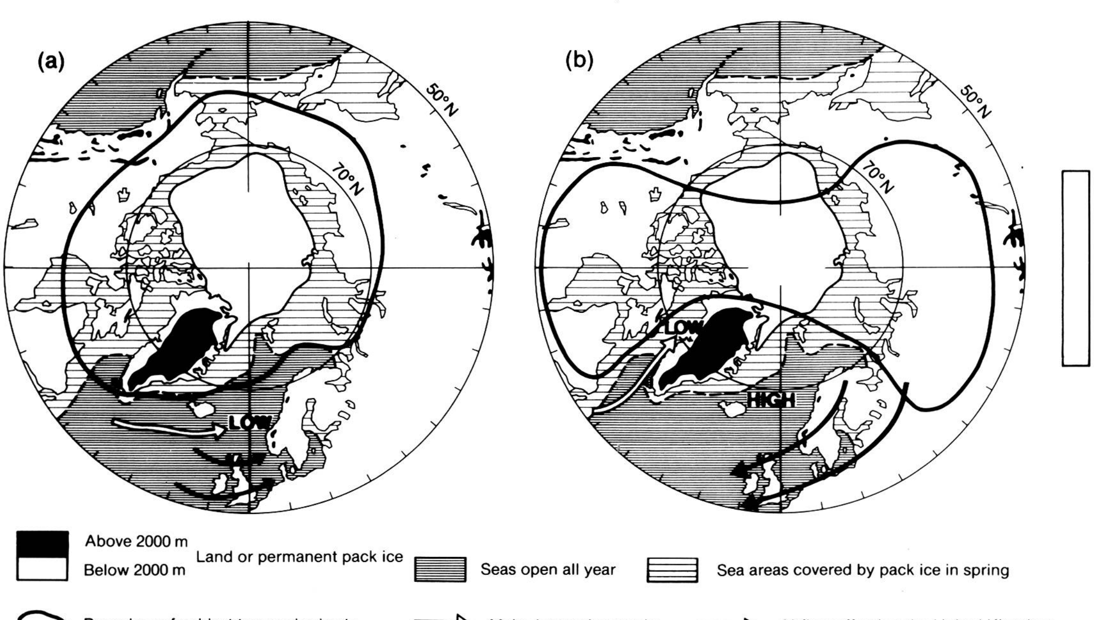

Figure 1. Circumpolar maps illustrating how the distribution of cold tropospheric air around the North Pole in winter can dictate which airstreams affect Britain: (a) mobile westerly, (b) blocked easterly. The block alongside represents *1.6×10^6 km^2, a measure of the extreme interannual variability of winter sea-ice cover (see text).

the North Pole, but clearly this is disallowed here because of the presence of seas north-west of Norway.

Fig. 1(a) shows a configuration which is about as close to the circular type as it is possible to get. This type of pattern is quite common. It is best thought of as representing an average over several days (in reality short-wave troughs would be observed to run east around the vortex, at least across the Atlantic). Such a pattern would be accompanied by a strong baroclinic zone extending east or north-east across the Atlantic, with deepening depressions tracking between Iceland and Scotland. This results in mild south-west or westerly winds prevailing over the United Kingdom, but with some colder outbreaks of north or north-westerlies.

Fig. 1(b) illustrates another configuration in which the cold air has almost split up into two centres. The land–sea distribution dictates that if there are going to be two major centres then these must be located over the Soviet Union and North America. This type of pattern is also fairly common, though not nearly as common as (a). The southward displacement of cold polar air over Canada results in a backing of the jet stream south of Greenland and in turn this can often steer depressions up the Davis Strait west of Greenland. The resulting warm advection between Greenland and Iceland helps build high pressure to the east of Iceland, or perhaps reinforce a Scandinavian anticyclone. In this way the United Kingdom comes under the influence of east or north-easterly winds. If these are fuelled by the cold-air centre over the Soviet Union it can become very cold indeed (as happened for example in February 1956, January 1972 and January 1987).

Synoptic charts indicate that there are many possible configurations of the very cold air, but it is felt that most winter patterns can be roughly approximated by one of the above.

Fig. 2 gives some observational evidence for these ideas. It shows a frequency distribution, as a function of longitude, of atmospheric blocks occurring north of about 50° N during the seven northern hemisphere winters from 1980/81 to 1986/87 (taken from Fig. 1 in Tibaldi and Molteni (1990)). It is immediately clear that there is a strong link between block frequency at a given longitude and the extent of 'sea water' along that longitude, albeit with a small phase shift in the Atlantic/European sector. The two maxima — over the Pacific and the Atlantic — fit in well with the atmospheric pattern in Fig. 1(b). Whilst Fig. 2 partly represents a 'chicken and egg' scenario, it also seems to show that boundary conditions at the earth's surface do have a forcing effect on the atmospheric circulation, in which the main physical mechanisms are those outlined above.

To tackle the forecasting problem one must now consider how the chances of (b) occurring in winter might be influenced by atmospheric patterns occuring in autumn.

If a feedback mechanism which involves sea-ice

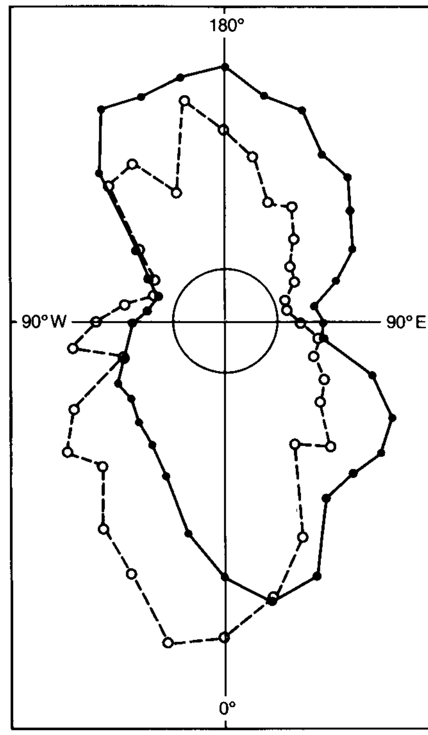

Figure 2. Polar diagram representing winter blocking frequency (solid line) and 'sea water extent' north of 50°N (dashed line) as a function of longitude. 'Sea water extent' was calculated from Fig. 1 to be the sum, along a longitude line, of the total distance occupied by 'seas open all year' and half the distance occupied by 'sea areas covered by pack ice in spring'. Scales are linear, the central circle being zero.

distribution does take place then it is probably worthwhile looking at the areas in which sea ice forms and melts each year. These correspond roughly with the sea areas 'covered by pack ice in spring' on Fig. 1 — subsequently referred to as 'key areas'.

To increase the chances of (b) occurring, and persisting for some time, it seems important that the key areas which fall within the domain have as great a cover of sea ice as possible during the winter because this would reduce the chances of the cold air being warmed out from below. Equally important, perhaps, is that the key areas which fall outside the domain in (b) have as little sea-ice cover as possible. Reducing the amount of sea ice in these areas which fall outside the domain in (b) would also seem to make (a) less likely.

Such an explanation would only be plausible if the interannual variability of winter sea-ice cover were reasonably large. The box drawn alongside Fig. 1(b) represents* the difference between the greatest and least 'mid-winter' areal extents of sea-ice (defined as where cover is greater than 10%) observed between 1973 and 1989 (data from NOAA, USA). Here the term 'mid-winter' means averaged over a 2-month period beginning

* The maps in Fig. 1 are on a zenithal equidistant projection, implying that the ratio between area on the page and area on the earth's surface is not quite fixed, but a slowly varying function of latitude. The area of the block alongside is normalized to 65° N. If normalized to 90° N, the area would be 3% smaller than shown, or to 50° N then 5% larger.

1 January. This area is considered large enough to support the above arguments (especially as energy considerations suggest the attendant anomalies in sea surface temperatures might be even more marked — the latent heat of fusion of ice is about 80 times greater than the specific heat capacity of water).

How then can sea-ice patterns which favour pattern (b) come about? The formation of sea ice must to some extent depend on the distribution of cold air around the North Pole during October and November, and naturally a distribution similar to that indicated by the domain in (b) is going to favour sea-ice development in the right areas. If this domain were approximated by an ellipse the orientation of the major axis would probably be 90°W — hence the importance of the 'east-west component'. The longer such a pattern persists during the autumn the greater will be the chances that the desired sea-ice patterns have developed.

It is also worthwhile outlining two of the limitations of these ideas. Where sea ice develops will partly be determined by the early autumn sea surface temperatures; no real account of this is taken here. Also an over-simplified view of sea ice has been taken. Rarely if ever does it have a well-defined edge — the distance in which the fractional cover of sea ice ranges from 10/10 (pack ice) to 1/10 can easily be over a hundred miles.

3. Method

In Davies *et al.* (1986) the retrospective temperature predictions were based on subjective analysis of the shapes of polar diagrams, whilst for the verification all winters were classified into just two categories, cold or mild. Here the intention was to improve upon this by adopting a quantitative approach. The polar diagram's shape would be represented by a single number, or 'winter index'; and actual temperature levels would be used in preference to categorized ones.

3.1 Data sources

Clearly two basic types of data were required: autumn upper-air charts to base the 'predictions' on, and winter temperature levels to verify against. The number of years it was possible to investigate was limited to 44 because of a lack of appropriate upper-air charts before 1946.

3.1.1. Upper-air charts

Davies concluded that November's charts would probably be a more useful guide to winter temperatures than those of October, perhaps because more sea ice forms in November than October. Thus this study concentrates on late in the autumn, using a 45-day period from 17 October to 30 November in every year.

The choice of which types of chart to use was determined by two factors, availability and suitability. The 100 mb level proved most suitable, indeed frequently the contours at this level are roughly elliptical (wave number 2), as the smaller more transient wavelengths rarely have much amplitude by the time they reach this height in the atmosphere. The 200 mb level was next best, followed by the thickness patterns. Consideration was given to using 50 mb charts, but at this level the patterns were too close to circles to be of any use. So 100 mb charts were used wherever possible (1960 onwards), thickness patterns for years when only they were available (1946–57), and 200 mb charts for 1958 and 1959. It was felt that the disadvantages of using different chart types were far outweighed by the advantages of having a long data set.

All charts were necessarily of the northern hemisphere circumpolar type, and there was one for each day, the analysis time usually being midnight. They came from three sources — the *European Meteorological Bulletin* for 1976 onwards, the Soviet SINOP bulletin for 1958–75, and the Meteorological Office (hand plotted) for 1946–57.

Scarcity of observations made it quite difficult using some of the 1946 and 1947 charts. There is, however, a fair degree of confidence in the orientations found for these years, particularly 1946.

3.1.2. Temperatures

The UK *Monthly Weather Review* provided the winter temperature data to verify against; as anomalies from 30-year climatological means for the England and Wales region. Scotland and Northern Ireland were excluded on the grounds that, with a relatively wide expanse of sea to the east, temperatures there would be less sensitive to a change in wind direction from west to east.

Anomalies were extracted for both the individual winter months and the winter as a whole; assuming for convenience that 'winter' is comprised of December, January and February.

3.2 Derivation of the winter index

In order to create a winter index, a simple weighting system was devised whereby each occurrence of a particular orientation of the circumpolar vortex on the upper-air charts scored a set number of points. The final winter index was then calculated by summing the points scored in a given period, such as 1–15 November; the idea being that the magnitude of this score was indicative of the likely severity of the forthcoming winter. Table I shows the weighting system used — the choice of 'scores' is explained below.

Table I. Weighting system for calculating winter indices

Point score	Orientation 60°W	70°W	80°W	90°W	80°E	Others
Axis ratio ⩾ 2:	2	4	4	4	2	0
Axis ratio < 2:	1	2	2	2	1	0

From past studies it is apparent that the important 'east–west component' is made up principally of orientations 70° W, 80° W and 90° W; hence these directions are afforded the highest weights of all (subsequently referred to as 'COs', meaning 'cold orientations'). Physically there is only a small difference between two adjacent orientations, such as 60° W and 70° W, or 90° W and 80° E. So for consistency it was felt that some weight had also to be given to 60° W and 80° E; half the score allocated to the COs was chosen. This also meant that the relationship betweeen 'orientation' and 'score' was free from large discontinuities.

Davies *et al.* (1986) also defined 'mild orientations' as being those between 0° W and 50° W; saying that out of all possible orientations these were the ones most likely to precede mild winter weather. To take account of this, negative scores could have been added to Table I for all orientations between 0° W and 50° W. The reasons for leaving them scoring zero were twofold: Davis had generally put much more emphasis on the COs, and the COs were far more common — occurring more than twice as often as the mild orientations.

Within any subjective analysis of archived data, unfortunately there is always scope for the analyst to interpret the data in a way which will lead to results which are more interesting or more significant than would have been the case had an objective analysis been used. Here, for example, it was not always possible to approximate the atmospheric pattern with an elliptical shape. Sometimes the patterns were almost circular making a direction of orientation much harder to identify precisely. To reduce the impact of this problem two sets of scores were incorporated into the weighting system (one being simply a factor of two greater than the other). For the atmospheric pattern on a particular chart to realize the higher of the two scores the necessary condition was that the 'axis ratio' (meaning the ratio of the length of the major axis to the length of the minor axis of the ellipse judged to best fit the atmospheric pattern) was greater than or equal to two. This approach is also physically consistent with the ideas presented earlier, because the greater the axis ratio the more elongated will the cold polar air have become, and thus the greater will be the forcing of sea-ice development along that direction of elongation (i.e. the orientation).

Fig. 3 shows one of the 100 mb charts used. To approximate the contour pattern with an ellipse the analyst must concentrate on the area north of 50° N, as this is where most of the sea ice will be forming. With this guideline in mind it should be fairly easy to see why the orientation came out as 90° W and the axis ratio about 3; giving a score of 4. Most patterns were easier to approximate with an ellipse than this one.

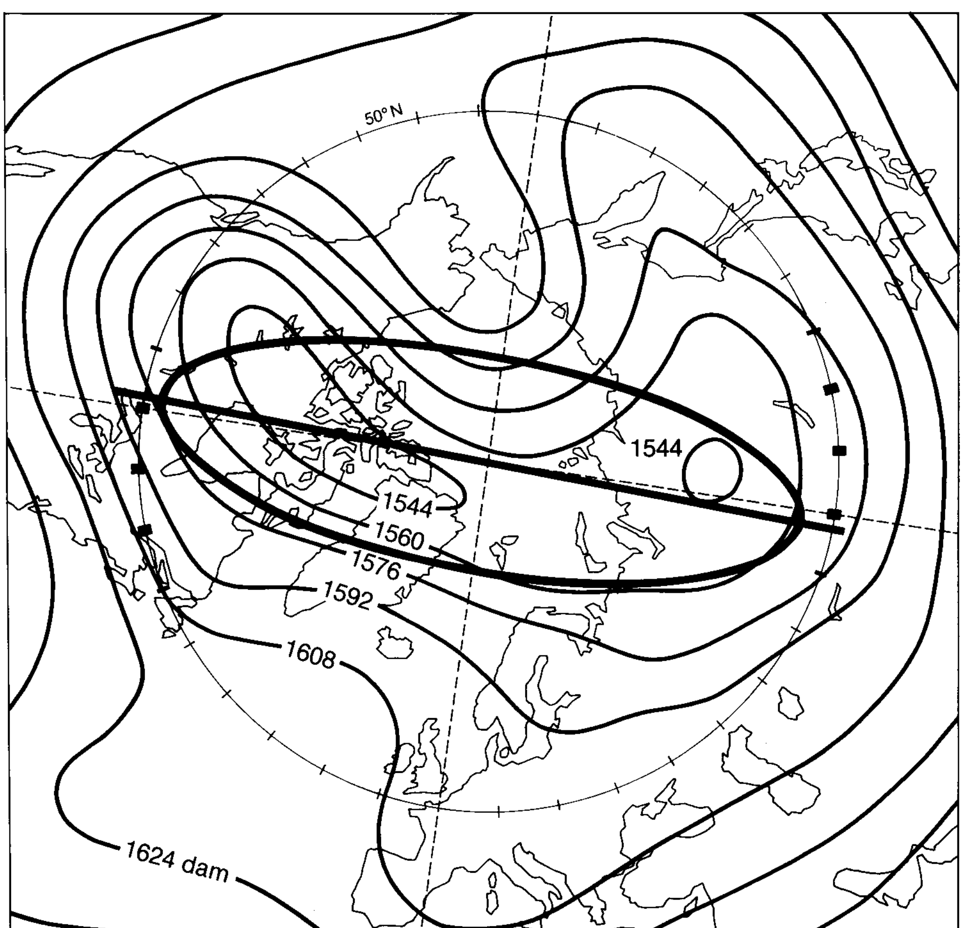

Figure 3. 100 mb analysis for 0000 UTC on 24 November 1985, with ellipse superimposed. Tickmarks are at 10° intervals.

So to calculate the winter indices the following procedure was adopted:

(a) On each chart the direction of orientation of the circumpolar vortex was identified (45 charts for each of the 44 years).

(b) On those charts where the orientation was 60° W, 70° W, 80° W, 90° W or 80° E the axis ratio was also calculated.

(c) According to the results of (a) and (b) a points score (0, 1, 2, 4) was assigned to each date.

(d) The points scored in a given period were summed. This sum was the winter index.

Initially four indices were calculated for each year; one for the 45-day period, and also one for each of the 15-day periods 17–31 October, 1–15 November and 16–30 November (see Table II). By dividing up in this way it would be seen whether or not the predictive value of an index depended on the part of the autumn on which it was based.

4. Results

As the winter index increases so should the temperature of the winter months, on average, decrease.

Table II. Winter indices and temperature anomalies for England and Wales, 1946–89

Year*	Winter index (WI)				Temperature anomalies (TA) — England and Wales (°C)				WI	TA
	17–31 Oct.	1–15 Nov.	16–30 Nov.	17 Oct.– 30 Nov.	Dec.	Jan.	Feb.	Winter mean**	1–30 Nov.	Jan. and Feb. mean***
1946	18	20	50	88	−1.4	−2.1	−5.7	−3.0	70	−3.8
1947	0	9	17	26	0.7	1.1	0.4	0.7	26	0.8
1948	4	1	5	10	1.1	1.2	1.4	1.2	6	1.3
1949	4	10	5	19	1.2	0.2	1.3	0.9	15	0.7
1950	12	10	42	64	−3.1	−0.3	−0.5	−1.3	52	−0.4
1951	7	29	20	56	1.0	−1.3	−0.8	−0.4	49	−1.1
1952	36	33	12	81	−1.4	−0.6	0.1	−0.7	45	−0.3
1953	8	11	9	28	2.6	−1.1	−1.7	−0.0	20	−1.4
1954	15	41	17	73	2.1	−1.3	−2.7	−0.6	58	−2.0
1955	4	15	23	42	1.3	−0.3	−4.4	−1.0	38	−2.3
1956	12	19	11	42	1.3	1.4	1.1	1.3	30	1.3
1957	16	38	30	84	0.0	−0.5	0.7	0.0	68	0.1
1958	4	19	34	57	0.2	−2.1	0.2	−0.6	53	−1.0
1959	16	30	10	56	1.4	0.1	−0.2	0.5	40	0.0
1960	12	25	7	44	−0.5	−0.3	2.7	0.6	32	1.1
1961	17	8	7	32	−1.8	0.4	0.3	−0.4	15	0.4
1962	9	46	38	93	−2.3	−5.3	−4.5	−4.0	84	−4.9
1963	4	0	5	9	−2.0	−0.3	0.5	−0.6	5	0.1
1964	22	3	39	64	−1.2	−0.1	−0.7	−0.7	42	−0.4
1965	17	56	8	81	−0.2	−0.7	1.7	0.2	64	0.4
1966	2	47	28	77	0.5	0.7	1.6	0.9	75	1.1
1967	0	28	5	33	−0.5	0.7	−1.7	−0.5	33	−0.4
1968	0	21	32	53	−1.5	1.9	−2.8	−0.7	53	−0.3
1969	50	5	14	69	−1.4	0.1	−0.7	−0.7	19	−0.3
1970	5	5	49	59	−0.5	0.9	0.9	0.4	54	0.9
1971	10	14	1	25	1.7	0.2	0.5	0.8	15	0.3
1972	41	12	3	56	1.0	0.9	0.5	0.8	15	0.7
1973	3	13	0	16	0.1	2.5	1.9	1.5	13	2.2
1974	34	8	9	51	3.2	3.2	1.0	2.5	17	2.1
1975	5	3	35	43	0.5	2.2	0.8	1.2	38	1.5
1976	25	12	11	48	−2.3	−0.5	1.5	−0.5	23	0.5
1977	3	0	26	29	1.5	−0.1	−1.1	0.1	26	−0.6
1978	10	23	44	77	−0.3	−3.1	−2.3	−1.9	67	−2.7
1979	16	15	4	35	1.2	−0.9	2.1	0.8	19	0.5
1980	3	12	3	18	0.9	1.2	−0.5	0.6	15	0.4
1981	42	12	2	56	−3.7	−0.4	1.3	−1.0	14	0.4
1982	16	10	19	45	−0.2	3.0	−1.6	0.5	29	0.8
1983	0	5	0	5	1.2	0.2	0.0	0.5	5	0.1
1984	22	43	9	74	0.6	−2.7	−1.3	−1.1	52	−2.0
1985	6	11	41	58	1.6	0.1	−4.5	−0.8	52	−2.1
1986	20	50	19	89	1.2	−2.6	0.0	−0.5	69	−1.4
1987	11	10	23	44	1.0	1.8	1.1	1.3	33	1.5
1988	22	26	8	56	2.6	2.7	2.3	2.5	34	2.5
1989	11	41	9	61	0.3	3.1	3.7	2.3	50	3.4

* Year is the year containing October, November and December.
** Winter mean = (Dec. × 31 + Jan. × 31 + Feb. × 28.25)/90.25
*** Jan. and Feb. mean = (Jan. × 31 + Feb. × 28.25)/59.25

However there is nothing to suggest that any relationship between the two variables would necessarily be linear. Perhaps then the best statistical test to apply to the data sets in the first instance is one based purely on rank.

4.1 Rank correlations

Kendall's coefficient of rank correlation (described in Williams 1986) was calculated for all possible pairings of 'temperature anomaly' against 'winter index', yielding the results shown in Table III.

Table III. Kendall coefficients of rank correlation, calculated for winter indices against winter temperature anomalies; 44 ranks in each case

Winter index	England and Wales temperature anomaly Dec.	Jan.	Feb.	Winter
17–31 Oct.	−0.093	−0.159	+0.081	−0.111
1–15 Nov.	−0.011	−0.273*	+0.007	−0.099
16–30 Nov.	−0.145	−0.172	−0.329**	−0.329**
17 Oct.–30 Nov.	−0.197	−0.327**	−0.158	−0.332**

* and ** indicate significance levels of 95% and 99.5% respectively. No coefficient was significant at the 99.95% level.

The following conclusions can be drawn from the coefficients:

(a) All but two of the coefficients are negative, strongly supporting the idea that higher winter indices point to lower winter temperatures.

(b) Considering December alone, no coefficient quite reaches the 95% level, suggesting little if any predictability. In turn this suggests that the correct prediction of the very cold December in 1981 (Reeve 1982) may have been fortuitous.

(c) Of the three winter months the results for January are perhaps most encouraging, suggesting that some accuracy in long-range forecasts could be achieved here.

(d) For February there are surprisingly large differences between the four coefficients; but there would seem to be some predictability if the late November index were used alone.

(e) November has more predictive value for the forthcoming winter than does late October.

In view of (b), (c) and (d) it would seem sensible not to try to use the winter index to forecast the temperature for the whole winter, but rather to concentrate on forecasting for just January and February.

4.2 A way of preparing future forecasts

Rank correlations help illustrate whether relationships between two sets of variables exist, but they don't really allow a forecast of one to be made knowing the other. Clearly if proper predictions for January and February are to be made then either a graph or an equation relating temperature to winter index will be required.

Least squares regression techniques were employed to achieve this; putting 'best-fit' polynomial curves through the data points. Brooks and Carruthers (1953) suggest using this approach when there is no theoretical guidance as to the nature of the correlation. They also state that rarely in meteorology would there be justification in using anything more complex than a second-order curve (i.e. quadratic). Hence that was what was used. The usual assumptions about data distribution applied.

Three cases were considered:

(a) January temperature compared with a 45-day index (17 Oct.–30 Nov.)

(b) February temperature compared with 15-day index (16–30 Nov.)

(c) January–February temperature compared with 30-day index (1–30 Nov.)

These pairings were chosen after careful examination of the coefficients in Table III; the intention being to match up a given predictand with it's most accurate predictor. Table II shows all data points used, Fig. 4 the fitted curves, and Table IV useful statistics derived from

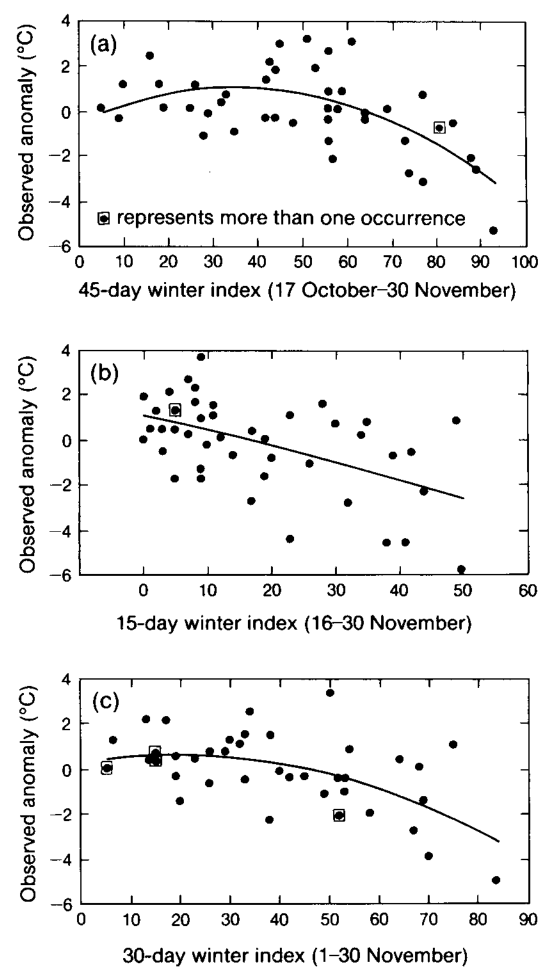

Figure 4. Plots of temperature anomaly against winter index, with best-fit quadratic curves added for (a) January, (b) February and (c) January and February combined.

Table IV. Statistics relating to the graphs in Fig. 4

	(a)	(b)	(c)
Equation (y=)	$-0.00125x^2 + 0.088x - 0.5$	$-0.00015x^2 - 0.066x + 1.1$	$-0.00090x^2 + 0.034x + 0.3$
Variance explained (%)	36	24	28
Significance level (%)	99.995	99.5	99.95
Standard error of estimate (°C)	1.4	1.8	1.4
Prediction accuracy for 75% confidence (°C)	1.8	2.2	1.8

the regressions. Use of both linear and quadratic coefficients was justified at the 95% level only in case (a), but to maintain consistency and facilitate inter-comparison all coefficients were retained in all three cases.

The reader may decide whether there is sufficient justification for making two separate forecasts (using (a) and (b)) rather than just a single forecast (using (c)). The author's view is that two separate forecasts could be made, because the differences between the coefficients for January and February in Table III are so large. However it is acknowledged that no physical explanation has been offered for these large differences.

5. Discussion

Perhaps the most illuminating of the figures in Table IV are those showing 'variance explained'. It would be interesting to see how these figures compared with those produced by other long-range forecasting techniques. Barnston and Livezey (1989) infer that the operational seasonal weather forecasts issued by the Climate Analysis Center in the USA achieve a skill level around 15%. Unfortunately these are categorical forecasts where the skill has been calculated in such a way that comparison with 'variance explained' is not valid. To overcome this problem the points on Fig. 4 were reanalysed as if forecasts in three equi-probable categories had been made. For the three cases (a), (b) and (c) this yielded respective skill levels of 14, 16 and 16% — clearly on a par with the above. This result is particularly encouraging in view of the long lead-time (1–3 months) between prediction and event.

Barnston and Livezey investigated complex analogue-based prediction methods for all four seasons for the USA using a 35-year database. The best skill level they could achieve was 16% for the winter season. There was also an indication that the latter months of the winter (i.e. January, and more especially February) were more predictable than December. This ties in well with conclusion (b) in section 4.1, and suggests that there could be a long-range predictability 'peak' in the latter part of the winter across much of the northern hemisphere.

Namias (personal communication from Davis) has found that November is a better predictor of conditions in January and February in the USA than is October. This is in agreement with conclusion (e) in section 4.1, and so must lend further weight to the results of this investigation.

It is important to consider what level of significance needs to be achieved to justify there being a physical relationship between winter index and winter temperatures. It is common for the 95% level to be used in 'a priori' type regressions — where there is a sound physical reason for expecting a relationship to exist between two variables. Nicholls (1980) states that a higher confidence level is appropriate when the relationship is 'a posteriori' — i.e. with no physical reasoning behind it. This investigation perhaps falls between these two extremes — a physical reason has been given but it is perhaps open to question. Either way the levels indicated in Table IV are too high to be dismissed lightly, even though there was an element of 'selectivity' involved in choosing the predictors. It is worth noting here that in some past papers in this field all sorts of predictors have been investigated, only to find that not much more than 5% of them reach a significance level of 95% (see for example Bergen and Harnack, 1982).

How 'useful' then might a prediction made using the above graphs be? This can be directly answered by quoting the values for 'variance explained'. Alternatively the '75% confidence limits' might be useful — an example will serve to illustrate their worth.

Assuming that having analysed the October and November charts, and calculated a 45-day index, a prediction for January was required. Say the index was 80. This reads off at about −1.5 °C, the most likely temperature anomaly. Then it could also be said that there was about a 75% chance that the temperature anomaly for January would fall between +0.3 °C and −3.3 °C (i.e. −1.5 ±1.8 °C).

The significance levels in Table IV are rather higher than those in Table III. This is partly because the best-fit lines are curves — notably on graph (a). It is interesting to consider what might explain this phenomena. There appear to be two possibilities — one statistical, the other physical. It is probable that both play some part.

The statistical explanation is that the dominance of the squared term is a manifestation of the predictor's ability to foresee cold winters but not mild ones.

The physical explanation arises out of having results which seem to bear out the supposition that the cold-air distributions and main depression tracks on Figs 1(a) and 1(b) are respectively related to low and high winter indices. In this way 'mid-range' winter indices could well be linked to an average cold-air distribution which fell somewhere between Figs 1(a) and 1(b), and thus a main depression track often directed north-eastwards through the Denmark Strait (between Greenland and Iceland). This would result in the UK's weather being dominated by an anticyclone over France, giving mainly south or south-westerly winds, with little chance of getting colder north or north-westerlies. Such a synoptic pattern would usually lead to higher winter temperatures than that shown in Fig. 1(a). So this may be the reason why the mildest Januarys on graph (a) are clustered around a winter index score of 50, and hence why there is a turning point on the fitted curve. Why the graph for February fails to show a similar effect is not clear.

The above explanation gives also a good example of why long-range forecasting is so difficult; because the atmospheric states leading to 'very cold' and 'very mild' conditions can be so close together.

The southern Greenland area seems to be a crucial 'dividing line' between depression tracks which are associated with very different types of winter weather in Britain. One reason for this must be the height of the Greenland ice cap. Note that nowhere else on Fig. 1 is there such a large extent of ground above 2000 m (a fact often lost on topographical maps because permanent ice is usually coloured white). This high ground helps in 'trapping' depression tracks either to the east or to the west for long periods. If then the winter atmospheric circulation is influenced by sea ice it could well be that the distribution around Greenland is most important of all.

6. A real-time forecast simulation

In section 4 a method was developed for preparing forecasts in the future using correlations identified in data from the past. Section 5 gave a discussion of these correlations and in particular the levels of accuracy that one might expect to attain. Whilst this is all statistically sound, it is also slightly speculative in the sense that no real-time test of prediction accuracy was attempted. Thus it was felt necessary to try to simulate a situation in which the method described had been used to prepare forecasts on an operational basis over a period of many years. To do this it was necessary to derive correlation equations of the type shown in Table IV using smaller data sets. The first set of equations would be derived using 15 years of data from 1946/47 to 1960/61. This set would be used to predict the 1961/62 winter, the input x values being winter indices from October and November 1961. The second set would be derived for 1946/47 to 1961/62, to predict 1962/63; and so on up to the last year of the data set. In this way 29 'real-time' forecasts were created, each of which could clearly be verified.

Table V illustrates the accuracies achieved by forecasts in this simulation and how they compared with two control predictions; namely climatology (predicting a zero anomaly every year) and persistence (predicting that the one- or two-month period will have a temperature anomaly equal to that of the same period in the previous year). In all cases the forecasts perform better than both controls, particularly those for January.

Table V. Root-mean-square errors (°C) in the real-time prediction simulation, for the same cases as in Fig. 4

	(a)	(b)	(c)
Simulated forecasts	1.65	1.77	1.49
Climatology	1.96	1.90	1.65
Persistence	2.35	2.41	1.80

For (a), (b) and (c) the variances explained by the predictions were 29%, 13% and 18% respectively. These values are consistent with those shown in Table IV. The fact that they are somewhat lower is not surprising as one would generally expect prediction accuracy to increase as the length of the database increased. Fig. 5 shows how predictions for January fared in each of the 19 years. Whilst it can be dangerous highlighting individual years, it is nevertheless interesting that the −1.4 °C anomaly predicted for the January of the infamous winter of 1962/63, based on just 16 years data, would have come out as −2.5 °C had a 43-year database (excluding 1962/63 itself) been available.

7. Conclusions

A simple, manual, statistical long-range forecasting technique has been developed which appears able to explain an unusually large amount of the variance of winter temperatures across England and Wales — 36% for January, and 24% for February. The lead times for predictions would be 1 and 2 months respectively. The investigation was based on 44 years of data — the significance of the relationships identified being about 99.95%. No skill was achieved in predicting December temperatures. In a simulation of real-time operational predictions over a 19-year period the variance explained reduced to 29% for January and 14% for February. This reduction seems consistent with the reduced database size (averaging 29 years).

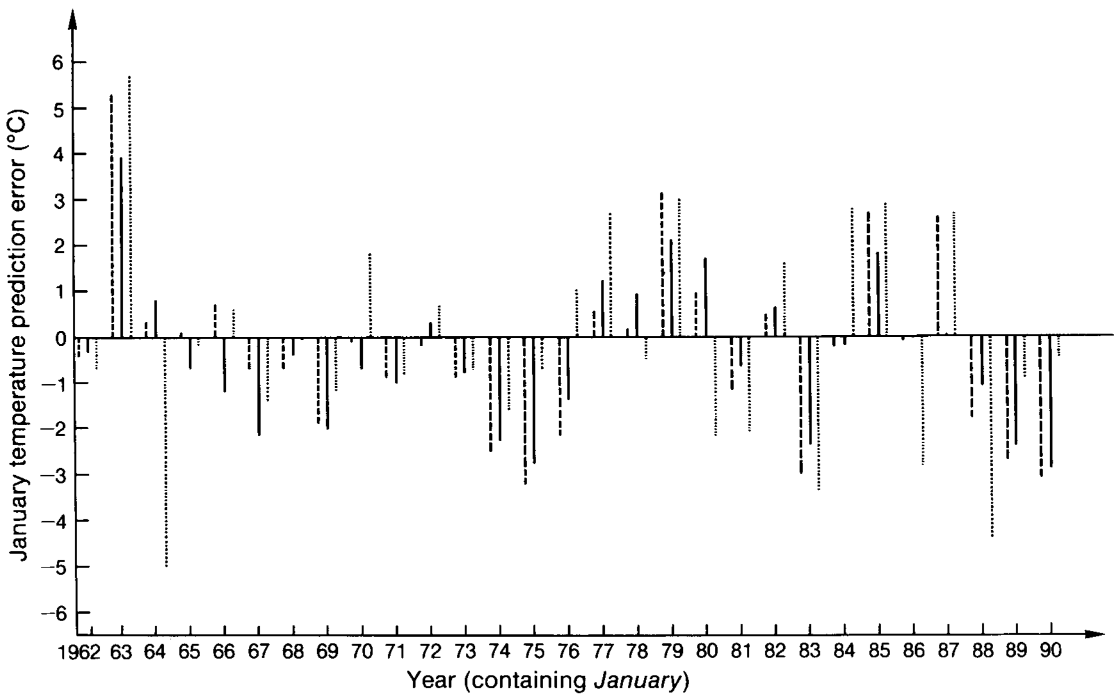

Figure 5. Errors in forecast January temperature anomalies during the real-time prediction simulation (central line of the trio for each year). The lines to the left and right in the trio represent errors in the control forecast — respectively climatology and persistence. (Note that labelling the year corresponding to *January* differs from earlier convention.)

The predictor comes from the distribution of cold air around the North Pole in late autumn. This distribution is thought to partly determine the areas where sea ice develops, which in turn, through feedback effects, partly determine the distribution of the coldest polar air through the winter. The position of the coldest polar air in winter is closely linked to the type of air masses simultaneously affecting Britain. There is some evidence to suggest that when there are anomalously small amounts of sea ice around Greenland, and also (perhaps to a lesser extent) between Alaska and Siberia, the probability of cold winter weather in the United Kingdom increases. Whilst the statistics are consistent with the physical explanation offered, it should be pointed out that they do not justify it. That would require a study based specifically on autumn/winter ice patterns. It is possible that the predictor is representing other physical mechanisms such as the poleward mass transport referred to in Davies (1989).

The lack of past successes has been in part attributable to a complete inability to foresee the development of atmospheric blocks, a problem which this study seems to have gone some small way towards overcoming. Too often in past work predictors have been sought on just local scales, whereas the physical mechanisms at work are probably operating on a hemispheric scale. Part of the problem is that so many of the routinely produced charts available to researcher and forecaster show only a relatively small section of the northern hemisphere — thus obscuring the way in which synoptic events on either side of that hemisphere are intimately linked. The beauty of the charts used in this investigation, aside from being circumpolar, was that the 100 mb level generally used was like a ready-made Fourier breakdown of the more complex atmospheric structure beneath, where only the very long-wavelength features were retained. This made calculating the 'winter indices' extremely easy — such that it would take only about 1 hour's work to come up with prediction(s) for the following winter.

It is likely that the winter indices described could also yield useful skill in forecasting winter temperatures for other countries in western Europe. France, Belgium and The Netherlands immediately spring to mind as the presence of warm sea to the west and a cold continent to the east make the peculiarities of their winter climates similar to those of the United Kingdom.

Future research could centre on the actual winter sea ice and sea surface temperature distributions, to see whether they genuinely do relate to both the winter and autumn circulation patterns. Lack of a well defined edge to most sea ice, and lack of sea-ice data in general, mean this task would not be easy though. The earlier assertion that sea surface temperature anomalies in early autumn in the 'key areas' could affect the winter sea-ice distribution also offers scope for improvements to the predictions. It would also be interesting to see whether the upper-air patterns in December had any predictive value for the rest of the winter. Indeed, to justify the 'isolated' correlation observed between atmospheric patterns in late November and February temperatures this is really a necessity.

The proof of the pudding, it is often said, is in the eating. It will be interesting to see whether or not future predictions, based on the results of this paper, attain the quoted accuracy. In about 10 years time we should have some idea.

Acknowledgement

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The storms of 24 May 1989 — the rainfall in the Thames Valley area

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Summary

Severe convective storms on 24 May 1989, following a spell of hot weather, led to some very intense point rainfalls at a number of places in southern England. This article examines the falls recorded by the rain-gauge network in an area within a 50 km radius of the Meteorological Office headquarters at Bracknell.

1. Introduction

The evolution of the severe convective storms of 24 May 1989, as shown by satellite and radar observation, is described in Waters (1991). This paper concentrates on the violent rainfall in the Thames Valley area, as recorded by the rain-gauge network.

2. The data

Initially, within a few days of the storm, only a limited amount of rain-gauge data was available, all from Meteorological Office manned sites. By a fortunate coincidence, two such sites, those at Easthampstead (Beaufort Park) and at South Farnborough, caught the full violence of the storms. By using readily available network radar data, it was possible to produce fairly quickly a sketch map showing the intensity of rainfall in the Bracknell, Farnborough and Woking area. This was incorporated into a short report, which was used by the then Advisory Services Branch of the Meteorological Office to answer the initial enquiries from those requesting information in regard to the flooding of premises. Most rainfall enquiries of this nature cannot normally be dealt with until quality-controlled rain-gauge data have been received from co-operating observers, which seldom happens less than 6 weeks after an event.

All the rain-gauge data having now been received and quality-controlled, a detailed map of daily rainfall over the main area of the storms has been prepared, and this is reproduced, in a reduced form, as Fig. 1. An earlier version of this map was included in an article on assessing and forecasting extreme rainfall by Collier (1990). Radar data from Chenies have been used to supplement the rain-gauge values to achieve a better definition of the shape of the isohyets. Within this area are six rain-gauges from which hourly data were available: Heathrow, Gatwick, Mickleham, South Farnborough, Beaufort Park and Odiham. Tilting-syphon rain recorder (TSR) records were available to the author from three sites: Mickleham, Beaufort Park and South Farnborough. The redrawn hyetogram from Mickleham is reproduced as Fig. 2, and the minute-by-minute record from the tipping-bucket rain-gauge (TBR) at South Farnborough appears as Fig. 3.

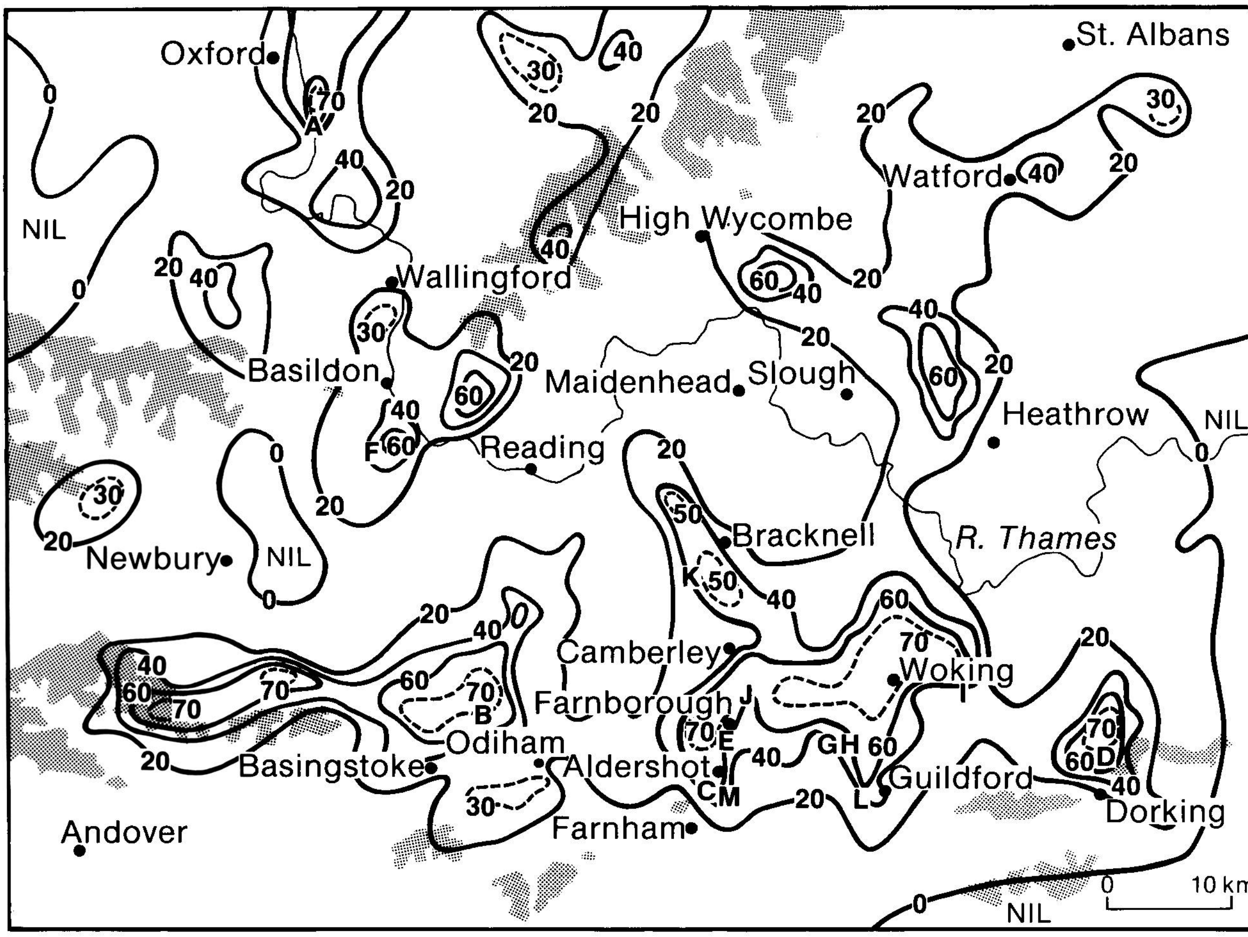

Figure 1. Contours of rainfall totals (mm) for the 24 hours from 0900 UTC on 24 May 1989, derived from rain-gauges in the Thames Valley area. Interpolation of isohyets was aided by the use of Chenies radar rainfall data integrated over the period 1100–1600 UTC. Ground above 600 ft is stippled and the letters refer to the stations included in Table I.

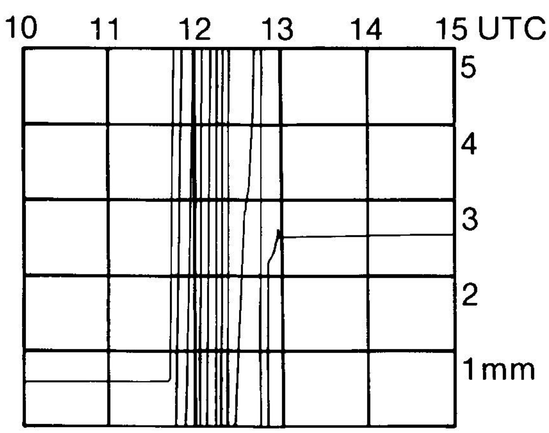

Figure 2. A reproduction of a section of the hyetogram from Mickleham tilting-syphon rain recorder for 24 May 1989.

3. Discussion

The records for 24 May show that by far the greater proportion of the rainfall took place in a very limited period, for example, 1215–1330 UTC at South Farnborough and 1145–1300 UTC at Mickleham. Very little rain fell outside the violent phase. It is therefore possible to say, with confidence, that Fig. 1 depicts fairly accurately the rainfall during the most intense 1¼ to 2 hours of the storms. The rain started earlier in the east than it did in the west; at Mickleham it began at 1140 UTC, but at Farnborough it did not start until about 1210 UTC.

Table I lists those rain-gauge sites in the area which recorded over 40 mm in the 24 hours starting at 0900 UTC on 24 May 1989; the table also shows the 1941–70 average monthly rainfall for May, where available.

A better impression of the size of these rainfalls is gained by the use of the return period, a statistical measure of the frequency with which an event is likely to recur (not a forecast of when it will occur again). For the 24-hour totals given in Table I it is possible to obtain a table of return periods, together with the modified Bilham (1935) classification as follows: 'noteworthy', having a return period of between 10 and 40 years, 'remarkable' between 40 and 160 years, and 'very rare' more than 160 years. These return periods are reproduced here as Table II.

However, as noted above, little rain fell outside a 2-hour period, and it is not unreasonable therefore to rework these return-period calculations as if the rainfalls were over only 2 instead of 24 hours. Table III shows the results.

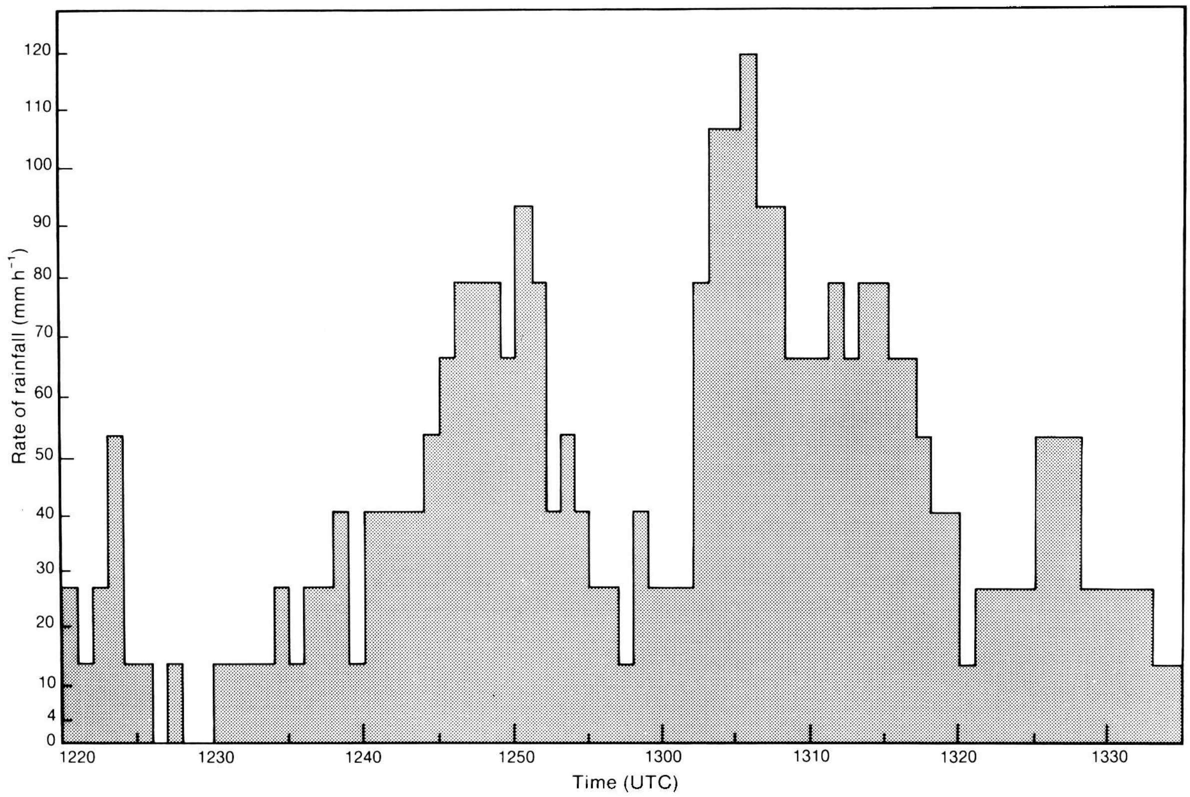

Figure 3. Minute-by-minute rates of rainfall at South Farnborough derived from tipping-bucket rain-gauge data for 24 May 1989.

Table I. Total 24-hour rainfalls from sites reporting over 40 mm at 0900 UTC on 24 May 1989, together with the average monthly figure where possible

Rain-gauge site	Total (mm)	Average monthly total (mm) for May (1941–70)
Sandford Sewage Works, Oxford (A)	68.5	
Chineham Sewage Works, Basingstoke, Hampshire (B)	68.5	
Aldershot Reservoir, Hampshire (C)	64.2	55
Juniper Hall, Mickleham, Surrey (D)	62.2	56
South Farnborough, Hampshire (E)	60.2	53
Upper Basildon, Berkshire (F)	57.0	
Pirbright Institute, Surrey (G)	56.5	50
Merrist Wood Agricultural College, Surrey (H)	53.5	
Royal Horticultural Society Gardens, Wisley, Surrey (I)	52.6	50
Frimley Pumping Station, Surrey (J)	51.6	54
Beaufort Park, Bracknell, Berkshire (K)	45.6	
Wodeland Avenue, Guildford, Surrey (L)	44.1	55
Aldershot Waterworks, Hampshire (M)	41.6	55

The letter in brackets after the site name identifies the location on the map at Fig. 1.

Some more-specific return periods have been determined from hyetograms and TBR data, particularly in relation to periods of less than 2 hours. The rarest falls were those lasting for about an hour; shorter falls of similar intensity are more common, as are similar totals achieved over longer durations. Tables IV and V respectively list return periods for a variety of amounts and durations at Mickleham (derived from Fig. 2) and at South Farnborough (from Fig. 3). No doubt similar figures could be obtained from the other sites listed, were suitable data available.

However, the pattern of rainfall in Fig. 1 makes it clear that these intense falls affected very restricted areas. On this occasion the intense cells were almost stationary throughout their lifetimes, and hence they show up on Fig. 1 as approximately circular areas of

Table II. Return periods and Bilham (1935) classification for the 24-hour rainfalls shown in Table I

Rain-gauge site	Return period (years)	Bilham classification
Sandford Sewage Works, Oxford	34.2	Noteworthy
Chineham Sewage Works, Basingstoke, Hampshire	34.2	Noteworthy
Aldershot Reservoir, Hampshire	28.5	Noteworthy
Juniper Hall, Mickleham, Surrey	19.3	Noteworthy
South Farnborough, Hampshire	21.3	Noteworthy
Upper Basildon, Berkshire	15.5	Noteworthy
Pirbright Institute, Surrey	13.9	Noteworthy
Merrist Wood Agricultural College, Surrey	10.2	Noteworthy
Royal Horticultural Society Gardens, Wisley, Surrey	11.5	Noteworthy
Frimley Pumping Station, Surrey	10.1	Noteworthy
Beaufort Park, Bracknell, Berkshire	6.3	Not significant
Wodeland Avenue, Guildford, Surrey	2.9	Not significant
Aldershot Waterworks, Hampshire	3.5	Not significant

Table III. Return periods and Bilham (1935) classification for the rainfalls shown in Table I, assuming that their duration was only 2 hours

Rain-gauge site	Return period (years)	Bilham classification
Sandford Sewage Works, Oxford	458	Very rare
Chineham Sewage Works, Basingstoke, Hampshire	458	Very rare
Aldershot Reservoir, Hampshire	400	Very rare
Juniper Hall, Mickleham, Surrey	292	Very rare *
South Farnborough, Hampshire	213	Very rare *
Upper Basildon, Berkshire	214	Very rare
Pirbright Institute, Surrey	193	Very rare
Merrist Wood Agricultural College, Surrey	147	Remarkable
Royal Horticultural Society Gardens, Wisley, Surrey	155	Remarkable
Frimley Pumping Station, Surrey	142	Remarkable
Beaufort Park, Bracknell, Berkshire	30	Noteworthy *
Wodeland Avenue, Guildford, Surrey	55	Remarkable
Aldershot Waterworks, Hampshire	60	Remarkable

* At Juniper Hall, South Farnborough and Beaufort Park, the 2-hour totals are known from hourly data, and these figures (instead of the 24-hour ones) have been used to calculate the return periods.

Table IV. Specific return periods and Bilham (1935) classification for the rainfall on 24 May 1989 at Juniper Hall

Start time (UTC)	Amount (mm)	Duration (h min.)	Return period (years)	Bilham classification
1200	41.2	0 54	135	Remarkable
1100	62.2	1 12	553	Very rare
1100	62.2	2 00	292	Very rare

Table V. Specific return periods and Bilham (1935) classification for the rainfall on 24 May 1989 at South Farnborough

Start time (UTC)	Amount (mm)	Duration (h min.)	Return period (years)	Bilham classification
1305	2.0	0 01	3	Not significant
1303	5.6	0 03	8	Noteworthy
1302	20.9	0 15	61	Remarkable
1240	41.3	0 30	374	Very rare
1233	50.1	1 00	307	Very rare
1200	56.2	2 00	213	Very rare
1200	60.2	6 00	93	Remarkable
1200	60.2	24 00	21	Noteworthy

diameters less than 10 km. Over most of the region in which rain fell, the totals mostly lie between 5 and 15 mm.

Another feature of Fig. 1 worth noting is the actual location of the heaviest centres of precipitation. All the cells with central rainfall totals over 50 mm were situated close to the line of the North Downs, and appear to have had some relationship with the river gaps, though the valley at Basingstoke is modest when compared with, say, the Mole gap at Mickleham. Maybe, the actual link is with the built-up areas associated with the river gaps, which might help to explain the location of the cell near Woking and that over south Bracknell, though the Upper Basildon cell is a little difficult to account for on this theory. Clearly, several factors were involved in triggering the intense convection responsible for these heavy falls, though the extra heat available over built-up areas is likely to have been one of them; another was probably the additional convergence associated with the North Downs themselves. Nonetheless, Fig. 1 is eloquent testimony to the considerable degree of topographic control that was operating.

4. Conclusions

Analysis of hourly and daily rain-gauge data for 24 May 1989, has shown how restricted were the areas of the Thames Valley affected by the most violent rain, and also how unusual the heaviest rainfalls were. Because the cells of precipitation remained almost stationary throughout their lifetimes, the distribution of rainfall shows a very strong degree of topographic control by the North Downs, even if it is somewhat difficult to explain the nature of that control.

Acknowledgements

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The winter of 1989/90 in the United Kingdom

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Summary

Generally the winter of 1989/90 in the United Kingdom was mild and wet, with seasonal sunshine values near average. A major feature of the season was the frequency of stormy weather from around the middle of December, and storms and severe gales in the last week of January, followed by a very stormy month in February.

1. The winter as a whole

Winter temperatures were above normal everywhere, ranging from 3.0 °C above normal in parts of the Home Counties to 0.3 °C above normal at Tiree, Strathclyde Region. Winter rainfall was above normal in most parts of the United Kingdom other than eastern Scotland and parts of north-east England, and ranged from 64% at Fyvie Castle, Grampian Region to 229% in the Cumbrian Mountains. Sunshine amounts were below average in Kent, east Sussex, south-west England, most of Wales, northern England and western Scotland, about average in Northern Ireland and above average elsewhere, ranging from less than half the normal around Loch Maree in north-west Scotland to 136% in the London area and the north-west of Grampian Region. The season was notable for the incidence of spells of stormy weather, the first of which affected the British Isles around the middle of December, followed by storms and severe gales in the last week of January, and a very stormy February.

Information about the temperature, rainfall and sunshine during the period from December 1989 to February 1990 is given in Fig. 1 and Table I.

2. The individual months

December. Mean monthly temperatures were above normal south of a line from South Wales to the Humber Estuary and below normal to the north, ranging from 3.1 °C below normal at Fort William, Highland Region to 1.6 °C above normal at Heathrow, Greater London. Mean monthly rainfall totals were above normal over most of England and Wales and below normal in Northern Ireland and most of Scotland, ranging from 232% at Brize Norton, Oxfordshire to 50% at Aberdeen Airport, Grampian Region. Hampstead, Greater London had no measurable rain from 10 November until 11 December, followed by 116.9 mm in the next 10 days. Parts of south-west Scotland were dry from 13 November to 12 December. In Northern Ireland it was the driest December since 1975. Monthly sunshine amounts were below normal in most parts of England and Wales, but above normal in Scotland, apart from the far north and east, ranging from 187% at Tiree, Strathclyde Region to 35% at Birmingham, West Midlands. Broom's Barn, Suffolk had the dullest December for 20 years. Sheffield, Weston Park, South Yorkshire, reported the lowest

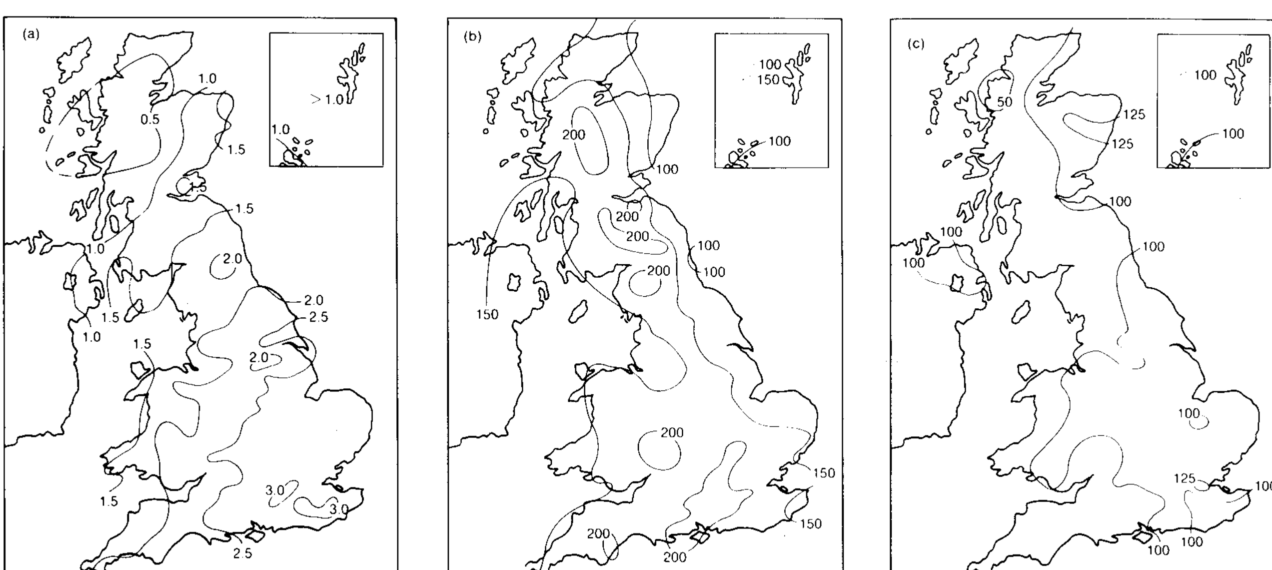

Figure 1. Values of (a) mean temperature difference (°C), (b) rainfall percentage and (c) sunshine percentage for winter, 1989/90 (December–February) relative to 1951–80 averages.

Table I. District values for the period December 1989–February 1990, relative to 1951–80 averages

District	Mean temperature (°C)	Rain-days	Rainfall	Sunshine
	Difference from average		Percentage of average	
Northern Scotland	+0.8	+2	181	97
Eastern Scotland	+1.2	+1	161	112
Eastern and north-east England	+2.3	+2	144	100
East Anglia	+2.7	+1	161	113
Midland counties	+2.5	+2	175	97
South-east and central southern England	+2.9	+3	196	97
Western Scotland	+1.8	+3	187	84
North-west England and North Wales	+1.8	+3	175	86
South-west England and South Wales	+2.2	+4	178	87
Northern Ireland	+0.9	+3	150	103
Scotland	+1.0	+2	180	98
England and Wales	+2.4	+3	171	97

Highest maximum: 18.0 °C in Midland counties in February.
Lowest minimum: −12.9 °C in eastern Scotland in December.

December sunshine total since 1933.

The month was mostly settled and dry with fog and frost at times until the 11th, after which followed a period of very wet and, between the 14th and 26th, windy weather, again becoming quiet for the last week. Strong winds from the south or south-west combined with an exceptionally high tide on the 14th to bring widespread flooding to many places on the south coast. A mini-tornado on the 14th at Long Stratton, Norfolk damaged more than 100 buildings. On the 16th gales and rain over south-west England caused severe flooding at Plymouth, Devon. On the 17th the observer at Falmouth, Cornwall, in an exposed coastal position, reported a gust of 104 kn while several anemographs in the area recorded gusts of more than 70 kn; these included 74 kn at Plymouth, Devon and 71 kn at Gwennap Head, Cornwall. However, the highest gust recorded by anemograph during the month was 78 kn at Fraserburgh, Grampian Region on the 18th. On the 13th snow fell as far south as the Midlands. Further snow fell in north Derbyshire on the 14th with up to 13 cm of level snow reported lying in the Buxton area. Moel-y-Crio, Clwyd measured 24 cm of snow lying at 09 UTC on the 15th. Further snow fell later on the 18th, over eastern Wales and the north-western Midlands. On the 21st a tornado struck the villages of West and East Stour in Dorset, uprooting trees and causing structural damage to buildings. A 500-gallon (2275-litre) oil drum was lifted and blown 200 metres and a 17-metre radio mast was toppled. A band of heavy rain with hail and thunder crossed southern areas of the United Kingdom on the 23rd. Over the Christmas period it was very mild, with strong south-westerly winds, followed by a quiet, dry end to the month over the United Kingdom.

January. Mean monthly temperatures were above normal everywhere ranging from 1.1 °C above normal at Cape Wrath, Highland Region to 3.8 °C above normal at Lyneham, Wiltshire. Monthly rainfall amounts were above normal everywhere except eastern coastal areas of England where they were slightly below normal and the east coast of Scotland where it was very dry. Wick, Highland Region had less than half the normal rainfall compared with over twice the normal over a large area of the western Highlands. Monthly sunshine amounts were below average in southern coastal counties and in Shetland and western Scotland, and above average elsewhere, reaching 156% in North Wales, but as little as 42% in southern Scotland.

The month was generally unsettled with periods of rain, heavy at times, or showers, occasionally wintry in northern areas. Much of England and Wales and north-west Scotland was dry on the 3rd and 4th, although there was heavy rain in the Glasgow area on the 3rd. Rain and strong winds affected all areas from time to time from the 9th. Thunder occurred in northern areas, mainly over Scotland and Northern Ireland between the 17th and 23rd. The night of the 16th/17th was very windy in northern areas, with gusts of 76 kn at Stornoway and 79 kn at Benbecula (both in Western Isles) late on the 16th and a record January gust of 109 kn with a mean speed of 72 kn at Fair Isle, Shetland early on the 17th. The 25th was an extremely windy day with severe gales over England and Wales with gusts to 93 kn at Aberporth, Dyfed and Gwennap Head, Cornwall. Gusts to more than 80 kn were widely reported on other exposed southern and western coasts and to more than 70 kn in many central and southern parts of England and Wales. A great deal of structural damage was done and a large number of trees brought down, the area affected was much more widespread than that during the storm of 16 October 1987. There were thunderstorms over both Scotland and southern England and Wales on the 26th, over north-west England and Wales on the 30th and over parts of the south on the 31st, frequently accompanied by hail.

February. Mean monthly temperatures were above normal everywhere and ranged from 0.4 °C above normal in the far north-west of Scotland to more than 4.3 °C in south-east England. Monthly rainfall totals were above normal everywhere in the United Kingdom and ranged from 111% at Aberdeen, Grampian Region to 438% in the western Highlands. At Fort Augustus, Highland Region it was the wettest February since records began in 1886, the previous wettest having been February 1989. At Paisley, Strathclyde Region it was the wettest February since 1894. Monthly sunshine amounts were generally above average in eastern areas and below average in western areas, ranging from 164% of average at Wyton, Cambridgeshire to 57% of average at Aspatria, Cumbria.

The month was generally unsettled and at times very wet with only about 7 dry days, mainly over England and Wales and eastern Scotland. It was generally very windy, with strong winds or gales on about 14 days and severe gales on the 1st, 19th, 27th and 28th. Gusts in excess of 60 kn were widely reported on the 12th and 26th, whilst gusts in excess of 70 kn were reported on the 1st, 7th and 11th in the south-west, including 81 kn at Burrington, Devon on the 11th. Early on the 3rd prolonged heavy rainfall occurred south-east of a line from the Bristol Channel to The Wash, resulting in flooding, and the rain turned to snow in many places before it cleared. On the 19th very heavy rainfall over north-west England and North Wales caused flooding, while central and eastern England stayed mainly dry. The coincidence on the 26th and 27th of strong winds, low atmospheric pressure and 'spring' tides led to severe flooding and wave damage along several British coasts: Towyn, Clwyd suffered a major disaster when sea defences were overwhelmed. On the 26th there were gusts of 85 kn at Leeds, West Yorkshire and 86 kn at Hemsby, Norfolk.

Notes and news

100 years ago.

SYMONS'S

MONTHLY

METEOROLOGICAL MAGAZINE.

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OUR THREE HUNDREDTH NUMBER.

To have been enabled to edit every one of three hundred consecutive monthly numbers is not given to many, and, looking back over the work of a quarter of a century, a feeling of thankfulness is naturally predominant.

We lay no claim to brilliancy or to financial success, or to a large circulation; but we are conscious of the friendliness of nearly all the leaders of Meteorological progress in both hemispheres. Perhaps because it is so small, but, be the reason what it may, we rejoice to know that the *Meteorological Magazine* has the highest honour which a book can have—that of being read. We know that this is so, because when we make a mistake (and of course the Editorial " we " is fallible), whether in dealing with Russia, America, or our Australian colonies, the very next mail is sure to tell us of it; and we rejoice that this is the case, for our whole aim has ever been to help forward the science which we love, and the best way to do that is to stamp out error wherever it can be found.

Comment: *Would it were ever thus!*

Review

Elementary fluid dynamics, by D.J. Acheson. 136 mm × 215 mm, pp. vi+397, *illus.* Oxford University Press, 1990. Price £15.00 (paperback), £45.00 (hardback). ISBN 0 19859 679 0.

Fluid dynamics is important in many branches of physics, engineering, chemistry and biology. Students and research workers in any of these areas require fluid dynamics textbooks tailored to their particular specialisms, but there is also a need for texts which give a broad view of the basic concepts. Dr Acheson's book comes into this wider category. It aims to give 'an introduction to fluid dynamics for students of applied mathematics, physics and engineering', and is part of the Oxford Applied Mathematics and Computing Science Series.

Topics covered include the equations of motion, vortex dynamics, waves, instability, aerofoil theory, boundary layers and viscous flow. As befits a text on elementary principles, a wide range of applications and contexts is indicated — from aeronautics and the flight of insects to Kelvin-Helmholtz billows and tornadoes. Each of the nine chapters is followed by several pages of exercises, some of which are demanding, and which extend the scope of the book considerably without adding much to its length. (The book, indeed, is physically compact — one could read it without difficulty or embarrassment on a bus or train.) Hints and answers to the exercises are given in a separate section. The reference list is comprehensive without being compendious. Text and figures are well presented and misprints are very few.

The chapters on waves, instability, vortex motion and boundary layers are those which are most relevant to meteorological concerns. Of these, the chapter on waves is particularly useful, having very clear discussions of dispersion, group velocity, sound waves, surface waves, internal gravity waves and various finite amplitude effects. The chapter on instability is also valuable; it gives a wide-ranging yet concise survey and is ambitious enough to treat some stability proofs in depth.

Although it does not hesitate to present the mathematical machinery and detail of the subject, the book maintains a refreshingly practical outlook. The first sentence of chapter 1 reads 'Take a shallow dish and pour in salty water to a depth of 1 cm', while on p. 342 the reader is enjoined to 'Take a pot of golden syrup, spoon out a generous helping, and let it drain slowly back into the pot'. The book also gives a welcome historical perspective to its subject, with extensive quotations from papers by Prandtl, Reynolds, Stokes, Taylor, Helmholtz and even Newton. In only one respect does the historical background seem insufficient: the text (on p. 265) leaves the impression that 19th century fluid dynamicists were somehow culpable because of their uncertainty about the applicability of the non-slip condition at rigid boundaries. The reader must consult referenced works by S. Goldstein (or G.K. Batchelor's *An introduction to fluid dynamics*) for clarification of this important issue.

This book can be highly recommended. It is written by an expert with wide experience of teaching and research in the field, who succeeds in communicating to the reader his enthusiasm for the subject. Some of the topics covered are highly relevant to meteorology, while others are clearly less so. However, the clarity and vigour of the presentation may encourage the specialist to venture beyond the purlieus of his usual interests, and there can be no harm in that!

A.A. White

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

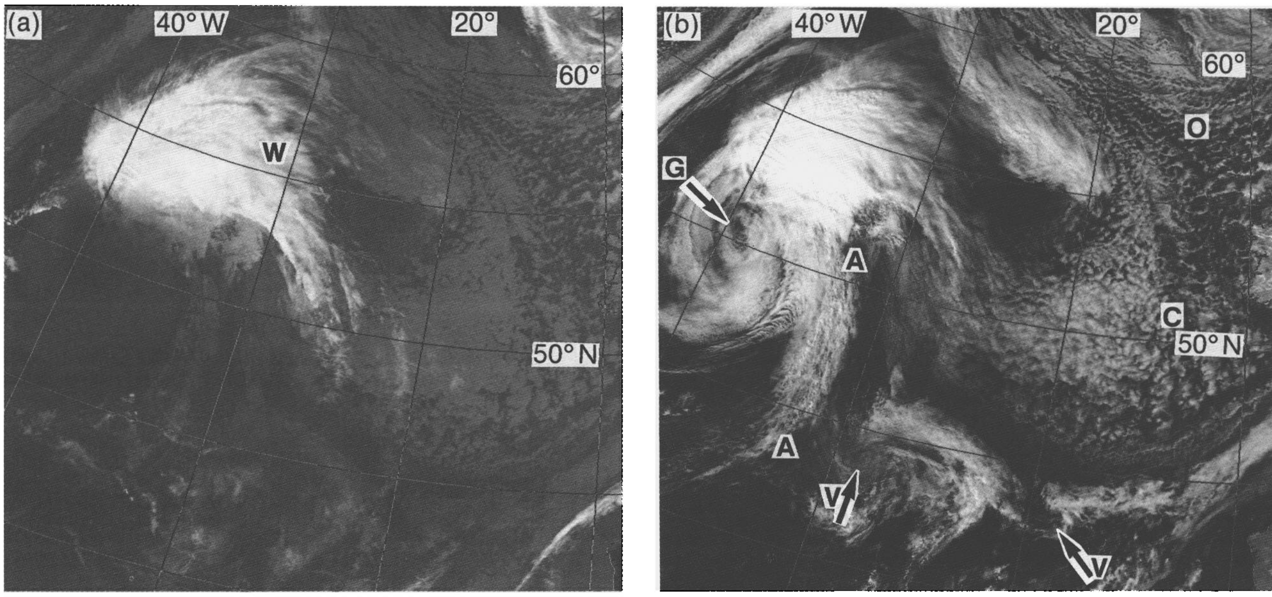
The telemetry of hydrological data by satellite, by I.C. Strangeways (Wallingford, Institute of Hydrology, 1990. £7.00) aims to bring together the basic information for a potential user of satellite telemetry. Although slanted hydrologically, much of the material can have a broader use.

Dynamics in atmospheric physics, by R.S. Lindzen (Cambridge University Press, 1990. £25.00, US$39.50) consists of 7 years of university lecture notes. An attempt is made towards general thinking about nature by including some history of the scientific inquiry into the subject. ISBN 0 521 36101 X.

Dynamics, transport and photochemistry in the middle atmosphere of the southern ocean, edited by A. O'Neill (Dordrecht, Boston, London, Kluwer, 1990. Dfl.145.00, US$89.00, £50.00) contains most of the papers included in the NATO Advanced Research Workshop held in San Francisco on 15–17 April 1989. The interdisciplinary nature of the study is accentuated. ISBN 0 7923 0977 4.

Global air pollution: Problems for the 1990s, by H.A. Bridgman (London, Belhaven Press, 1990. £30.00 (hardback), £12.95 (paperback)) aims to give students a firm grasp of the scientific principles of the subject in relation to the social and economic issues. The only equations used are chemical. ISBN 1 85293 094 2 (hardback), 1 85293 099 2 (paperback).

Satellite photographs — 3 September 1990 at 1521 UTC



Photographs by courtesy of University of Dundee

Figure 1. NOAA-9 images for 1521 UTC on 3 September 1990, (a) infra-red, and (b) visual.

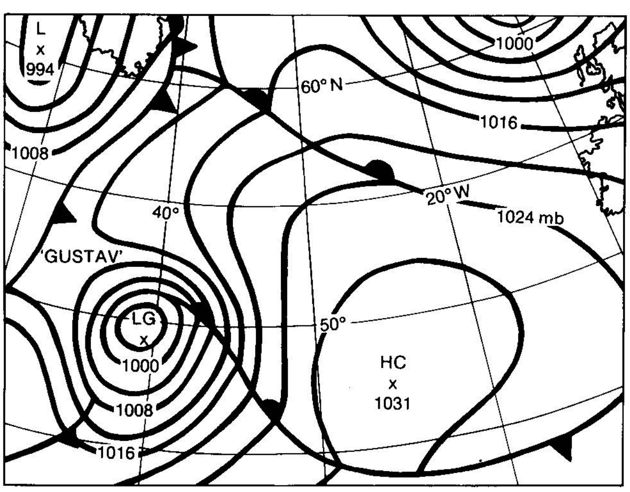


Figure 2. Surface analysis for 1200 UTC on 3 September 1990.

The satellite photographs in Fig. 1 were both taken from NOAA-9 at 1521 UTC on 3 September 1990. They show how particular cloud systems can appear very differently on visible and infra-red (IR) images, and highlight the complementary nature of data from these two channels. Key elements of cloud structure portrayed on visible images are cloud thickness and texture, and the response is not dependent on the cloud-top temperature. The response on IR channels, however, is very dependent on the temperature of the underlying surface and little detail in cloud structure can be detected in unenhanced images when the cloud-top temperature is similar to that of the background, i.e. land or sea surface.

The main feature towards centre-left on the IR image (Fig. 1(a)) is a wedge-shaped area of cloud tops (W), which is reminiscent of the signature associated with a wave depression before the occlusion process. It is very difficult to discern any significant circulation either at the surface or aloft. The visible image of the same system in Fig. 1(b) clearly shows, within the area of predominantly low cloud, that there is a marked circulation with a virtually cloud-free centre (G).

They are in fact images of ex-hurricane Gustav (see Fig. 2) which, although now degraded to a mere mid-latitude low, still had very strong winds in its circulation and 2 days later, on 5 September, still produced locally gale-force winds when it crossed close to northern Scotland. Coincident high spring tides resulted in local coastal flooding, e.g. near Towyn, North Wales, but the exceptionally high water levels were well predicted by the Meteorological Office Storm Tide Warning Service.

These images of Gustav are typical of hurricanes or tropical storms that have moved north, become engaged in the westerlies, but with no significant interaction with the polar front. The lack of any significant surface-based convection in the system — except possibly some remnants in the relatively shallow cloud band marked AA in Fig. 1(b) — is because the system has moved over progressively colder sea.

Other features of interest, highlighted on the visible image, include:

- Marked detail in the open (O) and closed (C) cell structure to the west of Ireland.
- Small vortices (V) along the weak cold front near 45°N.

A.J. Waters

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Chief Executive, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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