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Experimental monthly long-range forecasts for the United Kingdom

Part III. Skill of the monthly forecasts

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Summary

Evidence is shown for a recent fairly sudden, though modest, improvement in the skill of the monthly forecasts, especially those of temperature extremes and rainfall. These forecasts are derived from forecast patterns of pressure at mean sea level (PMSL) made for three periods within the month. A first analysis is given of the skill of the derived monthly mean PMSL forecasts and preliminary analyses of the recent skill of the temperature and rainfall forecasts for several distinct periods within the month ahead, including the second half-month, to help indicate whether the forecasts have skill on the purely 'long-range' time-scale.

1. Introduction

This paper concentrates on the skill of the issued forecasts which are based on the contributions of all the forecasting techniques described in Folland and Woodcock (1986). (Folland and Colman (1986) provide a preliminary discussion of the skill of the most important statistical technique, the multivariate forecasting technique.) A discussion about the skill of the forecasts of pressure at mean sea level (PMSL), temperature and rainfall issued in the medium range (first 5 days of the month ahead), mid range (remainder of the first half-month) and long range (second half-month) since July 1982 is included.

2. General remarks on the skill of the forecasts

The forecasts of monthly mean temperature anomalies for each district are given in terms of the 'best-estimate' of whether it will be very cold, cold, average, warm or very warm. In the long term the probability of each of these 'quints' is the same. Similarly, forecasts of percentage of average rainfall (hereafter referred to as rainfall percentage) are categorized according to whether it will be dry, average or wet, where each 'terce' is equally likely in the long term. A map of the ten districts for which forecasts are issued is given in Folland and Woodcock (1986). Until 1979 the forecasts were usually only made for the single most probable quint or terce category which is called the best-estimate forecast. The current system also forecasts the probabilities of each of the quints and terces, and is designed so that one of the quints or terces is forecast to have the highest probability and this is regarded as the best-estimate forecast. Thus best-estimate forecasts can be continuously assessed from 1964 to date. Assessment of the skill of the complete set of probability forecasts is more difficult, though important, and will be tackled in a later paper.

Since July 1982, a full record of best-estimate forecasts of temperature anomaly and rainfall percentage has been kept separately for the medium, mid and long ranges. In addition, forecasts of PMSL have also been analysed since July 1982 for six grid points near the United Kingdom (four of the points are shown in Folland and Woodcock (1986) with the two additional points at 55° N, 10° W and 55° N, 00° W) though only the skill of forecasts for the month as a whole, and its first and second halves, is available at present. These objectively made assessments cannot, of course, be taken as complete measures of the value or utility of the long-range forecasts. However, the assessments of the skill of recent PMSL forecasts do at least start to tackle the problem of estimating the value of what used to be called 'additional information', i.e. the worded part of the forecast that describes the expected sequence of circulation types and the general characteristics of the associated weather. From a scientific point of view the assessments of the forecast PMSL patterns are therefore fundamental, since the temperature and rainfall forecasts, as well as the additional information, are now largely derived from these patterns.

3. Skill of the temperature and rainfall forecasts

(a) *General problem of assessing long-range forecasts*

The assessment of the skill of forecasts is a very difficult matter. Each user of the forecasts has a different sensitivity to their content largely because their value (or 'utility') depends on the way the forecasts are phrased, their level of detail and on whether the user has an effective way of using the forecasts and monitoring their utility. The very act of receiving the forecasts, almost irrespective of their content, can be beneficial, as the background meteorological information supplied about district climatological averages etc. is of considerable potential value in its own right. For some users this information may be more useful than the low skill that the forecasts currently have in predicting deviations from these averages. On the other hand, some users may regard an individual forecast as essentially correct when an objective assessment shows little or even negative skill relative to a random chance level. For example, consider a forecast that predicts a change of circulation type, and a marked increase in temperature, in the second half of the month ahead. If the change actually occurs but was delayed for a few days after the beginning of the second half-month, a set of extremely cold observed temperatures at the beginning of the period may render the second half-month as a whole rather cold even though most of it was rather mild. Indeed, small timing errors of this kind may be imperceptible to many users interested in planning on the basis of the general nature of the weather over 2 weeks. This lack of sensitivity is itself influenced by the current non-availability of more detailed forecasts of good accuracy. Thus more detailed and accurate forecasts, if they become available, might appreciably influence the mode of operation of some users, quite apart from any increase in their number. Presumably, the occasional serious forecasting failures would then be much more damaging than is possible at the present time. So at this stage we have confined our assessments of forecasts to methods that help researchers into long-range forecasting to monitor their own performance. Every forecast assessment system is rooted in a need to create indices of the skill or information content of the forecasts relative (in most cases) to a measure of what is achievable by following some fixed, simpler strategy such as random chance forecasts ('guesswork'), climatology, or forecasts of the persistence of some recently observed weather anomaly.

The technique currently in most frequent use in the Synoptic Climatology Branch of the Meteorological Office for assessing UK long-range forecasts of temperature and rainfall of the best-estimate type is known as the Folland–Painting or FP system. As described in section (d), other measures of skill are also found to be useful for assessing the PMSL forecasts. This is not surprising as any assessment system has scientific value if it provides self-consistent answers to well-posed questions about forecast performance.

A final problem for all measures of forecast skill is the need to define, in an appropriate way, the climatological averages from which the anomalies are being forecast. Long-range forecasts are currently made in anomaly form but the climate continually fluctuates. In the United Kingdom this problem has been quite acute in recent decades (Gilchrist 1982, Folland, *et al.* 1985), especially for temperature averages in April and October. The traditional approach is to define 'average' over a recent period of 30 years which is regarded as representative of the current climate. This convention has been adopted here but its limitations should be borne in mind. Its use has consistently led to an excessive number of observations of colder than normal conditions in the north-west of the United Kingdom since 1964, especially in the north and west of Scotland, possibly related to the cooling of the North Atlantic to the west of Scotland since about 1955, a cooling which has only recently ceased (Folland and Parker 1986).

(b) *The FP forecast assessment system*

The basic ideas underlying the system are described in Appendix 1. Table I shows the FP scoring tables for (a) temperature quints, (b) 'grouped' temperature quints (here the cold, average and warm quints are grouped together) and (c) rainfall terces. The quint and terce boundaries are defined separately in each district and for each of the overlapping 24 calendar monthly periods for which forecasts are made each year. Table II shows the 'Sutcliffe' scoring tables (Freeman 1966) which had previously been the most important assessment technique and which are still in limited use.

Table I(a). *The Folland–Painting scoring table for assessing forecasts of temperature quints*

Forecast		Observed					Chance scores for forecast categories
		Very cold A_1	Cold A_2	Average A_3	Warm A_4	Very warm A_5	
Very cold	F_1	5.2	1.0	−1.2	−2.4	−2.6	0
Cold	F_2	1.0	3.4	−0.2	−1.8	−2.4	0
Average	F_3	−1.2	−0.2	2.8	−0.2	−1.2	0
Warm	F_4	−2.4	−1.8	−0.2	3.4	1.0	0
Very warm	F_5	−2.6	−2.4	−1.2	1.0	5.2	0
Chance scores for observed categories		0	0	0	0	0	

Table I(b). *As Table I(a) but for grouped temperature quints*

Forecast		Observed			Chance scores for forecast categories
		Very cold A_1	Cold to warm A_2	Very warm A_3	
Very cold	F_1	8.5	−1.5	−4.0	0
Cold to warm	F_2	−1.5	1.0	−1.5	0
Very warm	F_3	−4.0	−1.5	8.5	0
Chance scores for observed categories		0	0	0	

Table I(c). *As Table I(a) but for rainfall terces*

Forecast		Observed: Dry A_1	Average A_2	Wet A_3	Chance scores for forecast categories
Dry	F_1	4.7	−1.3	−3.4	0
Average	F_2	−1.3	2.6	−1.3	0
Wet	F_3	−3.4	−1.3	4.7	0
Chance scores for observed categories		0	0	0	

Table II(a). *The Sutcliffe scoring table for assessing forecasts of temperature quints*

Forecast		Observed: Very cold A_1	Cold A_2	Average A_3	Warm A_4	Very warm A_5	Chance scores for forecast categories
Very cold	F_1	4	2	0	−2	−4	0
Cold	F_2	1	4	1	−2	−4	0
Average	F_3	−3	1	4	1	−3	0
Warm	F_4	−4	−2	1	4	1	0
Very warm	F_5	−4	−2	0	2	4	0
Chance scores for observed categories		−1.2	0.6	1.2	0.6	−1.2	

Table II(b). *As Table II(a) but for rainfall terces*

Forecast		Observed: Dry A_1	Average A_2	Wet A_3	Chance scores for forecast categories
Dry	F_1	4	0	−4	0
Average	F_2	−2	4	−2	0
Wet	F_3	−4	0	4	0
Chance scores for observed categories		−0.67	1.33	−0.67	

Tables I(a)−I(c) are designed so that the chance score is always zero no matter what the observed (outcome) category. By contrast, the Sutcliffe tables have a positive chance score for average or near-average outcome categories (i.e. quints 2, 3 and 4) and a negative chance score for extreme outcome categories. This structure tends to give an artificially (slightly) higher score during a run of near-average conditions than during a run of extremes. For individual forecasts, a more serious problem with the Sutcliffe tables can be seen when comparing Table II(a) with Table I(a). Consider a forecast of quint 5 (F_5) followed by an outcome of quint 3 (A_3); the Sutcliffe system gives a score of 0 points. For a forecast of quint 3 (F_3) followed by an observation of quint 5 (A_5), the score is now −3 points. The FP system gives −1.2 points in both situations; this seems more logical as the 'error' in both situations is the same. Another difference between the tables is that a correct forecast of a quint or terce category gains the same maximum score in the Sutcliffe system no matter what the category is; in the FP system correct forecasts of extreme categories have a higher score than correct forecasts of a near-average category.

It should be noted that the values of the quint and terce boundaries and the estimates of observed anomalies in each district have been recalculated back to 1964 and therefore differ from the values published in the old *Monthly Weather Survey and Prospects* during the period of public issue. This development has been made possible by the construction of a new district-average climate data base that commences in January 1951 and which is regularly updated in an automatic way using quality-controlled data files created by the Advisory Services Branch. These data were still found to be inadequate in amount to revise satisfactorily the (previously rather uneven) rainfall terce boundaries. So it was decided to use the very comprehensive automated statistical model of the climate of extreme rainfall totals, calculated for the United Kingdom on monthly (and longer) time-scales by Tabony (1977) and converted into a regular grid-point format by Colgate (personal communication). The result is to provide quint and terce boundaries at fixed values of temperature anomaly or rainfall percentage that vary smoothly through the calendar year and between adjacent districts. The averages about which the anomalies are calculated (for a fixed set of stations) vary according to the epoch when the forecast was made.*

(c) *Assessments of monthly forecasts for 1964–86*

Table III (a) shows the annual mean FP skill scores for best-estimate monthly forecasts that were issued from 1964 to 1985. Table III(b) shows the equivalent results from the Sutcliffe system for comparison with previous papers, e.g. Ratcliffe (1970), Jenkinson (1975) and Hardy (1980). For both systems the skill, SK, of a given forecast is derived from the scores, S_d, for individual districts as follows:

$$SK = 100 \frac{\Sigma S_d}{\Sigma S_d^{max}} \quad \text{for } \Sigma S_d > 0$$

$$SK = 100 \frac{\Sigma S_d}{\Sigma |S_d^{min}|} \quad \text{for } \Sigma S_d < 0$$

where S_d^{max} and S_d^{min} are the maximum and minimum possible scores (e.g. S_d^{max} is the score that would be obtained if the outcome was correctly forecast). Thus SK varies between ± 100%. For example, if the observed and forecast quints for two districts are (A_5, F_4) and (A_4, F_2), then their combined skill score is −16%(see Table I(a)). If an annual mean value of skill is required, the sum of the scores, ΣS_d, is taken over all ten districts and 24 overlapping forecast months in a year (starting in January and finishing in mid-December to mid-January). SK can, of course, be calculated over any period and choice of districts.

* The averaging periods used to calculate district mean anomalies for use with Tables I(a)–I(c) are as follows:

Period of forecasts	Temperature	Rainfall
1964–75	1931–60	1941–70
1976–80	1941–70	1941–70
1981–86	1951–80	1951–80

The 1931–60 temperature averages for the ten districts are estimates based on changes in Central England Temperature between 1931–60 and 1941–70.

Table III(a). *Annual skill scores (percentages) of issued forecasts for 1964–85 compared with persistence, for all districts, using the Folland–Painting system (I = issued and P = persistence forecasts)*

	Temperature (quints)		Temperature (grouped quints)		Rainfall (terces)	
	I	*P*	*I*	*P*	*I*	*P*
1964	1	−23	−1	−6	2	12
1965	18	29	−4	29	6	−2
1966	12	−9	8	−5	4	−2
1967	5	16	12	9	0	−19
1968	5	−14	6	−14	−8	−11
1969	23	16	7	17	14	0
1970	20	13	4	13	0	−4
1971	−18	−14	11	−1	−1	−11
1972	1	11	5	11	14	12
1973	−9	1	5	−6	11	10
1974	7	23	−2	14	1	18
1975	9	−7	10	7	5	2
1976	7	25	3	34	9	15
1977	−7	0	−1	−3	1	19
1978	−15	−15	−4	−13	15	9
1979	13	23	17	30	10	−8
1980	−5	−25	−2	−17	−16	−3
1981	14	−16	4	−4	9	−9
1982	−11	−7	−2	−18	−3	2
1983	15	17	24	25	19	0
1984	14	−8	17	0	22	12
1985	13	−3	15	−7	15	3
1964–85 mean	7	4	6	7	6	3
Twice the standard error*	4	6	3	6	4	4

* Assuming each year is independent of the next, calculated from twice the standard error of the underlying annual scores, only then converted to skill.

Table III also shows skill scores for forecasts based on the use of persistence, i.e. a forecast of the same quint or terce category as was observed in the most recently observed non-overlapping month-long period. There is clearly a large variability in skill as well as a small overall positive 'bias' in the Sutcliffe quint skill values (because slightly more positively biased quint 2, 3 and 4 categories were observed between 1964 and 1985 than the chance expectation of 60%).Over the whole period, issued forecasts averaged over all districts have statistically significant annual skill while persistence forecasts show significant annual skill for grouped quints only.

Figs 1–3 show 4-year running-mean graphs of skill calculated from the FP system, where skill has been updated for each 2-month natural season. The diagrams show that it is almost certain that real variations have occurred in the skill of both issued and persistence forecasts. (The FP scores have been summed over running 4-year periods before converting them to skill.) Fig. 1 indicates an appreciable variation in skill of forecasts of the persistence of temperature quints (persistence from the previous month), a peak in skill of issued temperature forecasts in the 1960s and a recent sharp, though modest, recovery of the skill of issued temperature and rainfall forecasts from low values in much of the 1970s.

Table III(b). *As Table III(a) but using the Sutcliffe system*

	Temperature (quints)		Rainfall (terces)	
	I	*P*	*I*	*P*
1964	5	−22	2	21
1965	26	32	9	2
1966	14	−5	5	−1
1967	11	25	2	−18
1968	10	−9	−10	−13
1969	24	10	17	4
1970	25	14	1	−2
1971	−18	−14	4	−3
1972	4	16	13	11
1973	−1	9	11	11
1974	6	24	6	21
1975	12	−8	5	2
1976	8	29	4	11
1977	−8	−4	2	20
1978	−20	−17	14	7
1979	12	24	12	−3
1980	2	−20	−16	−3
1981	15	−20	7	−11
1982	−5	2	−5	0
1983	15	16	17	−4
1984	18	−5	20	10
1985	17	−1	17	5
1964–85 mean	9	6	7	4
Twice the standard error	5	6	3	4

Fig. 2 (grouped quint assessments) places more emphasis on extremes (quints 1 and 5) being correct; until recently, forecasts categorized into grouped quints showed less skill than did those categorized into quints.

Fig. 3 indicates that the rainfall forecasts have increased in skill to the same extent as those for temperature both in absolute skill and relative to persistence. In fact the skill of the three-category forecasts of rainfall (terces) and temperature (grouped quints) changes in a rather similar way throughout 1964–86. Fig. 2 suggests that a rather sudden marked improvement in predictions of extreme temperature occurred quite recently. Fig. 4(a) throws light on this result. It shows the 4-year running mean of the ratio of the number of quints 1 and 5 observed to the number forecast, irrespective of whether the forecasts were correct. This ratio increased suddenly from a near-constant value of about 0.2 between 1964 and 1980 to over 0.8 in 1982–85, i.e. the 'boldness' of the best-estimate temperature forecasts has recently quadrupled. Despite the increased boldness in 1982–85, the probability that a forecast of an extreme quint was correct was about the same as in 1964–80. The net result was a four-fold increase in the number of correct forecasts of quints 1 and 5 (Fig. 4(b)). This is encouraging, as skilful forecasts of extremes are probably of most use to customers. Note that the problem of lack of boldness in the forecasts and the need to tackle it was well recognized in the period of public issue, especially by Jenkinson (personal communication).

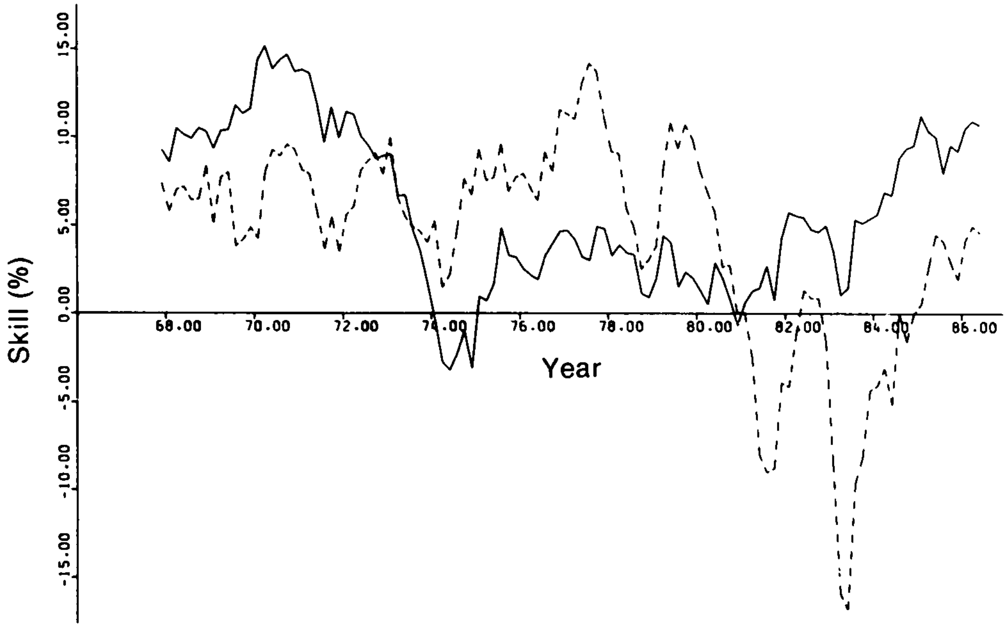


Figure 1. Four-year running mean skill of issued (——) and persistence (– – –) forecasts of temperature quints, based on the Folland–Painting system, plotted every two months. The last point plotted is for season 4 of 1982 to season 3 of 1986.

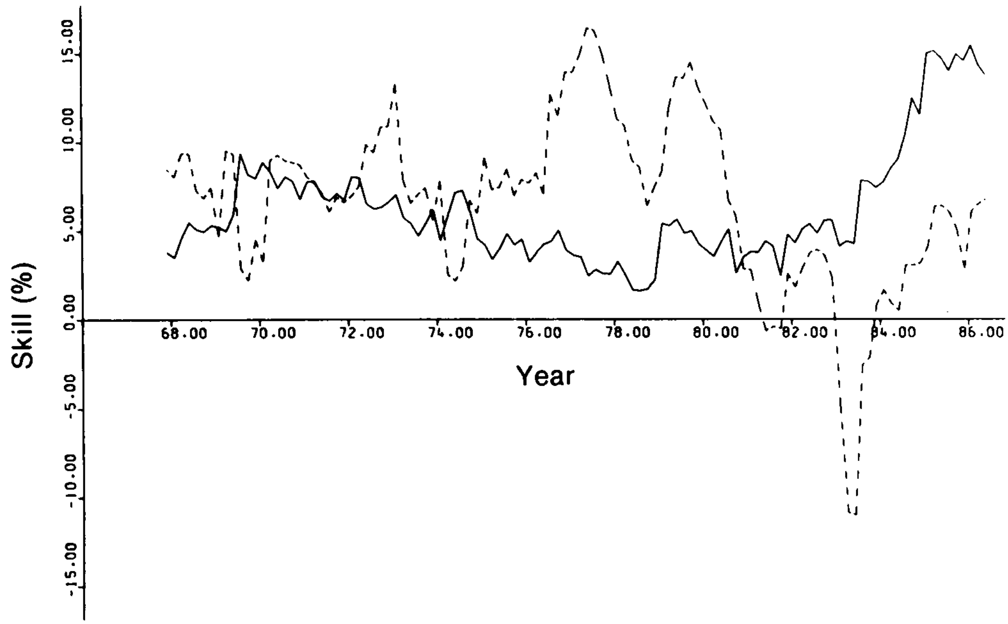


Figure 2. As for Fig. 1 but for grouped temperature quints.

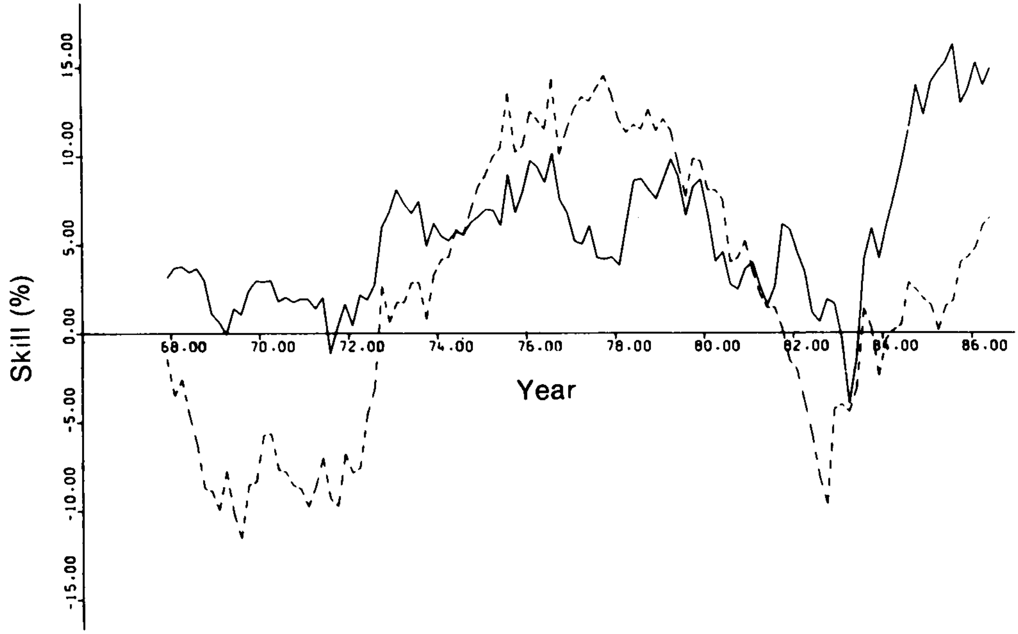


Figure 3. As for Fig. 1 but for rainfall terces.

There is still a strong tendency to forecast too many occasions of near-average rainfall (i.e. terce 2). Thus in 1982–85 the number of forecasts of terces 1 and 3 was only about 70% of the number observed — a percentage which was only a little more than in the period of public issue. Despite this, the likelihood that a forecast of terce 1 or terce 3 is correct appears to have increased (Fig. 5). Note that the chance percentage of such forecasts that are correct varies (mostly) with the number of terces 1 and 3 observed, though in the long run the chance percentage will be very near 33.3%.

Figs 6(a)–6(c) show how the skill of the issued forecasts has varied over individual districts. Four-year running-mean skill scores for all ten districts are shown, but for clarity only two are identified; district 5 (south-east and central southern England) and district 1 (eastern Scotland). District 5 has tended to have the least successful forecasts, especially in the 1970s. District 1 has generally more successful forecasts especially in the 1970s. Recently the skill scores have tended to vary less between the districts. The differences in the 1970s are important as Nap *et al.* (1981) and Baker (1982) draw rather over-pessimistic conclusions about the performance of UK long-range forecasts as a whole by analysing data only from district 5 during the 1970s.

The skill of monthly long-range forecasts also tends to vary with season (Table IV). Over the whole period 1964–86, the variations are not quite statistically significant, but they are appreciable. The correlation between the seasonal mean values of skill for temperature (quints) and rainfall (terces) is 0.85, which is statistically significant at the 5% level. It is too early to draw firm conclusions about recent trends in the pattern of seasonal forecast skill. So far, though, forecasts for the traditionally most skilful natural seasons (summer and winter) have contributed most to recent increases in skill, especially forecasts of temperature in winter and rainfall in summer. Over the last few years forecasts in spring have been least successful.

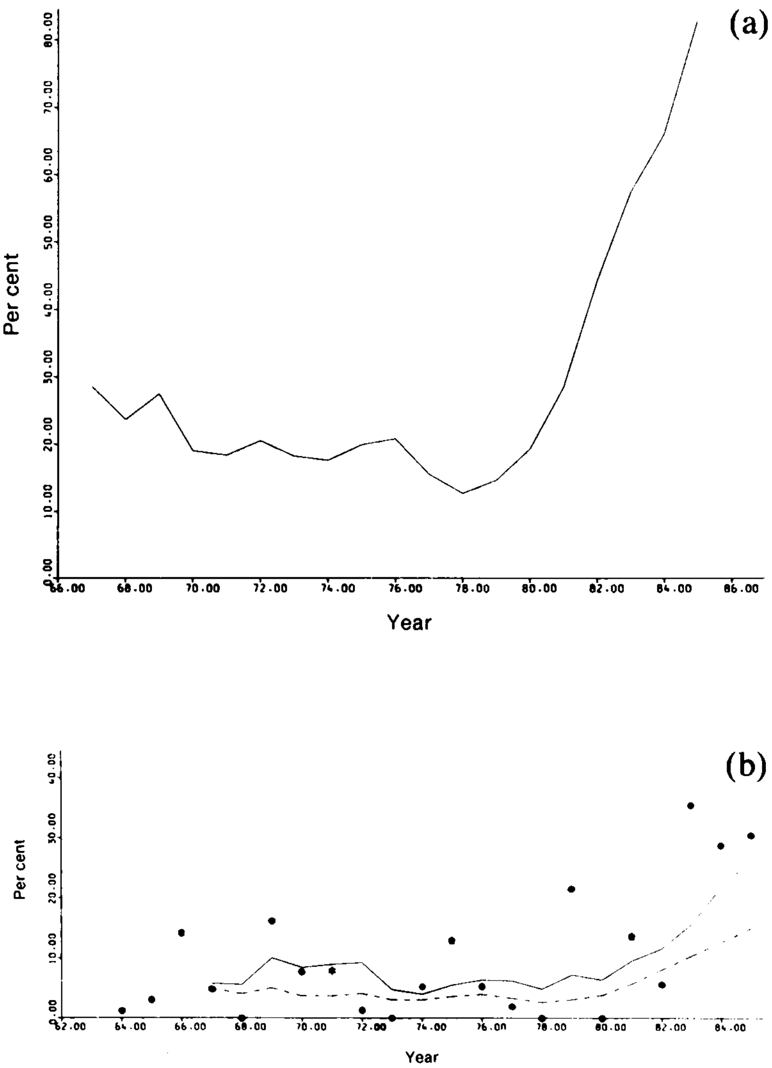


Figure 4. (a) Percentage of quints 1 and 5 forecast compared with number of quints 1 and 5 observed and (b) the percentage of observed quints 1 and 5 which were correctly forecast: individual years (•), four-year running mean (——), four-year running mean of chance percentage of correct forecasts of quints 1 and 5, given the number of quints 1 and 5 forecast (– – –).

(d) *PMSL forecasts for six grid points near the United Kingdom*

For each month, PMSL forecasts for the constituent medium-, mid- and long-range periods have been appropriately averaged to provide forecasts of mean monthly and half-monthly PMSL and PMSL anomalies (from a 1951–70 average) at each of the six grid points. Because the period available for testing is brief (the 4 years from July 1982 to mid-June/mid-July 1986) only a short summary of the results is given (Table V).

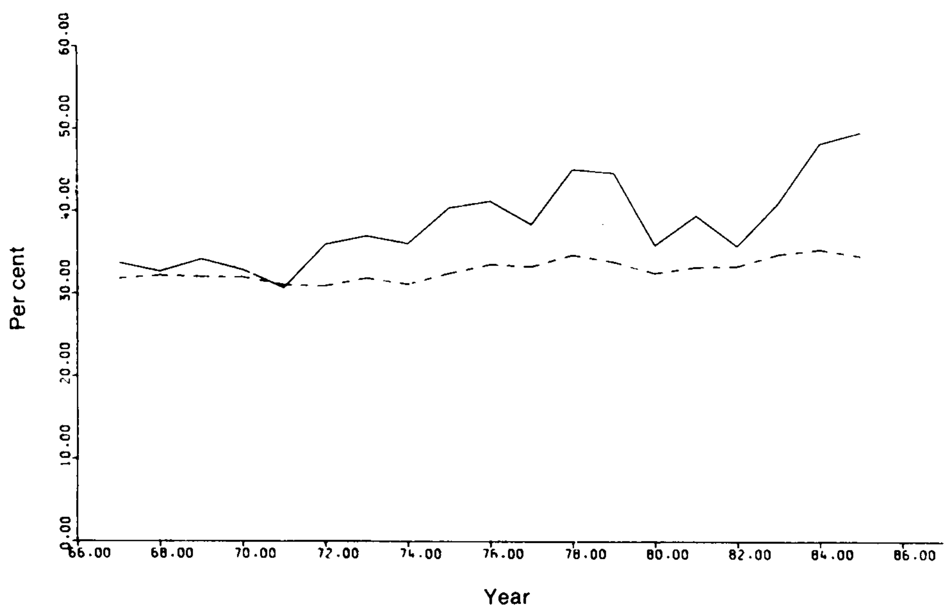


Figure 5. Four-year running mean of percentage of forecasts of rainfall terces 1 and 3 that were correct (——) and that expected by chance to be correct given the number observed (– – –).

The skill of the PMSL anomaly forecasts has been categorized according to the confidence levels C, D or E that accompany each forecast (the confidence scale runs from A (highest) to E (lowest), but only the range C to E is currently used) to provide an indication of whether these expressions of confidence made when the forecast is issued are meaningful. Four measures of skill are shown:

(i) A measure of the skill of the PMSL anomaly forecasts in predicting correctly the observed sign of the PMSL anomalies. This is called the 'sign skill' and is defined by:

$$SS = 100 \frac{(N_c - N_i)}{T}$$

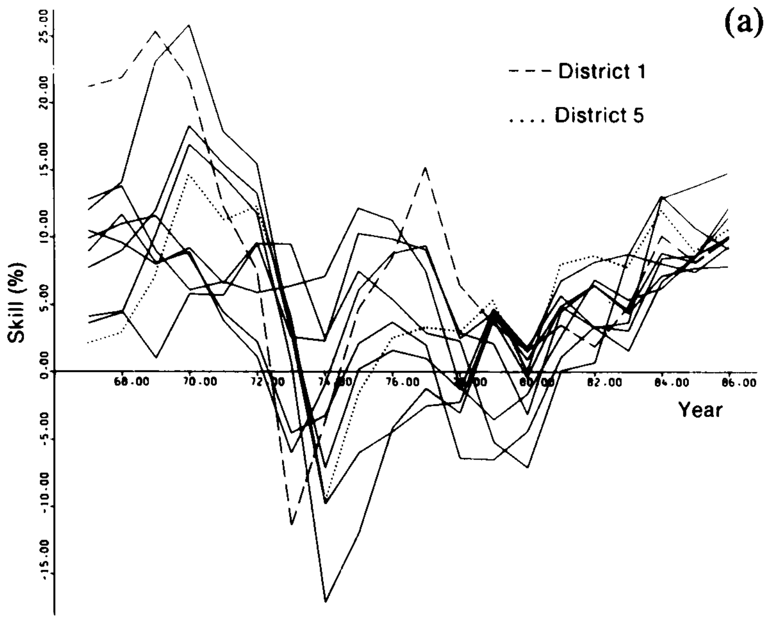
where N_c and N_i are the number of correctly and incorrectly forecast grid points respectively, and T is the total number of grid points forecast. This index has a value of zero when the numbers of correct and incorrect forecasts are the same. *SS* provides the same measures of skill as does the FP system when applied to two equi-probable observed and forecast categories (climatological probability 0.5 for each category).

(ii) The root-mean-square error of the PMSL anomaly forecasts, $(RMS)_F$ in millibars.

(iii) The root-mean-square error of forecasts assuming persistence of the PMSL anomaly observed in the previous month, $(RMS)_P$ in millibars.

(iv) The mean correlation, r_A between the forecast and observed PMSL anomalies. This is calculated as the grand average of correlations calculated for individual monthly forecasts (using Fisher's z transformation to help calculate the average (e.g. Snedecor and Cochran 1973)).

It appears that there is significantly more skill in the forecasts overall when the forecasters have most confidence (confidence C) in them at the time of issue. It is encouraging that the PMSL forecasts,



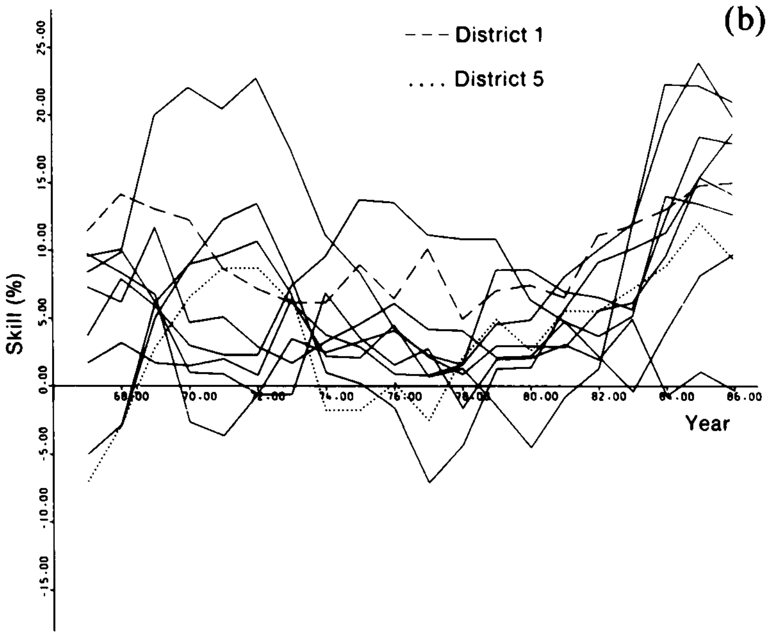


Figure 6. Four-year running mean skill of forecasts for all ten districts of (a) temperature quints, (b) grouped temperature quints and (c) rainfall terces. Districts 1 and 5 are highlighted.

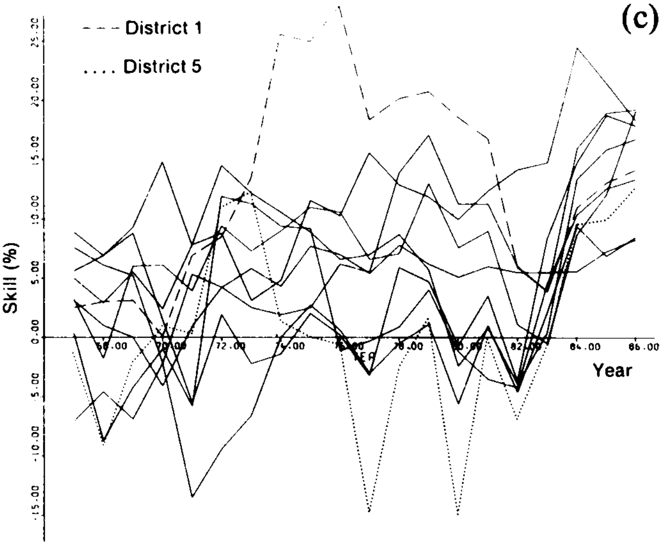


Figure 6 continued.

Table IV *Seasonal skill scores (percentages) of issued forecasts between 1964 and pre-summer 1986 compared with persistences, for all districts, using the Folland–Painting system*

Natural seasons (two months)	No. of forecasts*	Skill	Persistence skill
(a) Temperature (quints)			
Winter (Jan., Feb.)	92	10	5
Spring	92	5	6
Pre-summer	92	1	4
Summer	88	18	16
Autumn	88	2	3
Pre-winter	88	4	−8
(b) Temperature (grouped quints)			
Winter	92	11	3
Spring	92	6	16
Pre-summer	92	1	4
Summer	88	18	20
Autumn	88	−1	4
Pre-winter	88	1	−5
(c) Rainfall (terces)			
Winter	92	6	4
Spring	92	4	−2
Pre-summer	92	3	1
Summer	88	16	12
Autumn	88	7	5
Pre-winter	88	1	−3

* There are four overlapping monthly forecasts in each season in each year and a forecast for the ten districts in a given month is counted as one forecast.

Table V. *Summary of various skills for different confidences of forecast during recent years (see text for explanation of notation)*

	Confidence C	D	E	All	Twice standard error	Significance*
(a) Monthly mean PMSL forecasts						
No. of forecasts	17	46	33	96		
SS	75	23	16	30	19	1%
$(RMS)_F$ (mb)	4.31	6.21	6.32	5.96		
$(RMS)_P$ (mb)	6.82	8.21	8.79	8.19		
$(RMS)_F/(RMS)_P$	0.63	0.76	0.72	0.73		
r_A	0.34	0.16	0.27	0.23	0.17	
(b) Monthly temperature and rainfall — Folland–Painting skill scores						
Temperature (quints)	29	3	11	11		
Temperature (grouped quints)	23	6	17	14		
Rainfall (terces)	40	15	2	15		1%

* Using an analysis of variance on the three categories, and assuming $N/2$ independent monthly forecasts, where N = number of forecasts.

Note: $(RMS)_C$, the root-mean-square error of a forecast of climatology, is about $0.75 \times (RMS)_P$ in principle, so is harder to improve on than persistence. However, the values of *SS* and r_A for climatology forecasts are in principle zero, illustrating the difficulty of scoring long-range forecasts expressed in ordinary scientific units.

Twice the standard error is calculated assuming $N/2$ independent monthly forecasts.

especially, hint at this relationship. Table V indicates, therefore, that an overall measure of consistency exists between the skill of the different elements of the forecasts and the quality of the evidence used to construct them. This is perhaps one of the best pieces of scientific evidence so far available that long-range forecasting can be done at all, that predictability does vary and that the user, to a limited extent, can decide on which forecasts to place more reliance. However, the user is most likely to benefit from applying this knowledge over an extended period.

4. Variation of skill throughout the monthly forecast

High skill in the medium range (days 1–5) will clearly tend to raise the skill of the forecasts averaged over the month as a whole. So a false impression could be gained of trends in skill in the truly long range from changes in monthly average skill alone. Table VI gives a preliminary indication of the variation of sign skill, *SS*, for different periods within the monthly forecasts since the data were first available in a homogeneous form (July 1982). *SS* is applied to best-estimate forecasts of temperature anomaly and rainfall percentage on the medium, mid (day 6–mid-month) and long (second half-month) ranges and to PMSL forecasts for the two individual half-months and for the whole month. *SS* is a very basic measure of skill, being based on only two categories, and will generally give larger values of skill than a more searching terce or quint scheme. It is adequate to show, though, whether skill exists at all.

To increase the number of forecasts available for assessment, the forecasts for each district are used. However, adjustments have then been made to the nominal number of district forecasts to allow for their lack of statistical independence. These adjustments are made separately for temperature and rainfall forecasts and allow for the correlation of observed district-averaged anomalies (a) in space (between districts) and (b) in time (due to the persistence and, sometimes, overlap of observed conditions in successive forecast periods); the details are described in Appendix 2. The procedure entails the introduction of the factor f_i, whose form is derived in Appendix 2, which is used to reduce the apparent number of forecasts summed over all districts; f_i is shown in Table VI for each forecast period i within the month.

Table VI. *Sign skill (SS) of forecasts for periods within a month for the period July 1982 to mid-June/mid-July 1986 (see text for explanation of notation)*

	Medium range	Mid range	First half-month	Second half-month	Mid and long ranges	Whole month
(a) PMSL*						
SS	—	—	34	8	—	30
(b) Temperature						
SS	43	6	21	8	9	16
Significance	10^{-3}%	—	2%	—	—	10%
f_i	0.115	0.109	0.109	0.110	0.103	0.102
(c) Rainfall						
SS	35	13	26	20	20	25
Significance	5×10^{-4}%	10%	2×10^{-1}%	1%	5%	1%
f_i	0.117	0.151	0.149	0.149	0.136	0.133
D_iN_i	960	960	960	960	960	960

* No significance tests available.

Note: The percentage of forecasts having the correct signs of their anomalies is given by 50 + 0.5 *SS*.

Table VI shows that, on the monthly time-scale, the number of statistically independent district forecasts is typically only about 10–15% of the number issued . This number (for a month) is considerably less, for example, than that cautiously assumed by Hardy (1980). Estimates of the statistical significance of *SS* are based on two tests. Firstly a χ^2 test (Snedecor and Cochran 1973) is used to indicate whether the tendency to forecast correctly the sign of the observed anomalies is statistically significant after allowing for the actual number of observations and forecasts, of both signs, of the anomaly. For rainfall, the two categories of opposite sign are above and below 100% of average rainfall respectively. Allowance was also made for a marked tendency to forecast exactly 100% of average rainfall or zero anomaly of temperature in the mid range or long range. These are regarded, in principle, as neither correct nor incorrect.

A second test, based on the binomial distribution, is used to show whether the observed fraction of forecasts having the correct sign of the anomaly is significantly larger than the chance value, which is assumed to be 0.5. Both tests give similar results and only their average indication of statistical significance is reported.

The following important conclusions can be deduced from Table VI:

(i) There can be no doubt that the forecasts have appreciable skill in the medium range (days 1–5 of the forecast which are in practice usually days 2–6 or 3–7 ahead). The skill value of 43% observed for temperature implies that over 71% of the district temperature forecasts had the correct sign between July 1982 and mid-June/mid-July 1986 (since January 1985 the number with correct sign has averaged nearly 80%).

(ii) The rainfall forecasts tend to be better than the temperature forecasts except in the medium range: Table VI has the advantage of providing the same, if very basic, measure of skill for both parameters so that a direct comparison of skill is possible. The extra skill of the rainfall forecasts is clearer in the second half-month ahead (long range), when it is apparently statistically significant. However since summer 1985 the temperature forecasts have been more skilful, possibly related to the increased use of information about sea surface temperature anomalies near the UK coast (Folland and Woodcock 1986).

(iii) The average structure of sign skill through the monthly forecasts is unexpectedly complex. Thus the skill of the rainfall forecasts on the monthly time-scale is unexpectedly large (25%) when compared with the medium-range time-scale (35%) and is unexpectedly small (smallest) in the mid range (13%). However, mid-range skill has apparently improved over the last year. There is a marked overall tendency for the skill averaged over a longer forecast period to be larger than its weighted average over constituent shorter periods. This is a regular feature even in tables (not shown) for individual years constructed in the same way as Table VI, despite large interannual variations in other details of the skill. This tendency may result from timing errors in the forecasts which are likely to reduce skill more strongly on shorter time-scales than on longer ones — a feature worth closer scrutiny since it could affect the perception of 'predictability' and the design of future forecasting systems.

5. Conclusions

Despite a substantial reduction in staff effort, the use of a small number of improved forecasting techniques and the creation of a more structured forecasting procedure appear to have recently resulted in a modest improvement in skill. Skill of course is still low and it remains to be seen whether the improvement can be maintained; past history demonstrates that fluctuations in skill are almost inevitable in the future. It is hoped that current efforts to (a) introduce regular dynamical forecasts in the longer ranges, (b) to intensify research into the dynamics and statistical description of low-frequency weather variability and (c) to exploit information contained in world-wide sea surface temperature anomaly patterns, may allow further slow improvements in technique and performance to take place.

6. Acknowledgements

The authors would especially like to thank K. Shone, B.N. Parker and J. McCoy for their past help in developing the computerized assessment system and D.E. Jones and N. Ward for numerous discussions about the performance of long-range forecasts.

References

Baker, T. 1982 An evaluation of long-range forecasts. *Weather*, **37**, 262–265.

Daan, H. 1985 Sensitivity of verification scores to the classification of the predictand. *Mon Weather Rev*, **113**, 1384–1392.

Flood, C.R. and Weller, M.J. 1969 The verification of long-range temperature forecasts. (Unpublished, copy available in the National Meteorological Library, Bracknell.)

Folland, C.K. and Colman, A. 1986 A multivariate technique for use in long-range forecasting. Proceedings of first WMO Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe. Programme on long-range forecasting research, Report series No. 6, Vol. II. Geneva, WMO.

Folland, C.K. and Parker, D.E. 1986 Worldwide and regional variations of surface marine temperature 1856–1985. Proceedings of the third Hellenic–British Climatological Congress in Athens 17–21 April 1985. Athens Hellenic Meteorological Society.

Folland, C.K. and Woodcock, A. 1986 Experimental monthly long-range forecasts for the United Kingdom. Part I. Description of the forecasting system. *Meteorol Mag*, **115**, 301–318.

Folland, C.K., Parker, D.E. and Newman, M. 1985 Worldwide marine temperature variations on the season to century timescale. Proceedings of the Ninth Annual Climate Diagnostics Workshop. Department of Atmospheric Sciences, Univesity of Oregon, Corvallis.

Freeman, M.H. 1966 The accuracy of long-range forecasts issued by the Meteorological Office. *Meteorol Mag*, **95**, 321–325.

Gilchrist, A. 1982 Long range forecasting in the Meteorological Office. Part I. *In* ECMWF seminar on Problems and Prospects in Long and Medium Range Forecasting, Sept 1981.

Hardy, R.N. 1980 The skill of Meteorological Office long-range weather forecasts from 1965 to 1979. (Unpublished, copy available in the National Meteorological Library, Bracknell.)

Jenkinson, A.F. 1975 The accuracy of the Meteorological Office long range weather forecasts. *Weather*, **30**, 288–290.

Jones, D.S. 1979 Elementary information theory. Oxford, Clarendon Press.

Nap, J.L., Van den Dool, H.M. and Oerlemans, J. 1981 A verification of monthly weather forecasts in the seventies. *Mon Weather Rev*, **109**, 306–312.

Ratcliffe, R.A.S. 1970 Meteorological Office long-range forecasts: six years of progress. *Meteorol Mag*, **99**, 125–130.

Snedecor, G.W. and Cochran, W.G. 1973 Statistical methods. Sixth Edition. Iowa State University Press.

Tabony, R.C. 1977 The variability of long-duration rainfall over Great Britain. *Meteorol Off Sci Pap*, No. 37.

Yevjevich, V. 1972 Probability and statistics in hydrology. Colorado, Fort Collins, Water Resources Publications.

Appendix 1 *The FP scoring system for long-range forecasts*

The fundamental basis for the FP system arose from an unpublished suggestion by Kirk around 1970 that information theory might provide a more flexible and satisfactory approach to assessing long-range forecasts. This is currently a matter of debate (e.g. Daan 1985). The initial development of Kirk's ideas was carried out by Painting (personal communication) in 1975. The FP system can provide a variety of diagnostics about forecast performance (both best-estimate and probability forecasts). Here attention is concentrated on deriving the Tables I(a)–I(c) used to estimate the skill of best-estimate forecasts.

Fig. A1 shows a hypothetical probability distribution of, say, monthly mean temperature in a given district and calendar month derived from many years of historical data. A best-estimate forecast, X_F, is made in one of the categories shown (which need not have the same size) and the category in which the verifying observation, X_A, falls is noted. The 'distance' between X_F and X_A is defined as the area, S_{FA}, under that part of the probability curve that lies between, and includes, the categories into which X_F and X_A fall. The information content of the forecast is then defined as:

$$I = -\log_e (S_{FA}). \qquad \text{(A1.1)}$$

This definition is related to the idea of the 'self information' of an event in information theory (Jones 1979). It is possible to calculate I for all combinations of forecast and observed values to provide a table of information values. Table AI shows the resulting information values I_{ij} ($i = 1$ to 5, $j = 1$ to 5) for (equi-probable) forecasts and observations of quints. Note that $I = 0$ for a forecast of quint 5 and an observation of quint 1 which, quite naturally, has no information content.

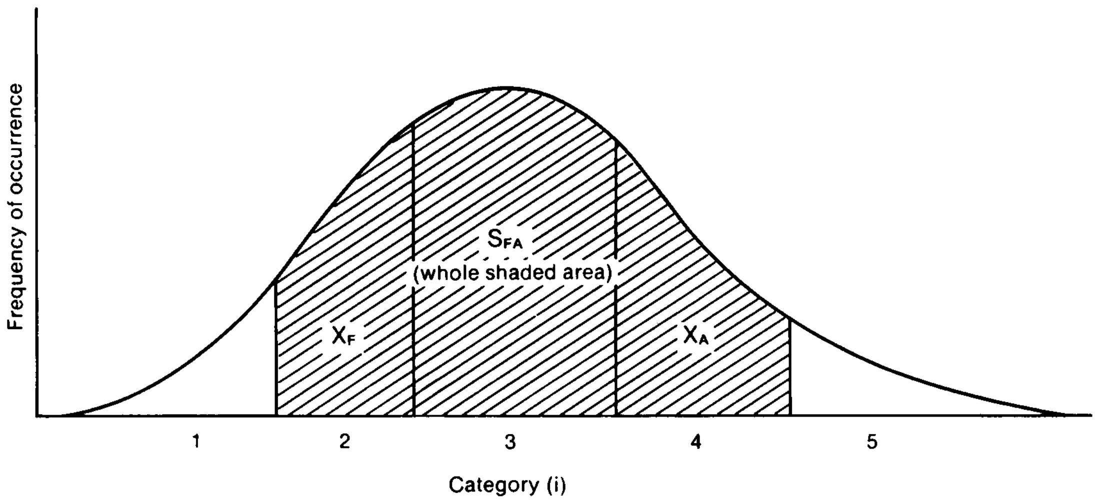


Figure A1. The basis of the Folland–Painting system using a probability curve. X_F and X_A are respectively the forecast and observed values for a variable X, and S_{FA} is the area under the probability curve that lies between, and includes, the categories into which X_F and X_A fall. The five categories (i) into which X_F and X_A fall do not necessarily have equal areas under the probability curve.

Table A1. *Information scores for forecast and observed quints using the Folland–Painting system*

Forecast	Observed 1	2	3	4	5
1	1.61	0.92	0.51	0.22	0
2	0.92	1.61	0.92	0.51	0.22
3	0.51	0.92	1.61	0.92	0.51
4	0.22	0.51	0.92	1.61	0.92
5	0	0.22	0.51	0.92	1.61

It is desirable for scientific purposes to provide a set of information values I'_{ij} whose average would be zero if the forecasts were unrelated statistically to the observations. This can be done, e.g. for a set of quint categories, by making a long series of forecasts where the quint categories of successive forecasts are chosen using a random number generator which operates on a uniform distribution of numbers in the range 1 to 5. The expected result of this operation can be achieved using a standard mathematical result:

$$I'_{ij} = I_{ij} - \frac{\sum_{i=1}^{5} P_{ij/j}.I_{ij}.\sum_{j=1}^{5} P_{ij/i}.I_{ij}}{\sum_{i=1}^{5}\sum_{j=1}^{5} P_{ij}.I_{ij}} \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (A1.2)$$

where P_{ij} is the chance probability of an observation of category i and a forecast of category j, $P_{ij/i}$ is the chance probability of category ij happening given that the forecast category j occurred etc. We note also that in the quint table:

$$\sum_{i=1}^{5} P_{ij/j} = \sum_{j=1}^{5} P_{ij/i} = 1. \quad \ldots\ \ldots\ \ldots\ \ldots\ \ldots\ \ldots \quad (A1.3)$$

The resulting values, I'_{ij}, are called the 'effective information gain' values above a (random) chance level. To help comparison with the older Sutcliffe scoring system, we normalize the effective information gain values to a new set, S_{ij}, so that the long-term average score for a correct forecast is 4 (allowing for the long-term probabilities of each correct category; in a quint scheme these are 0.2 for each correct category). Tables 1(a)–1(c) result from appropriate applications of this procedure, and assume that the forecasts and observations of each category are made with their expected probabilities (i.e. 0.2 for forecasts and observations of quints and 0.333 for those of terces). In recent years these assumptions have been reasonably acceptable for quints but before 1981 the number of forecasts of extreme temperature (quints 1 and 5) was consistently much too low, only about 1/5 of the number observed (see also section 3(b)). The problem will be discussed in a future paper; it is enough to note that the FP system can automatically be adjusted (via equation (A1.2)) to deal with this problem. Flood and Weller (1969) provide an interesting discussion of the possible consequences for skill when the Sutcliffe scoring system is not adjusted to allow for an insufficient number of forecasts of extremes.

Appendix 2 *Calculation of the equivalent number of independent district forecasts*

Let there be N_i forecasts for a given period i within the month (including the month itself) made over a period of time for D_i districts. The total of D_i times N_i forecasts is modified to an equivalent number of independent forecasts N'_i given by:

$$N'_i = a_i D_i b_i N_i = f_i D_i N_i$$

where $f_i = a_i b_i$ and b_i is the reducing factor that estimates the effective number of independent forecasts made through time for a given district due (mainly) to the persistence of observed anomalies between successive forecasts, and a_i is the reducing factor that estimates the effective number of independent districts mainly because of the high spatial correlation of observed anomalies between districts. Thus $a_i < 1$ and $b_i < 1$. The high spatial correlation of temperature and rainfall anomalies means that the number of truly independent districts is much less than the ten for which forecasts are made. Using data for the period July 1982 to mid-June/mid-July 1986, estimates of a_i were made using the formula (Yevjevich 1972):

$$a_i = \frac{D_i}{K_i(D_i - 1)\,\bar{r}_i + 1}$$

where $\bar{r}_i$ is the average correlation of the observed anomalies in each district with those in every other district and K_i is a complex factor that allows for the variation in the standard deviation of the temperature anomalies or rainfall percentages between districts and between different months of the year and has a value of a little below unity. The value of a_i varies only slowly with the choice of forecast period i and averages rather over 0.1 for temperature and about 0.15 for rainfall. The value of b_i has been estimated from the following approximate expression adapted from Yevjevich (1972):

$$b_i = \frac{N_i}{1 + 2(\bar{r}_{1i}^{\,2} + \bar{r}_{2i}^{\,2} + \bar{r}_{3i}^{\,3})}$$

where $\bar{r}_{1i}$ is the average correlation (over all districts) of observed anomalies (for given forecast period length i) in successive forecast periods, $\bar{r}_{2i}$ is the average correlation of observed anomalies with those in the next but one forecast period, etc. Values of $\bar{r}_{4i}$ and beyond were insignificantly different from zero for all lengths of forecast period within the month and so were not used.

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Snow forecasts from the Meteorological Office fine-mesh model during the winter of 1985/86

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Summary

The performance of the Meteorological Office fine-mesh model in forecasting snow during the winter of 1985/86 is examined. The snow predictor currently used in the model is compared with other possible predictors to see whether an alternative predictor could provide more precise guidance.

1. Introduction

The fine-mesh model is one of the important sources of guidance for forecasters in the United Kingdom and, in his assessment of the current state of short-range weather forecasting, Woodroffe (1984) states that the model is the best tool at the forecaster's disposal for forecasting snow 24 hours or so ahead. A basic description of the fine-mesh model can be found in an article by Gadd (1985).

The forecasting of snow is a two-stage process. The first stage is to decide whether or not precipitation is likely, and the second stage is to forecast the temperature structure of the near-surface layer of the atmosphere. This second stage compounds the forecasting problem since small temperature errors may imply the wrong form of precipitation. The main purpose of this paper is to examine the performance of the fine-mesh model with regard to the second stage, but firstly, a few remarks are required as to the quality of the model's precipitation forecasts.

The fine-mesh model is a grid-point model with a grid length over the United Kingdom of about 75 km. As a result of approximations used in the modelling process, accurate detail cannot be achieved on a scale below one or two grid lengths, about 100 km. The enhancement of precipitation due to orographic effects and local convection cannot therefore be simulated realistically by the model.

Errors of about one grid length in forecasting precipitation are often unimportant as the movement of systems makes them appear as minor timing errors. However, in slow-moving or quasi-stationary situations, such an error can imply the wrong character of weather for a whole region, but even with this degradation, the fine-mesh model has proved to be very useful in assessing the general distribution and amounts of rain. Up to the winter of 1985/86 there was no regular objective verification of precipitation forecasts from the model, though since 1962 a partially objective statistic has been produced in the Central Forecasting Office (CFO) at Bracknell based on the forecast of precipitation for London made by the senior forecaster (Woodroffe 1984, Flood 1985). This statistic shows that the skill of the forecast does appear to have improved in recent years and this improvement is mainly attributed to the increased accuracy of fine-mesh model guidance.

2. Snow prediction

Whether snow melts or not before reaching the ground depends on the temperature and humidity near the surface and the rate of precipitation. Forecasting the low-level atmospheric structure is difficult and to overcome this, attempts have been made to identify snow predictors which can be forecast more readily. For example Boyden (1964) examined a number of predictors giving the probability of snow and recommended the use of the 1000–850 mb thickness corrected for mean-sea-level pressure (MSL) by adding a factor (MSL−1000)/4; this predictor will be referred to as 1000–850 P henceforth. A further correction for station height is also required (arrived at by subtracting station height in metres divided by 30).

The 1000–850 P has become one of the most widely used predictors chiefly because it is usually not too difficult to predict the 1000–850 mb thickness. With the advent of the 10-level model, and in particular the limited-area version (the rectangle), it was appreciated that the model forecast of the 1000–850 mb thickness was reliable enough for the predictors to be displayed as part of the model output. Therefore the 1000–850 P was used to show the probability of snow occurring by adding lines of snow probability (80%, 50% and 20%) to the form of output used by the forecaster. The use of the snow-probability lines based on 1000–850 P has continued with the introduction of the higher-resolution fine-mesh model. The snow-probability lines are mean-sea-level values which need to be adjusted to suit local terrain. However the fine-mesh model orography is too smooth (because the grid length is insufficient to resolve local detail) to make realistic adjustments to the snow probability at each grid point. Fig. 1 shows the orography currently used by the fine-mesh. There are many places where the model orography differs substantially from reality. Note for example, the absence of valleys.

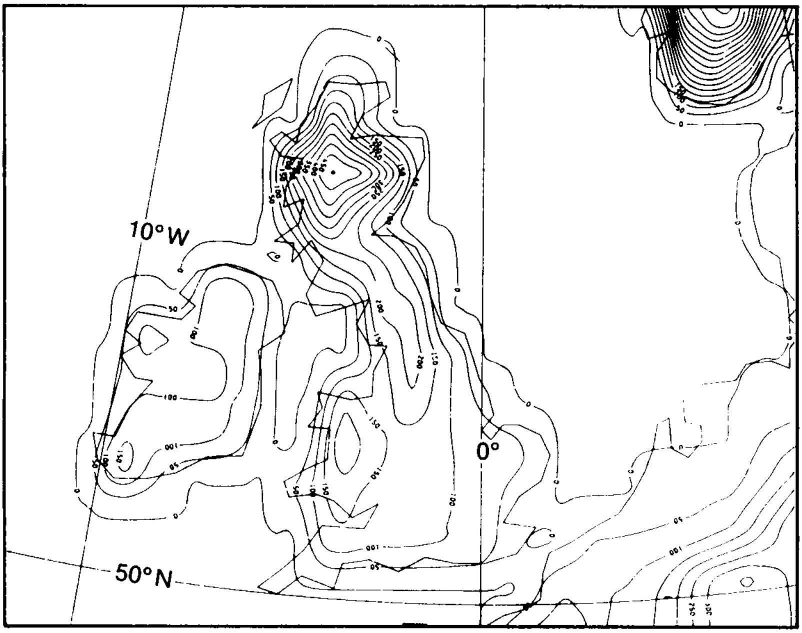


Figure 1. Part of the operational fine-mesh orography. Lines drawn every 50 metres.

Forecasters in CFO have recognized for some time that in the case of precipitation ahead of active warm fronts, the 1000–850 P predictor underestimates the probability of snow. The 20% snow-line in such instances is usually interpreted as defining a 50% actual probability of snow (Hunt 1985). The discrepancy is not a result of model errors in forecasting the 1000–850 mb thickness. Indeed, since the 1000–850 mb thickness of 1300 gpm (corresponding to a 20% probability of snow when MSL is 1000 mb) is considered to be important, the forecaster in CFO has forecast charts of 1000–850 mb thickness available so that they can be examined in marginal situations and used for forecasting snow over high ground.

Boyden pointed out possible reasons for the failure on some occasions of 1000–850 P as a predictor. Firstly, the layer of air above the freezing level contributes to the thickness but is not relevant to the form of precipitation. Secondly, the 1000–850 mb thickness is relatively insensitive to the lowering of the freezing level caused by melting snow. Both factors taken together are important when considering active warm fronts, particularly in situations where an inversion just above the surface is undercut by very cold air.

The efficacy of 1000–850 P as a predictor is partly due to the experience and skill of the user. However, major snowfall events are often finely balanced, particularly in southern Britain on occasions when warm air from the south-west comes up against very cold and dry continental air. When using 1000–850 P, many forecasters compensate for warm fronts as well as attempting to assess the likely structure of the low-level air by studying upstream dew-points and temperatures.

In practice a single-valued predictor would be more helpful. If a representative upper-air ascent is available or the low-level structure can be forecast, many forecasters choose to use the wet-bulb freezing level as a predictor. In an operational trial of snow predictors, Lowndes *et al.* (1974) suggested that the wet-bulb freezing level was the most efficient predictor. To make effective use of wet-bulb freezing level or any other predictor relying on information close to the surface in a numerical model requires an accurate simulation of the near-surface layers. Before the winter of 1985/86, forecast surface and boundary-layer temperatures from the fine-mesh were not accurate enough, but the introduction of a scheme for modelling the soil heat flux has improved the forecast temperatures markedly. It is therefore worthwhile examining some other predictors to see whether their performance matches that of 1000–850 P.

3. A comparison of snow predictors using the fine-mesh model

The only routine verification of snow forecasts produced by the fine-mesh model is a subjective assessment made by the senior forecaster in CFO of the 24-hour forecast. The assessment is based on the position of the snow-probability lines over the United Kingdom and on the forecast precipitation area. It is made only when the forecast pressure pattern is considered to be good, so that cases of incorrect model evolution over the United Kingdom are excluded. The performance of the model during the period 26 December 1985 to 7 April 1986 is summarized in Table I.

Table I. *CFO subjective assessment of fine-mesh snow forecasts at T+24 hours, during the period 26 December 1985–7 April 1986*

Score	Criteria	Number of forecasts
A	Snow well forecast	28
B +/−	Snow slightly over/under estimated in amount or extent	47
C +/−	Snow badly over/under estimated in amount or extent	29

Considering the 29 forecasts scored as 'C', 14 underestimated amounts of snow, 8 overestimated and the remaining 7 were a combination of precipitation error and forecast thickness error. The majority of forecasts scored as 'C' were due mainly to errors in precipitation rather than thickness, and several others to the model's underestimation of areas of very light snow during February. These results show an encouraging degree of skill (over 70% score A or B, excluding cases with major evolution errors) in the prediction of snow.

It was not possible to reproduce the above verification using other predictors so an objective comparison has been made using 11 cases from the period covered by the above assessment. These

11 cases were chosen because on each occasion the forecasting of significant snowfall was finely balanced. The predictors examined were as follows:

(a) 1000–850 P.
(b) Dry-bulb freezing level.
(c) Wet-bulb freezing level.
(d) Mean temperature of the lowest 100 mb above the ground.

Table II shows the probability of snow for particular values of the first two predictors derived by Boyden. The difference between 30% and 70% snow probability using 1000–850 P is less than 10 gpm. For this predictor to be useful, the fine-mesh model needs to forecast the 1000–850 mb thickness within 1% accuracy. The forecast values at T+24 hours of the 1000–850 mb thickness at nine UK/Irish upper-air stations were compared with the actual radiosonde values in the 11 cases assessed. The mean error was found to be 1.5 gpm and the root-mean-square (r.m.s.) error 6 gpm — comfortably within the range required. In one case thickness errors greater than 10 gpm were found to be due to an inaccurate evolution.

Table II. *Snow probabilities derived from values of the 1000–850 mb thickness and dry-bulb freezing level*

Percentage probability of snow	90	70	50	30	10
1000–850 P (gpm)	1281	1290	1293	1298	1303
Dry-bulb freezing level (mb)	12	25	35	45	61

To use the dry-bulb freezing level as a predictor, the model needs to predict the freezing level to within 20 mb. Lowndes *et al.* (1974) derived values for wet-bulb freezing levels for showery and non-showery precipitation which show even less margin for error. Comparison of forecast dry- and wet-bulb freezing levels at T+24 hours with radiosonde values for the 11 chosen cases gave the following results. For the dry-bulb freezing level the mean error was found to be 15 mb and the r.m.s. error 26 mb; for the wet-bulb freezing level the mean error was found to be 20 mb and the r.m.s. error 29 mb. The percentage of forecasts correct within 20 mb was 72% for the dry-bulb freezing level. These figures demonstrate that the freezing level in the model is not sufficiently reliable to use as a predictor for snow.

The mean temperature of the lowest 100 mb above the ground, (known as M100 henceforth) has recently been suggested as a possible snow predictor. However M100 would need to be corrected if the fine-mesh orography differed significantly from the actual orography. Suggested values for this predictor, derived from comparison with observations by W. Hand (personal communication) are shown in Table III.

Table III. *Mean temperature of lowest 100 mb above ground used to predict type of precipitation at the surface*

Mean temperature of the lowest 100 mb above ground (°C)	Precipitation type at surface
Less than −1.5	Snow
−1.5 to 0.5	Sleet
More than 0.5	Rain

In tests using M100, the 0.5 °C isotherm gave useful guidance for the position of the rain/sleet boundary, but −0.5 °C seemed more appropriate for the sleet/snow boundary than the −1.5 °C suggested. This is perhaps evidence of a slightly warm bias in the model at low levels.

4. The predictors in action — fine-mesh model case study, 7 January 1986

By 06 GMT on 7 January, a warm front was approaching south-west England, bringing moderate or heavy rain and sleet to southern Cornwall. As the front continued to push slowly northwards, the rain soon turned to snow and sleet inland, especially over the higher ground in southern England and Wales. The snow reached the Midlands during the afternoon and extended into East Anglia and north-west England during the evening. Over southern England and South Wales the snow did not last long and was followed by rain or sleet, but further north the snow persisted. Fig. 2 shows the synoptic situation at 18 GMT, with the heaviest snow over the Midlands. During the evening, the warm front became quasi-stationary from Sussex to central Wales, with moderate or heavy snow to the north of this line.

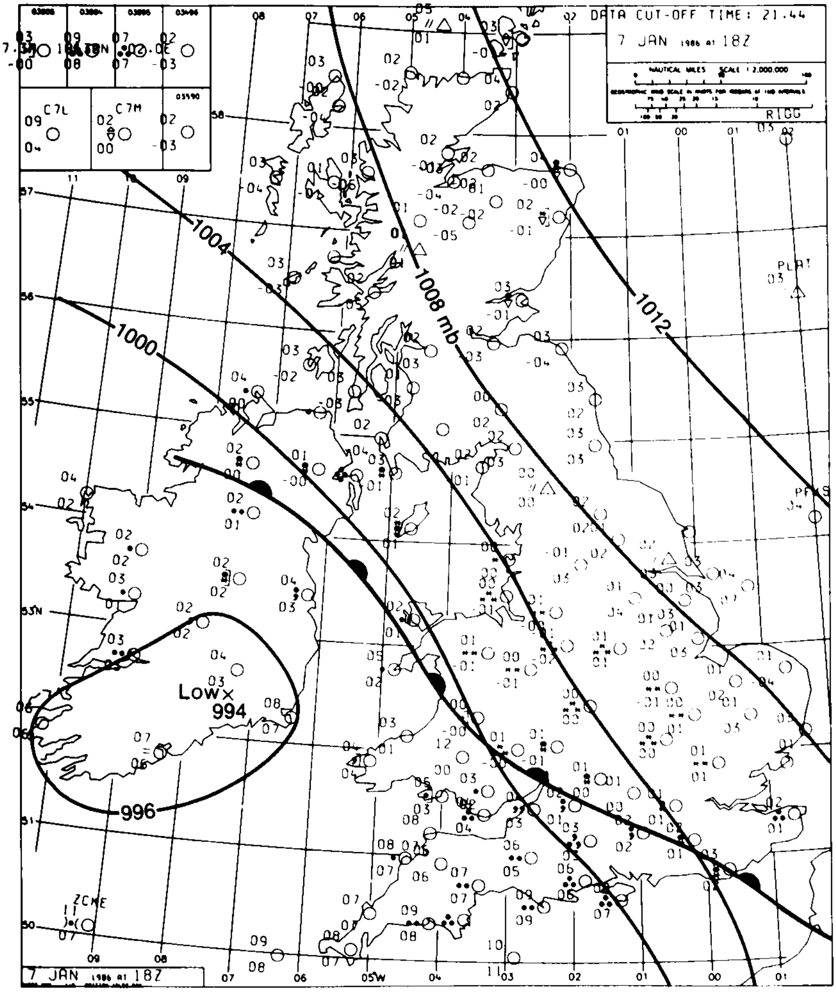


Figure 2. The synoptic situation at 18 GMT on 7 January 1986.

The fine-mesh forecast from data time 12 GMT on 6 January predicted these developments and enabled forecasters to issue advanced warnings of snow with a high degree of confidence. Fig. 3 shows the fine-mesh model's forecast precipitation area and snow-probability lines for 18 GMT on 7 January.

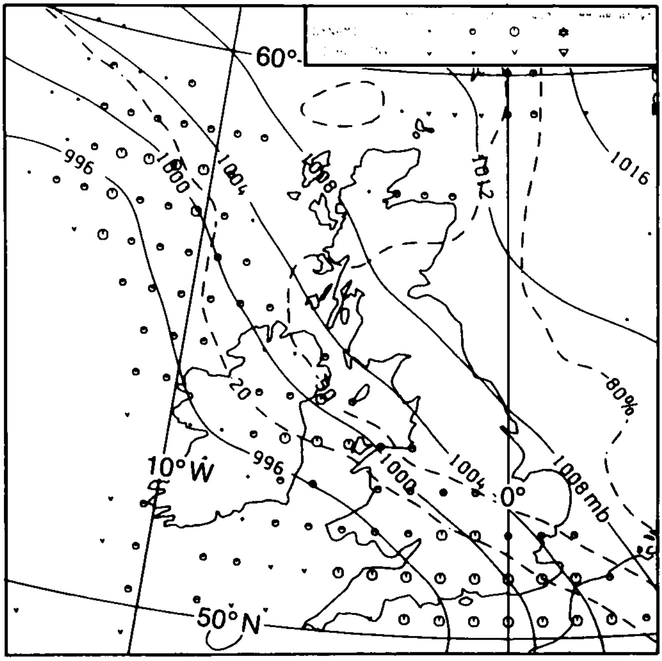


Figure 3. Fine-mesh 30-hour forecast of surface pressure and intensity of precipitation for 18 GMT on 7 January 1986. The pecked lines are snow probabilities.

This was a very good 30-hour forecast from the fine-mesh model with an accurately forecast precipitation area. The only defect is that the area of heavier precipitation does not extend far enough northwards into the Midlands, but the model is only one grid length in error. The evolution is correct and errors in the forecast 1000–850 mb thickness at 12 GMT on 7 January and 00 GMT on 8 January were very small. From Figs 2 and 3 it can be seen that the observed snow area lies between the forecast positions of the 20% and 50% snow-probability lines. For the area of heaviest precipitation over the Midlands, a correction of 1 to 4 gpm must be subtracted from the 1000–850 P to allow for station height above mean sea level. This effectively increases the forecast probability of snow to 50% or more and is excellent guidance for the Midlands, received more than 24 hours in advance. Figs 4 and 5 show the model's prediction for the height above mean sea level of the dry- and wet-bulb freezing levels respectively. Values greater than 2000 feet have been shaded to indicate areas of low risk of snow. Over the Midlands, for example, both the dry- and wet-bulb freezing levels are less than 1000 feet, giving an indication of the wintry precipitation expected. The main error is over Sussex and Kent, where forecast freezing levels of 1500 to 2000 feet indicate that the model had pushed the warm air slightly too far east. The fine-mesh model's 1.5 m screen temperature forecast for 18 GMT is shown in Fig. 6. Only the 0–3 °C isotherms have been shown, with the shaded area indicating temperatures greater than 3 °C. Forecast temperatures over the Midlands and much of Wales were 0–1 °C; an accurate forecast which would have helped to confirm the probability of snow rather than rain. Fig. 7 shows the critical values of the M100 snow predictor. The forecast positions of the 0.5, −0.5 and −1.5 °C isotherms are shown,

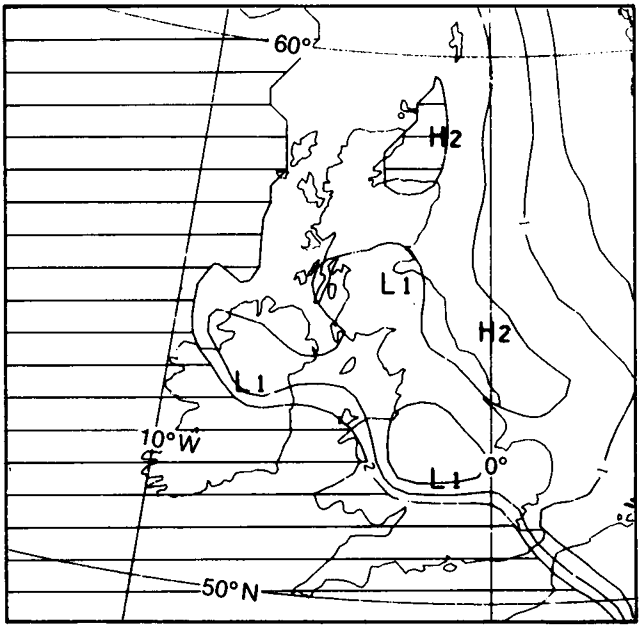


Figure 4. Fine-mesh 30-hour forecast of the height of the dry-bulb freezing level for 18 GMT on 7 January 1986. Isopleths are labelled in thousands of feet with the shaded area > 2000 feet.

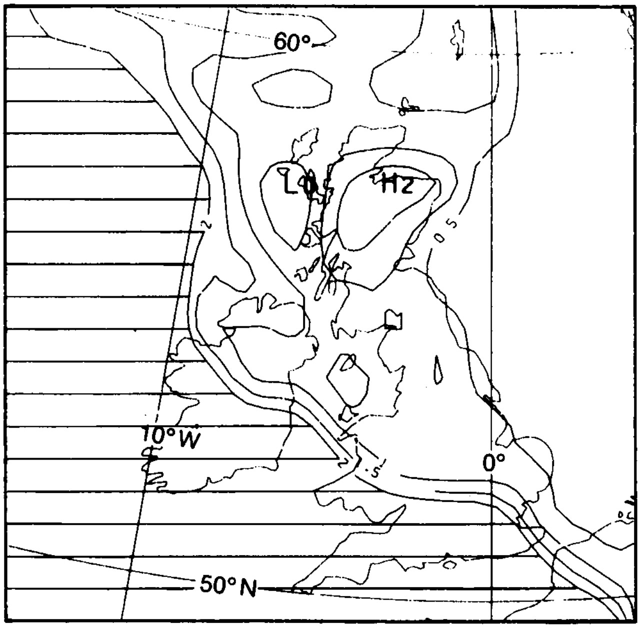


Figure 5. As Fig. 4 but for wet-bulb freezing level.

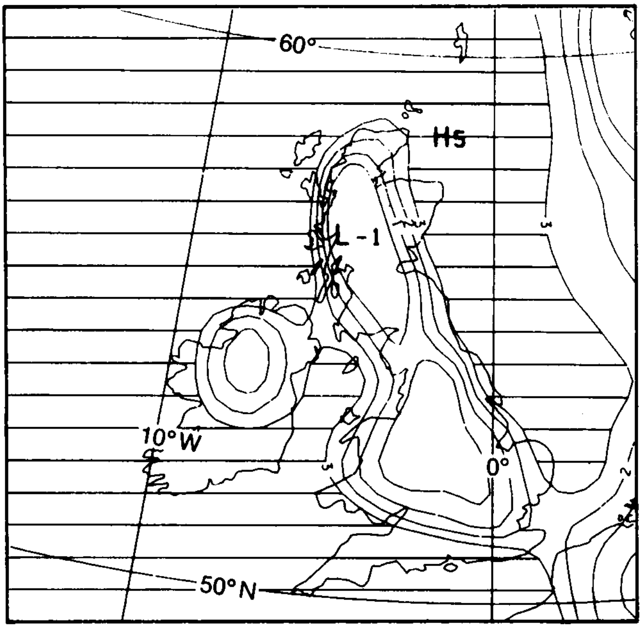


Figure 6. Fine-mesh 30-hour forecast of the 1.5 m temperature for 18 GMT on 7 January 1986. Isopleths are degrees Celsius and shaded area > 3° C.

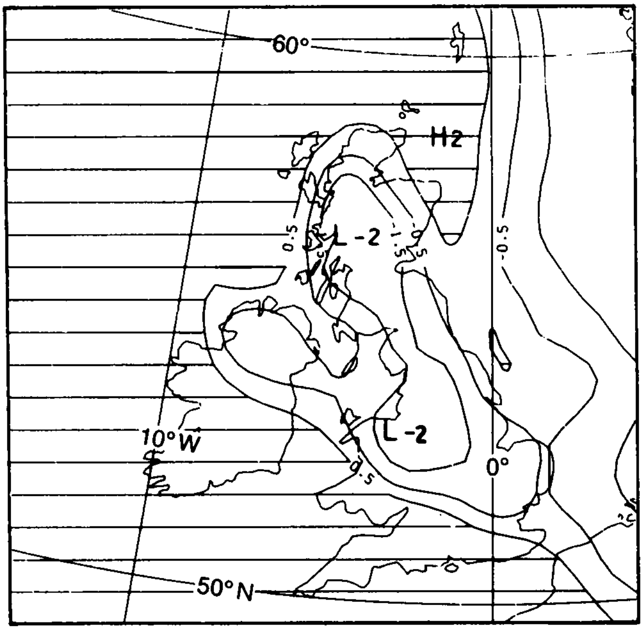


Figure 7. As Fig. 6 but for mean temperature of the lowest 100 mb. Shaded area is > 0.5 °C.

whilst the shaded area indicates a temperature of more than 0.5 °C. Bearing in mind that a small negative correction must be made to the value over Wales due to inaccurate fine-mesh orography, the position of the 0.5 °C isotherm accurately marks the boundary between rain and sleet, whilst the −0.5 isotherm gives the sleet-snow boundary. The −1.5 °C isotherm suggested from comparison with observations is too far north in this case.

This was one of the best fine-mesh snow forecasts of the winter and it gave good guidance of probable snow areas 24 hours in advance. The main error was over Sussex and Kent where the model guidance was for rain rather than sleet. However, the borderline nature of the weather in this area was indicated by the report of moderate to heavy sleet on the south coast with a temperature higher than at Manston in Kent where moderate rain was reported.

5. Conclusion

The 1000–850 mb thickness, adjusted for mean-sea-level pressure, appears to be the most useful predictor of snow when used with the fine-mesh model. The main advantage over other predictors is in the model's accuracy in forecasting the 1000–850 mb thickness. However, because there is a wide range of values over which the transition from rain to snow may occur, much of the success of 1000–850 P depends upon the experience of the user. The other predictors examined have a smaller range of values over which the transition from rain to snow may occur, but the fine-mesh model is not yet able to forecast these predictors as accurately as 1000–850 P.

Further improvements in the modelling of the boundary layer are envisaged in the near future, and the performance of the predictors will be re-examined. On the scale of the fine-mesh, it is unrealistic to expect a definitive solution in finely balanced situations. This may be of small comfort to the airfield forecaster, forecasting for more than 12 hours ahead, but the advent of higher-resolution mesoscale models may improve matters.

References

Boyden, C.J. 1964 A comparison of snow predictors. *Meteorol Mag*, **93**, 353–365.
Flood, C.R. 1985 Forecast evaluation. *Meteorol Mag*, **114**, 254–260.
Gadd, A.J. 1985 The 15-level weather prediction model. *Meteorol Mag*, **114**, 222–226.
Hunt, R.D. 1985 The models in action. *Meteorol Mag*, **114**, 261–272.
Lowndes, C.A.S., Beynon, A. and Hawson, C.L. 1974 An assessment of the usefulness of some snow predictors. *Meteorol Mag*, **103**, 341–358.
Woodroffe, A. 1984 Short-range weather forecasting — a current assessment. *Weather*, **39**, 298–310.

551.594.52

Report on the sighting of aurora borealis at Royal Air Force Lyneham

By P.J. Smith

(Meteorological Office, Royal Air Force Lyneham)

Auroras are caused by a stream of charged solar particles (the solar wind) being focused by the earth's magnetic field. As the particles enter the high atmosphere they collide with the molecules of the various atmospheric gases which then become 'excited', i.e. the molecules change their internal energy state. When they subsequently decay to their normal energy state they emit packets of energy at visible wavelengths, usually red, green or yellow. This release of energy is often organized and the resulting patterns are in the form of rays or curtains of coloured light. A more detailed discussion of auroras can be found in Falck-Ytter (1985)*.

Auroral displays are usually found in the zone between 65 and 70° latitude. Occasionally they form at lower latitudes, but it is rare for displays to be clearly visible in southern England. It was therefore with great interest that I watched a spectacular auroral display from Lyneham Meteorological Office (51° 30′N, 01° 59′W) during the night of 8/9 February 1986. There was little cloud and the visibility was good, between 6 and 10 km. I was the only observer, with obligations to Air Traffic Control, so my observations of the aurora are necessarily simplified and generalized with only approximate times. Also, since the aurora displayed a great variety of activity, I have endeavoured to report only the major changes.

At 2020 GMT a homogeneous arc appeared from the west-north-west to the north-east, faint, white in colour and at an elevation of about 5°. By 2035 GMT the display had developed into a rayed arc, moderately bright, pale green in colour and with several small rayed bands separate to, but overlapping, the base of the arc (Fig. 1(a)). At 2100 GMT it faded to a faint homogeneous arc, north-north-west to

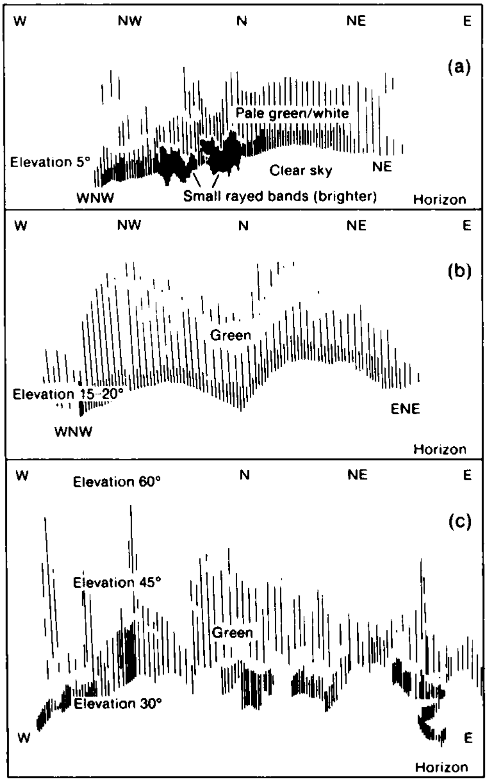


Figure 1. Sketches of auroral displays (a) at 2035 GMT, (b) at 2200 GMT and (c) around 2330 GMT.

north-north-east, and rose to 10° elevation. However, by 2145 GMT the display had developed again into a homogeneous band, of moderate brightness, greenish hue, orientated west-north-west to east-north-east, with the base having risen slightly to 15–20° elevation. At this time one or two rays began to

* Falck-Ytter, H.; *Aurora. The northern lights in mythology, history and science*, Floris Books, Edinburgh, 1985.

appear and by 2200 GMT had developed into two prominent rayed areas (Fig. 1(b)). The aurora continued to rise, eventually reached 30° elevation and stretched almost from east to west. It continually changed form, occasionally breaking into 'curtain-like' formations, with frequent single rays reaching up to 60° (Fig. 1(c)). The aurora continued in this manner until 2330 GMT. There was also considerable meteor activity with one remarkable sighting at 2130 GMT of a very bright green meteor that appeared briefly in the west at 30° elevation.

From 2330 GMT onwards, the aurora varied in activity, sometimes becoming almost homogeneous, but remaining as a broad band, moderate in brightness and faintly green. At 0130 GMT it faded to a faint homogeneous arc, 30° in elevation, occasionally displaying some rays, but probably partially obscured by thickening haze. By 0200 GMT it had disappeared.

551.571.36(417)

High absolute humidities in Ireland, 12–13 July 1983

By S.D. Burt

(Sandhurst, Berkshire)

Summary

An occasion of prolonged high absolute humidities in central and western Ireland during July 1983 is described. It is suggested that the event is probably the most extreme of its type on record for the British Isles.

A recent note in this magazine (Lewis 1986)* drew attention to the occurrence of high absolute humidity in parts of England on 1 July 1968. Readers may be interested in a more recent occasion of even higher, and longer-lasting, high absolute humidity — not in England on this occasion, but over central and western Ireland on 12–13 July 1983.

The synoptic situation at 1200 GMT on 12 July 1983 was as illustrated in Fig. 1. The British Isles lay under the influence of an anticyclone centred between Iceland and Scotland; surface winds were light north or north-easterly in most districts. Over all but the extreme north and west of Scotland (where a weak cold front had introduced cloud and rain) and a narrow strip down the east and north-east of England (where fog and low stratus prevailed) the day was exceptionally warm. Afternoon temperatures exceeded 30 °C over the whole of England and Wales away from the coast (reaching 32 °C in the Southampton area and in south Wales) and even 31 °C in southern Scotland.

Over Ireland the weather was also hot, but in the south, cloudier weather with scattered thunderstorms had developed overnight, somewhat in advance of another weak cold front associated with a depression to the west of Spain. Humidities were already high, and mist and low cloud developed widely as temperatures fell. Even so, night temperatures were uncomfortably high; at Birr the overnight minimum was 17.0 °C, and at Roche's Point 16.9 °C (see Fig. 2 for locations). However, as the day wore on, the mist and low cloud cleared and further breaks in the medium cloud cover, together with a westward drift of warm air from England and Wales, allowed temperatures to rise quickly. Meanwhile, the cold front advancing slowly north-east continued to spread moist Atlantic air before it over southern and central Ireland. As a result central and western districts of Ireland experienced exceptionally high absolute humidities for most of the day.

* Lewis, R.P.W.; An occasion of high absolute humidity in England: 1 July 1968, *Meteorol Mag*, **115**, 1986, 115–117.

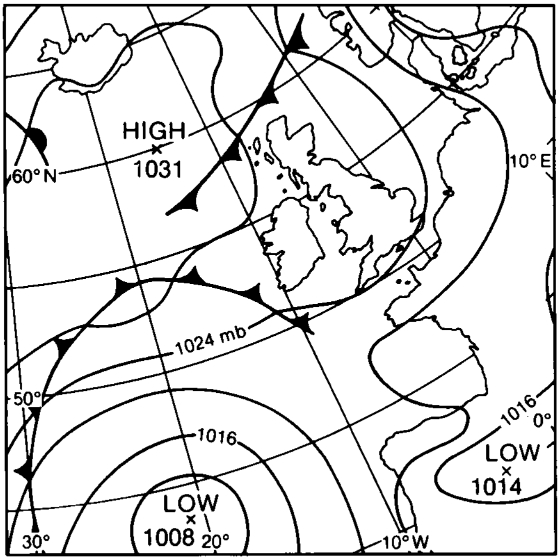


Figure 1. Surface analysis for 1200 GMT on 12 July 1983.

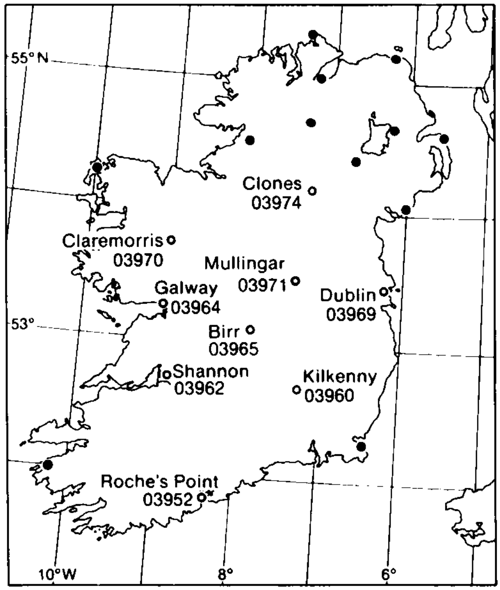


Figure 2. Locations of places referred to in the text. Other synoptic stations in Ireland are marked but not individually identified.

The first report of a dew-point in excess of 20 °C came from Kilkenny at 0900 GMT — 21.3 °C with a dry-bulb temperature of 24.7 °C, under clear skies with only 3 knots of wind. By 1200 GMT dew-point temperatures at Kilkenny, Birr, Galway, Claremorris, Mullingar and Clones were all above 20 °C; at Birr 23.2 °C was reported, associated with a dry-bulb temperature of 26.0 °C, under 6 oktas stratocumulus cover, with mist (visibility 2000 metres) — in conditions of flat calm. At this site the dew-point remained above 20 °C for 16 consecutive hours, although it did not subsequently exceed the

1200 GMT value. Most other sites, however, reported their highest values of dew-point during the late afternoon or early evening. Fig. 3 shows the surface observations for 1800 GMT; by this time the surface cold front had been omitted from the Atlantic analysis, although a consideration of the wind and dew-point fields would seem to indicate its remains across southern Ireland at about 52.5° N.

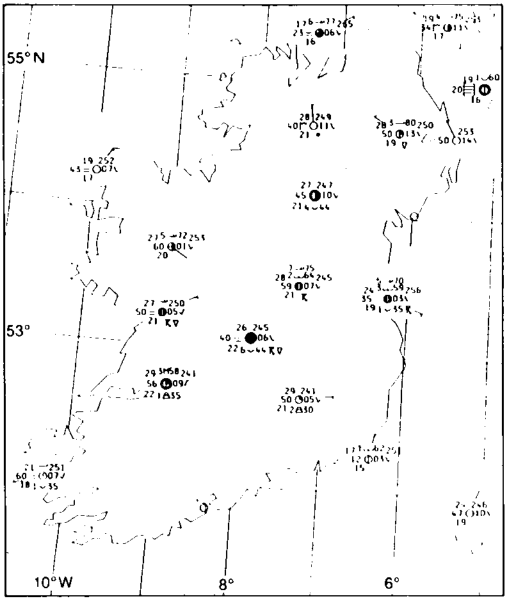


Figure 3. Surface observations at 1800 GMT on 12 July 1983.

At 1900 GMT Shannon reported the highest dew-point temperature for the British Isles known to the author, namely 23.8 °C. At this observation, the dry-bulb temperature was 28.1 °C (wet-bulb temperature about 25.1 °C, relative humidity about 77%, vapour pressure about 29.5 mb), with 3 oktas altocumulus floccus, and a 5-knot north-easterly breeze. The heavy thunderstorm that broke within the next hour must have brought welcome relief; at 2000 GMT the temperature was down to 24.0 °C, accompanied by an 18-knot easterly breeze.

Table I lists dry-bulb and dew-point temperatures for eight sites in central and western Ireland for 24 hours commencing 0600 GMT 12 July, while Fig. 4 presents a sequence of observations made at Kilkenny, Shannon and Birr over the same period.

Temperatures and humidities remained high throughout the night of 12/13 July and for most of the following day (although generally not as extreme as on 12 July). At Birr the overnight minimum was 18.9 °C, with thick fog by morning (Fig. 4), while at 0800 GMT the dew-point had climbed to 21.5 °C, and thence to 21.6 °C at 1000 and 1100 GMT. At 1000 GMT a dew-point of 21.8 °C was reported from Claremorris. As late as 2000 GMT the dew-point was still as high as 21.1 °C at Kilkenny, while the last report of 20 °C or more (20.2 °C) came from Mullingar at 2200 GMT. Not until overnight 13/14 July did values of absolute humidity fall below exceptional levels, after what was probably a spell of unprecedented length. At Birr the dew-point remained at or above 18 °C from 0700 on 12th until 2100 on 13th inclusive, an unbroken period of 39 hours, including 33 consecutive hours at or above 19 °C and 17 hours in all above 21 °C. Frequency-duration data of dew-point temperatures above specified thresholds for eight of the stations identified on Fig. 2 appear in Table II. While this table is probably complete for the highest values, the only data available to the author are for the 48 hours ending

Table I. *Dry-bulb (T_{dry}) and dew-point (T_{dew}) temperatures (°C) at various sites in Ireland, 12–13 July 1983 (extracted from synoptic observations as received at the Meteorological Office)*

Time GMT	Kilkenny 03960		Shannon 03962		Galway 03964		Birr 03965		Dublin 03969		Claremorris 03970		Mullingar 03971		Clones 03974	
	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}	T_{dry}	T_{dew}
0600	*18.3*	*17.7*	16.3	15.2	17.0	17.0	17.6	16.8	17.5	15.3	17.2	17.0	16.7	15.2	17.2	15.9
0700	19.4	18.6	17.4	16.4	17.6	17.4	18.8	18.0	17.6	15.7	19.2	18.1	18.5	16.5	18.2	16.7
0800	20.9	19.1	18.5	17.4	19.0	18.2	20.0	19.2	19.5	16.9	20.0	18.6	20.1	17.0	20.1	17.3
0900	24.7	**21.3**	20.1	17.9	20.3	18.4	*21.3*	*20.3*	21.3	17.2	*22.0*	*19.0*	23.1	18.2	22.0	17.7
1000	25.6	21.1	19.9	18.1	22.2	19.6	22.7	21.5	23.0	17.8	24.0	19.4	25.1	19.9	24.2	18.7
1100	26.0	20.9	20.6	18.0	24.0	20.2	24.2	22.1	24.0	17.6	25.4	20.5	26.5	19.5	25.2	19.5
1200	27.4	21.1	22.6	19.3	24.8	20.6	26.0	**23.2**	**25.9**	**19.1**	26.0	20.4	27.8	20.3	26.6	20.6
1300	28.4	20.4	25.4	20.7	23.5	20.5	25.2	22.8	25.1	18.5	27.0	20.5	27.9	19.7	25.3	21.0
1400	29.0	20.3	*26.9*	*20.7*	23.8	19.8	23.5	22.0	24.5	**19.1**	27.4	20.8	**28.4**	20.0	26.0	20.9
1500	29.1	20.0	28.4	20.7	25.5	20.8	24.7	22.8	23.0	18.6	26.0	20.5	27.1	21.4	27.5	19.9
1600	**29.6**	19.8	29.0	21.6	25.9	20.4	25.8	20.9	24.0	18.7	27.2	**21.5**	27.1	21.7	**27.8**	19.5
1700	29.5	20.0	**29.3**	22.7	**26.5**	21.0	26.4	21.7	24.2	18.9	**27.7**	20.6	28.1	21.2	27.6	20.0
1800	28.7	**21.3**	29.0	22.1	**26.5**	**21.3**	26.4	22.4	23.8	18.7	27.3	20.2	27.6	20.5	27.3	21.1
1900	26.7	**21.3**	28.1	**23.8**	26.0	**21.3**	**26.5**	22.6	22.9	18.4	26.6	20.3	26.6	22.0	27.4	**21.2**
2000	25.2	20.7	24.0	18.1	25.5	21.0	25.5	22.3	22.6	18.2	25.4	20.9	25.1	**22.1**	26.1	20.6
2100	24.0	20.8	23.1	17.3	23.5	21.0	24.9	22.4	22.4	17.9	23.6	20.9	23.7	21.2	24.1	20.9
2200	22.5	20.2	21.9	19.0	22.5	20.8	23.7	22.2	21.2	18.5	22.2	20.4	21.6	20.4	23.1	20.3
2300	20.6	19.6	21.5	18.9	22.5	20.5	22.4	21.0	20.6	18.0	20.2	19.2	20.8	19.7	21.9	19.6
0000	19.0	18.2	20.7	18.1	22.1	**21.3**	21.6	20.5	21.2	17.6	19.5	18.7	20.4	19.6	20.5	17.8
0100	18.9	17.8	20.7	18.8	20.2	19.2	20.7	19.7	19.7	17.6	18.9	18.3	19.7	19.1	19.2	17.1
0200	18.8	18.0	20.8	17.9	20.4	19.6	21.1	20.1	19.0	17.9	18.0	17.4	18.7	18.1	18.5	16.5
0300	18.6	18.1	20.0	18.7	20.5	19.9	20.5	19.7	18.7	17.1	17.0	16.7	18.3	18.0	17.9	16.2
0400	17.6	17.3	18.9	17.8	20.0	19.4	20.0	19.8	18.5	17.1	16.6	16.4	17.8	17.5	17.3	15.6
0500	17.5	17.0	18.8	17.7	19.3	18.8	19.3	19.1	18.4	17.2	17.0	16.8	17.8	17.5	17.1	15.2
0600	17.5	16.9	18.7	17.9	18.5	18.5	19.5	19.3	19.0	17.6	18.8	18.5	18.7	18.4	17.4	15.3

The highest values in each column are printed in bold. Figures in italics denote linear interpolations between observations on either side of the missing hour for observations not received.

Table II. *Frequency-duration of dew-point temperatures above specified thresholds for eight stations in Ireland for the 48 hourly observations commencing 0000 GMT on 12 July 1983. The figures in parentheses denote the longest continuous spell within that period.*

Dew-point °C	Kilkenny		Shannon		Galway		Birr		Dublin		Claremorris		Mullingar		Clones	
⩾23.0	0		1		0		1		0		0		0		0	
⩾22.0	0		3	(3)	0		10	(5)	0		0		2	(2)	0	
⩾21.0	6	(2)	4	(4)	6	(5)	17	(7)	0		4	(2)	10	(3)	4	(2)
⩾20.0	20	(7)	9	(7)	18	(10)	23	(16)	2	(2)	20	(12)	23	(9)	13	(6)
⩾19.0	32	(16)	18	(8)	30	(19)	36	(33)	6	(4)	27	(15)	33	(17)	19	(13)
⩾18.0	35	(18)	27	(11)	37	(37)	40	(39)	17	(9)	33	(19)	37	(19)	25	(14)

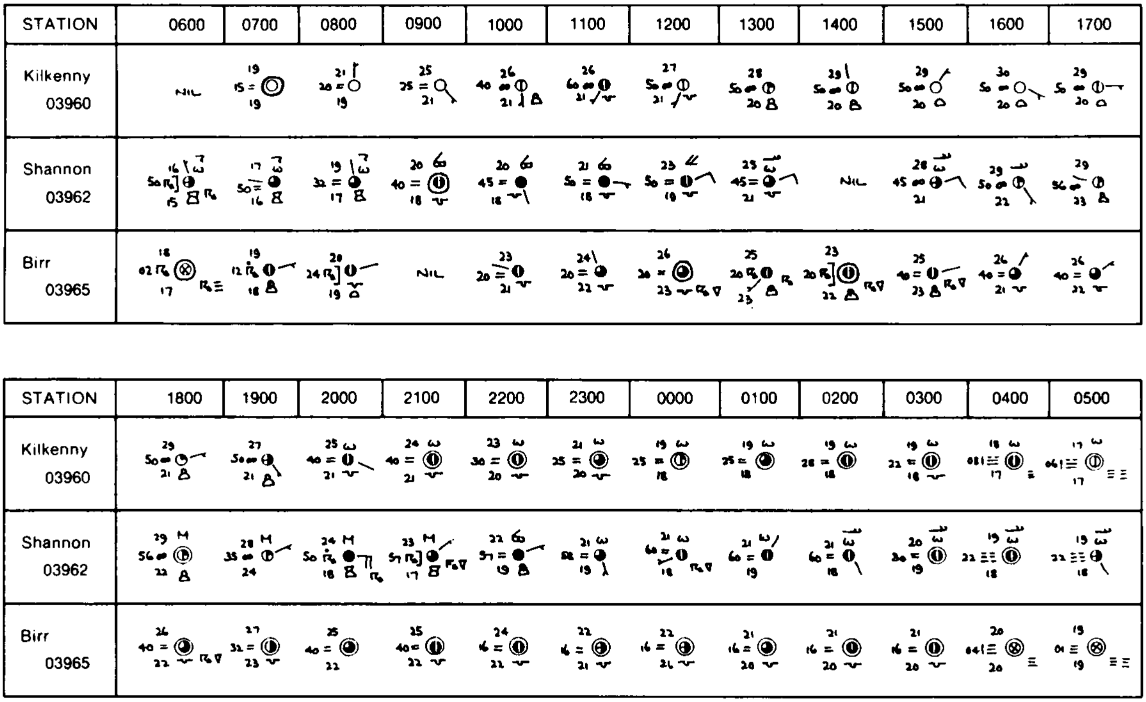


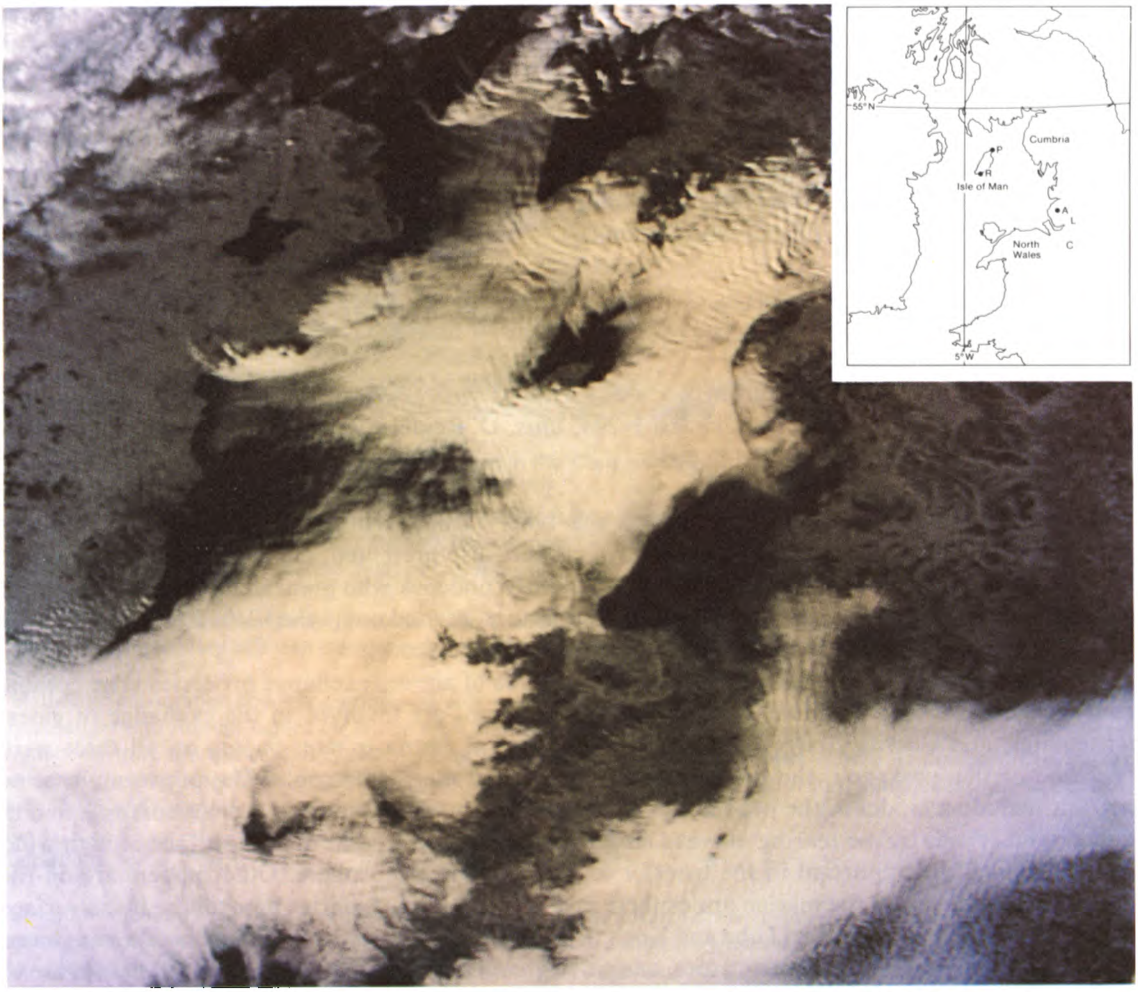
Figure 4. Simplified plot of observations made at Kilkenny, Shannon and Birr over the 24 hours commencing 0600 GMT on 12 July 1983.

2300 GMT on 13 July. At this time, dew-points at the eight stations ranged between 19.2 °C (at Mullingar) and 17.1 °C (at Dublin) and accordingly it is certain that consideration of observations for 14 July would increase some of the spell lengths given in Table II.

The month of July 1983 provided many occasions, in almost all parts of the country, of steamy heat of an intensity almost unknown in the British Isles but, so far as the author is aware, the degree and persistence of absolute humidity that prevailed over central and western Ireland on the 12/13 July was not surpassed. If any readers are aware of any other occasions (in July 1983 or otherwise) when authenticated dew-points at any station or stations within the British Isles are known to have reached or exceeded the values reported in this article, would they please forward details to the author.

Satellite photograph — 30 September 1986 at 1412 GMT

The high-resolution NOAA-9 visible image displayed on the Meteorological Office HERMES (High-resolution Evaluation of Radiances from MEteorological Satellites) system shows the distribution of fog and low cloud over central Britain beneath a pronounced low-level inversion which, according to the 1100 GMT radiosonde ascent (see Fig. 1) from Aughton (marked 'A' in inset map), is 300 m above sea level. Following several days of anticyclonic conditions, a weak south-south-westerly airflow had become established over the British Isles. Cloud originating over the sea is seen to dissipate over the high ground of North Wales and the Isle of Man. However, cloud appears to be largely deflected



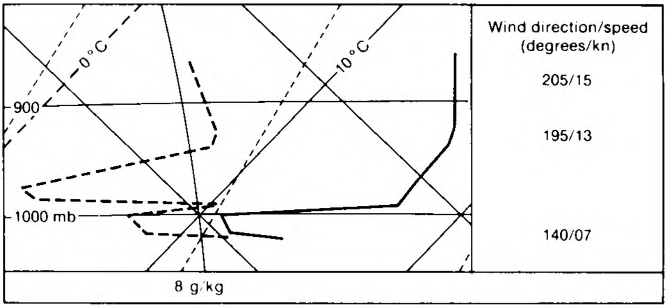


Figure 1. Part of the Aughton radiosonde ascent at 1100 GMT on 30 September 1986.

around Cumbria, although tongues of fog do appear to reach the coast, where surface observations indicate weak sea-breezes. Over the Isle of Man, Ronaldsway (R) in the south had a sunless day with intermittent drizzle and fog, whilst Point of Ayre (P) in the north had a dry day with 9.6 hours of sunshine.

The cloud top shows considerable structure, with lee wave patterns in the north, in particular downwind of the Isle of Man where a 'herring-bone' pattern is apparent. Over the land, there is evidence of banding along the wind direction, particularly within the narrow band of cloud that reaches Lancashire (L) via the low-lying Cheshire Plain (C).

Review

Oceanic whitecaps and their role in air–sea exchange processes, edited by E.C. Monahan and G. MacNiocaill. 168 mm × 247 mm, pp. xii + 294, *illus.* D. Reidel Publishing Company, Dordrecht, 1986. Price £40.25, US $64.00, Dfl 145.00.

This book contains 22 papers presented at the 1983 Galway Whitecap Workshop. Abstracts of 18 poster papers (in some cases with figures), which were also presented, are included at the end. The book is introduced with a short biography of Dr Alfred Woodcock who pioneered the measurement of aerosols in the marine boundary layer during investigations, carried out in the 1940s and 1950s, into the role played by salt particles in the formation of rain in the tropics.

The papers cover a wide range of topics within the area of air–sea exchange processes. The oceanic whitecaps, which were the main concern of the workshop, are involved in the exchange of gases, particulates, and electric charge between the ocean and the atmosphere; papers on all three were presented at the workshop, the greatest number being on marine aerosols. The papers on marine aerosols include a model of the production of droplets at the sea surface by bubble bursting, and at higher wind speeds by the tearing of wave crests. Droplets produced at the sea surface at high wind speeds may well be important in the transfer of water to the atmosphere. Other papers are on the modelling of aerosols in the marine atmosphere and observations of marine aerosols near the surface and from satellites. Two papers (Toba and Koga, Hasse) discuss the relationship between the roughness of the sea surface and wave characteristics, a topic of great interest to meteorologists. Whitecaps are of interest here since they indicate that wave breaking is occurring.

The workshop was not concerned only with the atmosphere, and papers on the characteristics of waves, whitecaps and bubbles are well represented. The final papers in the volume are concerned with satellite sensing of whitecaps, either because of possible effects (through changes to the surface albedo or emissivity) of whitecaps on the retrieval of other quantities (e.g. the aerosol content, discussed in another paper) or as indicators of the near-surface wind speed.

The style of the papers is the same as that found in scientific journals, while the quality is generally higher than is normally found in the proceedings of conferences or workshops. Although some time has elapsed between the workshop and the appearance of this volume, I would agree with the editor's opinion that the papers still provide an up-to-date review of this area. To help make this a valuable source book, the editors have also included a large supplementary bibliography of papers which they feel are pertinent to the subject but which are not referenced by the other contributors.

A. Grant

Meteorological Magazine

GUIDE TO AUTHORS

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Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

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 referred to 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.

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