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Automated temperature forecasting, an application of Model Output Statistics to the Meteorological Office numerical weather prediction model

By P. E. Francis, A. P. Day and G. P. Davis
(Meteorological Office, Bracknell)

Summary

The method of Model Output Statistics is explained together with the technique for developing forecasting equations by regression analysis. Data from the Meteorological Office numerical weather prediction model and climatological archives are used to develop equations to forecast temperature extremes up to 5 days ahead and temperature at fixed hours for a 36 hour period. When applied to independent data, for the winter half of the year, these equations yield forecasts of temperature values with acceptable accuracy. Such comparisons as can be made with subjective forecasts indicate that the Model Output Statistics results are comparable with or better than the subjective forecasts, at least in terms of root-mean-square error and bias.

1. Introduction

'Model Output Statistics' (MOS) is a numerical technique for forecasting those meteorological variables that are not explicitly represented in a numerical weather prediction (NWP) model. The basis of the technique lies in identifying consistent relationships between forecast values of those variables that are explicitly represented, for example, temperatures, humidities and winds at fixed pressure levels and discrete grid points, and observed values of physically related variables such as surface temperature, cloud height and amount, and visibility. The required relationship is usually determined by means of a statistical analysis using a multivariate linear regression model.

An alternative system, the perfect prognosis method, establishes similar empirical relationships between observed atmospheric variables and the 'weather' feature of interest, and then in the forecast mode uses the forecast numerical fields as predictors in place of the observed variables. The strength of the perfect prognosis (PP) method is that it is independent of the NWP model used to obtain the forecast predictor variables and only the final forecast 'weather' values are model dependent. In contrast, the MOS method is model dependent; the established empirical relationships tending to compensate for persistent bias in model forecasts, for example phase errors in synoptic scale waves. This gives an advantage in terms of the accuracy of results for MOS at the expense of the need to re-examine the relationships used when significant changes are made to the NWP model. Any improvements in numerical weather forecasting will bring the performances of the MOS and PP methods closer together, since, given greater accuracy in the forecast fields, the major weakness in both MOS and PP systems will always be the inherent errors of a statistically based relationship between local and synoptic weather patterns, whether actual or forecast.

A considerable amount of work on MOS has been carried out by American research groups, using the technique to forecast a wide variety of weather variables, with mixed success. The work of most interest in the present context is contained in a series of papers (Klein and Hammons 1975; Hammons, Dallavalle and Klein 1976; Carter, Dallavalle, Forst and Klein 1979) in which an operational system for the automated forecast of surface temperatures is developed and assessed. The success of that system has provided much of the impetus for carrying out the limited trial described in this paper.

As a preliminary to presenting the results of the trial we consider it important to outline briefly the principles and methods adopted in constructing the statistical model on which the results are based. The package of computer programs for the statistical analysis was taken from BMDP-79 developed at the Health Sciences Computing Facility, University of California, Los Angeles.

2. The Statistical model

An examination of the many published papers that discuss MOS applications reveals an uncritical reliance on the use of multiple regression techniques to produce predictive equations that express as much as possible of the variance of the predictand. The question of the stability of such equations when applied to independent data is not explored in any depth, and little attempt is made to justify the inclusion of physically unrelated variables as predictors. The statistical techniques described in these papers are interesting in themselves but it is doubtful if they constitute a sound enough basis on which to build a prediction model. A more reasoned approach to the question of selection of predictors is certainly worth considering.

The solution adopted here is two-fold in structure. First, only those observations of weather variables and those products of the NWP model which can be seen as being related to the predictand in a physical sense are presented to the regression screening process as possible predictors. The second step is to curtail the regression screening process in a manner which takes into account the meteorological implications of the predictors selected by the statistical technique. These restrictions ensure that there is an underlying physical coherence in the prediction system, a coherence that is strengthened by the inclusion of physical processes in the NWP model. The resulting predictive equation should then apply to independent data in a more stable manner, and perhaps also carry over to a different NWP model. Note that it is difficult to determine the relative statistical significance of predictors that are sometimes closely correlated with one another.

Stage one of the selection process effectively limits the number of possible predictors, to the degree that a selection process called 'all possible subsets' regression can be employed in preference to the more usual 'stepwise' regression procedure. 'All possible subsets' regression presents the results of combining the offered predictors into groups of increasing size, allowing those combinations that express the higher amounts of variance of the predictand to be examined. 'Stepwise' regression follows a path of including or dropping predictors, starting with the predictor that singly expresses most variance. The experience of the authors is that the more comprehensive choice offered by 'all possible subsets' allows more powerful combinations of predictors to be found, especially when more than two or three predictors are to be included in the group. Which combination to use as the predictive equation is determined by insistence on a physically meaningful role for every component of the equation, the inclusion of extra variables being stopped at the point beyond which no physical significance can be attributed to the new predictor. When a choice of equations is available, i.e. several meaningful combinations with the same number of components in each, the combination expressing the highest amount of the variance of the predictand is chosen.

Two applications of MOS methods are reported in this paper, both of which use equations constructed following the rules given above. The test of these rules is whether or not they yield stable and consistent predictive equations, judged by their performance on independent data.

3. Data

The Meteorological Office numerical weather prediction model is a grid-point model with ten levels which is routinely operated in two versions. The fine-mesh version has a grid spacing of 100 km in mid latitudes and covers a rectangular area over the North Atlantic and western Europe. The coarse-mesh version covers the Northern Hemisphere down to 20° N and has an equivalent grid spacing of 300 km. Both versions of the model are run twice a day, at midnight and midday GMT. Output from the models is in the form of analysed and forecast values of a number of meteorological variables at each grid point and every pressure level from 1000 to 100 mb. These grid-point values are routinely stored on magnetic tapes for a limited period. After eighteen months the cyclic usage of these tapes causes the data to be lost by over-writing. A more extensive archive of data for MOS purposes was initiated by extracting data, for a limited area round the United Kingdom, starting from the then current eighteen months of forecast archive which extended back to October 1978. Thus there are now nearly three years of data in the MOS archive.

In order to investigate MOS applications at the location of observing stations, the model grid-point values are then interpolated to the position of the relevant station. Thus there are also in existence a number of 'single station' forecast data sets that contain the interpolated model variables. During the period of the MOS archive there have not been any major changes in the Meterological Office NWP model, hence the data in the archive are reasonably consistent.

In addition to forecast data, the most recent observed data are used in the regression model. The climatological archives of the Meteorological Office contain quality controlled archives of the necessary observations. Data from these archives and the 'single station' MOS archives are submitted together to the regression screening process.

4. Development of a model for temperature forecasting

When making a forecast of temperature, the subjective forecaster has to take into account the thermal structure and the moisture content of the air masses expected to be influencing the weather in his area during the forecast period. Cloud cover at medium and low levels also has to be forecast, as well as wind speed and direction. These variables greatly influence the radiative heat balance which controls surface temperatures, especially during hours of darkness. As far as possible, any objective forecasting model such as MOS must be designed to include representations of these processes.

Two applications of MOS are considered in this paper, the forecasting of daily temperature extremes and the forecasting of temperature at fixed hours. Both applications should be governed by the above guidelines, and consequently the forecasting models should be similar in content. The possible predictors that are physically sensible are shown in Table I, but not all these could be presented to the regression program at once and a careful reduction was necessary. Preliminary work indicated a broad division of the forecasting problem into two categories, viz day-time and night-time hours. During daylight hours, i.e. for maximum temperature and, say, 09–18 GMT, the preferred combination of predictors was usually taken from forecast temperature values at 1000 mb and relative humidity values at 700 mb. During night-time hours, forecast 1000–850 mb thickness values, 950 mb relative humidity, and 1000 mb wind speeds were preferred for minimum temperatures and fixed-hour values. This broad grouping of predictors enabled the reduction in numbers of possible predictors required. Relevant observations from Day 0 were also included as shown in Table I.

Table I. *Variables available for selection by the regression programs*

Numerical weather prediction model variables	Day 0 station observations	MOS predictions
1000 mb temperature	minimum temperature	Day 1 minimum
1000–850 mb thickness	06 GMT temperature	Day 1 maximum
950 mb relative humidity	12 GMT temperature	
850 mb relative humidity	14 GMT temperature	
700 mb relative humidity	12 GMT dew-point	
1000 mb wind speed	14 GMT dew-point	
1000 mb u wind component	12 GMT low-cloud amount	
(relative to model grid)	14 GMT total cloud amount	
1000 mb v wind component		
(relative to model grid)		

The predictive equations for temperature extremes were developed using data from the coarse-mesh grid, since extended period forecasts were to be made. Data from the fine-mesh NWP model were used to develop the forecast equations for temperatures at fixed hours. In both cases data were taken from the midday forecast run, and from two 6-month winter seasons, i.e. October to March in 1978/79 and 1979/80. The independent data for testing purposes were the corresponding period of 1981/81. At the time of writing (July/August 1981) only two summer seasons are available; preliminary tests have shown this is not really a sufficiently wide data base to give reliable results. Eventually 3-month seasons may be employed but a sufficient number of cases would have to be aggregated first. The relative advantages of shorter seasons on which to have data are shown in Hammons, Dallavalle and Klein (1976).

5. Forecasting maximum and minimum temperatures

(a) *Preamble*

Four stations were chosen in an investigation of the usefulness of MOS techniques in forecasting maximum and minimum temperatures. The stations are in different climatic areas of the United Kingdom and were expected to pose different problems during the investigation. The stations are Exeter in the south west, Dyce near Aberdeen in north-east Scotland, Waddington near Lincoln in central east England, and Heathrow Airport near London. Following the technique described earlier a set of variables considered to be physically relevant was offered to the regression analysis program, with maximum temperature (09 to 21 GMT, tomorrow) or minimum temperature (21 GMT tonight for 12 hours) as the dependent variable (the predictand). Once the equations for Day 1 were finalized the process was repeated for Day 2 with the addition of the forecast maximum and minimum values for Day 1 as extra predictors. The combinations of variables chosen for the four stations are shown in Table II.

(b) *Evaluation of prediction equations*

There are a number of features common to the equations for the four stations. At all the stations the equation for Day 1 maximum temperature includes the 14 GMT station temperature observation, this being probably the latest temperature observation available. These equations also include two forecast 1000 mb temperatures with assessment times of 12 and 18 GMT on Day 1. The fourth variable in these

Table II. *Variables used in the selected prediction equations for* (a) *maximum temperature and* (b) *minimum temperature*

(a)

Model variable used in forecast	Forecast period in hours T + 24 (T + 48)	T + 30	(T + 72)
1000 mb forecast temperature	H_1 W_1 D_1 E_1 H_2 W_2 D_2 E_2	H_1 W_1 D_1 E_1	
1000–850 mb forecast thickness			H_2 W_2 D_2 E_2
1000 mb forecast *u* wind component (relative to model grid)	D_1	E_1	
700 mb forecast RH	H_1	W_1	

For Day 1 predictions all stations also use the observed 14 GMT temperature on Day 0 at their site. For Day 2 predictions all stations also use the Day 1 predicted maximum temperature.

(b)

Model variable used in forecast	(T + 30)	Forecast period in hours T + 12 (T+ 36)	T + 18 (T + 42)	(T + 48)
1000–850 mb forecast thickness		D_1	H_1 W_1 E_1 H_2 W_2 E_2	D_2
950 mb forecast RH	H_2 W_2 E_2	W_1 D_2	H_1 D_1 E_1	
1000 mb forecast wind speed		H_1 W_1 E_1 H_2 W_2 E_2	D_1 D_2	
1000 mb forecast *u* wind component (relative to model grid)	D_2	D_1		
1000 mb forecast *v* wind component (relative to model grid)		D_1 D_2		

H_1, W_1 and D_1 also use the observed 12 GMT temperature and E_1 the observed 14 GMT dew-point on Day 0 at their site. H_1, W_1 and E_1 also use their observed total cloud amount at 14 GMT on Day 0. All stations also use the predicted Day 1 maximum for predicting the Day 2 minimum.

H = Heathrow, D = Dyce, E = Exeter, W = Waddington

Subscript 1 denotes Day 1 predictions and subscript 2 denotes Day 2 predictions (bracketed forecast periods).

equations for Day 1 maximum temperature varies from station to station. At Heathrow and Waddington a forecast value of 700 mb relative humidity (RH) is chosen, although for different assessment times, which value, along with a negative coefficient, serves to act as a cloud indicator. At Dyce and Exeter the particular arrangement of topography necessitates the inclusion of a forecast component of wind, again at different assessment times. Equations with more than four variables show little improvement in forecast results. The forecast equation for the Day 2 maximum temperature at all stations uses a thickness value valid T + 72h (there being no 1000 mb temperature for or beyond T + 48h), where T is 12 GMT on Day 0. The forecast maximum temperature for Day 1 is also included as a term in the equations for Day 2, taking the place of the 14 GMT temperature value in the equations for Day 1.

The equations for minimum temperature forecasts show Dyce to be anomalous compared with the other three stations. In addition to an observed temperature on Day 0, a forecast surface resultant wind speed, i.e. at 1000 mb, relative humidity at 950 mb and a 1000–850 mb thickness, common to all stations, the equation for Dyce includes both forecast components of surface wind in place of the observed total cloud amount at 14 GMT on Day 0. These wind components are not difficult to justify on physical grounds, bearing in mind the effect of wind coming off the North Sea or over the Scottish mountains. Similar equations are obtained for minimum temperatures on Day 2, except that the forecast maximum temperature for Day 1 replaces the Day 0 temperature observation and the Day 0 cloud amount is no longer a significant predictor.

The equations obtained from the regression analysis were used to forecast maximum and minimum temperatures in a third, independent, season; October 1980 to March 1981. The errors of the forecasts are summarized in Table III, where the corresponding statistics for both climatological and persistence

Table III. *Root-mean-square errors in forecasts of* (a) *maximum temperature and* (b) *minimum temperature for the period from October 1980 to March 1981*

Station	Standard deviation in observed maxima	Root-mean-square errors in the forecasts				
		Day 1		Day 2		
		MOS	Persistence	MOS	Persistence	Climatology
			degrees Celsius			
(a)						
Dyce	3.7	1.9	3.1	2.4	4.1	3.5
Exeter	3.5	1.5	2.4	1.9	3.1	3.1
Heathrow	3.9	1.7	2.7	2.1	3.5	3.2
Waddington	4.0	1.6	2.9	2.1	3.8	3.5
Combined	3.8	1.7	2.8	2.1	3.6	3.3
(b)						
Dyce	3.3	1.7	3.4	2.3	4.0	3.1
Exeter	4.5	1.9	4.0	2.5	5.3	4.6
Heathrow	4.6	1.8	3.7	2.3	5.0	4.4
Waddington	3.9	1.6	3.2	2.2	4.3	3.7
Combined	4.1	1.8	3.6	2.3	4.7	4.0

forecasts are also included. The results of the MOS forecasts are significantly better than those using persistence or climatology but what is really needed is a comparison with subjective forecasts issued at roughly the same time, i.e. 1630 GMT.

Forecasts of 'tomorrow's' maximum temperature may be compared by means of a coarse score evaluated by several meteorological outstations in order to judge the accuracy of radio forecasts issued by London Weather Centre at 1755 clock time. This is not a particularly sensitive score, since errors are categorized and marked in 2 °C bands, though it allows a rough comparison to be made when the MOS forecast errors are marked in the same way. At Heathrow and Waddington MOS and subjective forecasts both score around 87% of possible marks, at Exeter MOS results (91%) are 8% better than subjective, while at Dyce the subjective results are clearly better (90% compared to 84%). This poor result at Dyce is also immediately apparent from the figures in Table IIIa where the root-mean-square (r.m.s.) error values for maximum temperature forecasts at Dyce are higher than for the other stations in spite of a relatively low variance in observed maxima. These results are probably due to a higher day-to-day variation of maximum temperature at Dyce in the 1980/81 winter season, confirmed by the higher persistence errors.

Other easily obtainable forecasts are those issued by London Weather Centre in the mid afternoon, giving the overnight minimum temperature for Heathrow. The r.m.s. error of these forecasts is 2.0 °C, slightly higher than the result of the MOS forecasts, 1.8 °C. Mean errors are comparable, both forecasts having a negative bias, i.e. forecasting too cold on average, in this particular period. Root-mean-square errors of less than 2 °C are also obtained using the MOS method for all of tomorrow's maximum temperature forecasts (Table IIIa) and the overnight minimum temperature forecasts (Table IIIb). Beyond 24 hours it is apparent that in winter it is easier to forecast maximum temperatures; the overall r.m.s. error (combining all four stations) for the day after tomorrow's maximum forecast being 2.1 °C compared to the value of 2.3 °C for tomorrow night's minimum temperature r.m.s. forecast error.

(c) *Extended period forecasts*

Finally in this section on forecasting extreme temperatures it is tempting to explore the possibilities of forecasting for several days ahead, using forecast information from the octagon. Fig. 1(a) shows the r.m.s. error values, aggregated for all 4 stations, of equations that forecast temperature extremes up to 5 days ahead, for the period October 1980 to March 1981. These equations follow the style of those for the Day 2 extremes, i.e. they incorporate the forecast maximum for the previous day as a predictor for both maximum and minimum temperature of the current day. The number of variables used in the equations reduces as the forecast period increases, until in some cases only the previous day's maximum is used in the equation. Another noticeable feature of the equations is that relatively later forecast temperatures and thicknesses are used as the forecast period increases. Thus equations for Day 4 temperature extremes already contain forecast data valid for Day 5. This is undoubtedly a result of phase errors known to occur in the numerical model. The r.m.s. error values associated with climatological forecasts are also shown in Fig. 1(a), and by Day 5 the overall MOS values of r.m.s. error are still better than those of climatology. Fig. 1(b) illustrates the change in mean errors of the maximum and minimum forecasts up to Day 5, again for the period October 1980 to March 1981. These are comparable with the mean errors of climatological forecasts (−0.3 °C for maxima and −0.5 °C for minima).

The medium-range forecaster in the Central Forecasting Office (CFO), Bracknell, makes a daily forecast of maximum and minimum temperatures for Heathrow, but using information based on the midnight NWP model run. A comparison of forecast errors for Heathrow temperature extremes is possible if the CFO forecasts are given an extra 12 hours 'lead time' in order to allow for the later data available to a MOS forecast based on 12 GMT NWP products. Fig. 2 contains r.m.s. error and mean error information for temperature extreme forecasts by both MOS and subjective methods up to 120 hours ahead. In Fig. 2(a), again using independent data from October 1980 to March 1981, it can be seen

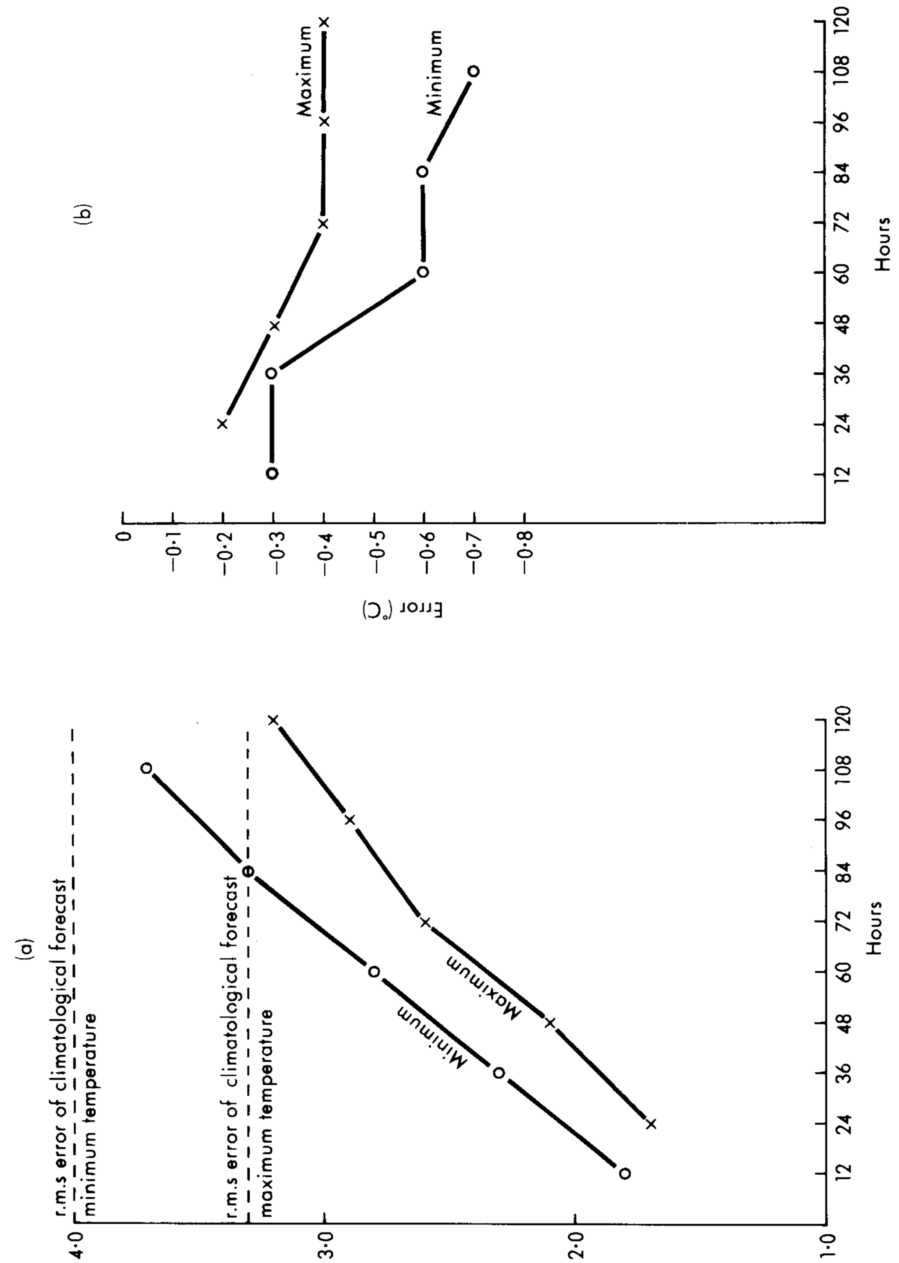

Figure 1. Maximum and minimum temperature forecasts for all stations, October 1980–March 1981. (a) Root-mean-square error values and (b) mean error values.

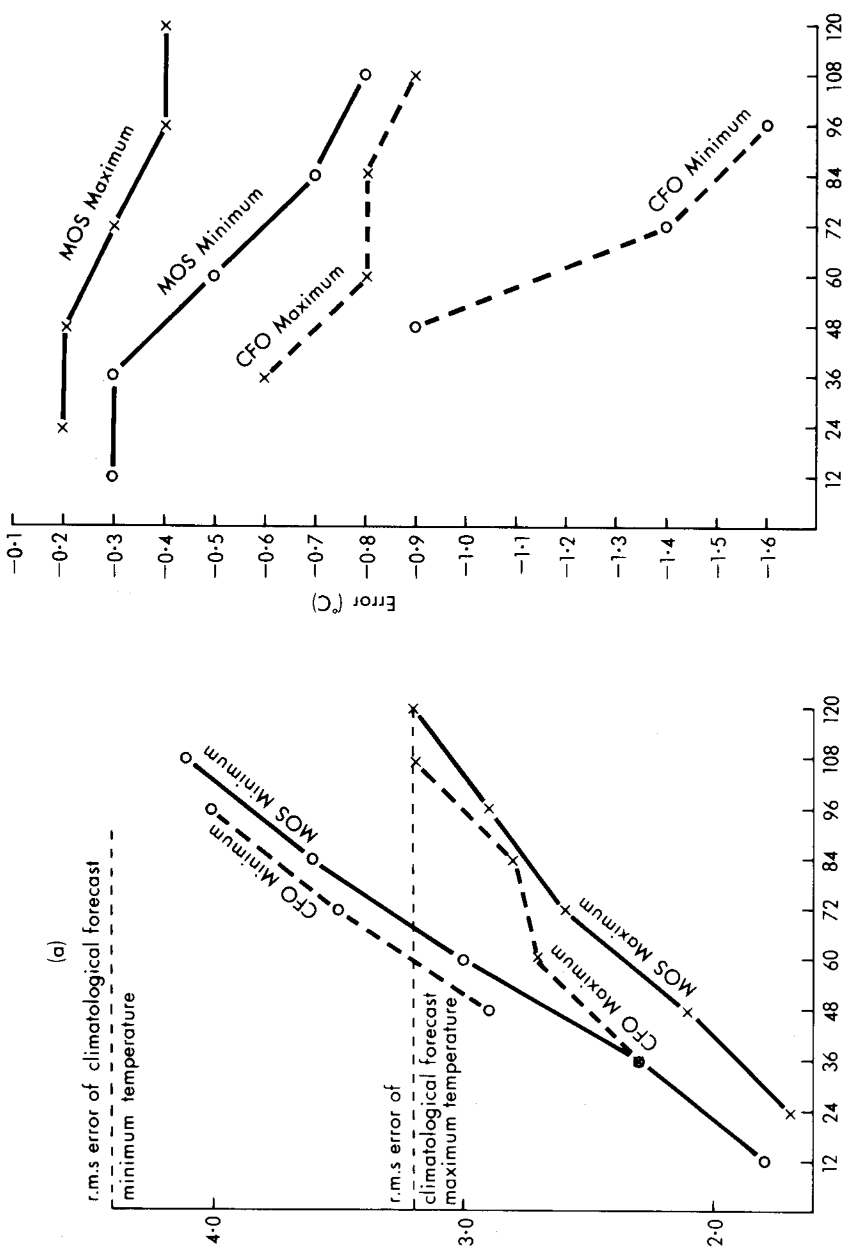

Figure 2. Maximum and minimum temperature forecasts by MOS and CFO for Heathrow, October 1980–March 1981. (a) Root-mean-square error values and (b) mean error values.

that the r.m.s. error values for MOS forecasts are slightly, but consistently, better than those obtained by subjective methods. Curiously, the results for forecast maxima are more separated at the beginning of the period rather than at the end. It is when the values of mean errors are examined, Fig. 2(b), that one strength of the MOS method is revealed. The subjective forecasts in CFO have an increasing cold bias over the period, especially the minimum forecasts, an effect that is much less marked in the MOS results. A comparison of the standard deviation of errors for the two groups of forecasts shows similar values for the minimum forecasts throughout and for the maximum forecasts beyond Day 2. Climatological forecasts for Heathrow over the same six-month period have mean errors of −0.2 °C for maximum and −0.8 °C for minimum.

6. Forecasting temperatures at fixed hours

(a) *Preamble*

London Weather Centre (LWC), in common with some other public service offices, issues temperature forecasts for periods of from 24 to 36 hours ahead with values at two hour intervals through the period. These forecasts are used by regional Gas Boards to estimate the demand for gas.

The main forecast is that issued at 1530 hours clock time which covers the 36 hour period from 1700 on Day 0 to 0500 on Day 2. This forecast is based on numerical products from the 00 GMT run, modified in the light of an up-to-date surface analysis.

A trial was initiated to determine whether MOS forecasts could produce values of temperature at fixed hours as good as subjective forecasts for the same period. The LWC 'Met Gas' forecast at around 1530 is ideally suitable for a comparison with MOS products based on the 12 GMT run on the NWP models. LWC assess their forecasts against temperature observations taken at LWC, these being representative of the inner city area with a marked 'heat island' effect. It was decided that in addition to producing forecast temperatures at fixed hours for checking at LWC, the opportunity would be taken to produce similar forecasts for checking at Heathrow, where a larger variance is exhibited in the diurnal temperature curve. This station was taken as being more representative of the London suburbs, but an additional reason for extending the trial to Heathrow will be discussed in the section on rationalization.

LWC provided information containing the Met Gas forecasts issued from October 1980 to March 1981. MOS equations for these 'winter' months were then developed for both LWC and Heathrow using actual data from climatological archives and forecast data from both fine-mesh and coarse-mesh NWP models run on 12 GMT data. The coarse-mesh model data were used to extend the forecast period beyond the latest assessment time of data from the fine-mesh model, i.e. 00 GMT on Day 2. A separate equation was derived for temperature at each of the synoptic hours from 18 GMT on Day 0 to 06 GMT on Day 2. The variables offered as predictors were again those listed in Table I.

(b) *Evaluation of prediction equations*

Table IV shows the variables that were chosen for each of the forecast equations for the two stations and illustrates the similarity between the choice of predictors for each station. Most of the forecast equations use the starting temperature at 14 GMT on Day 0, with the exception of those for times near that of minimum temperature when the midday temperature value is sometimes preferred. The other observed parameter sometimes selected is the cloud amount at 14 GMT on Day 0, an obvious indicator of radiation receipt and thus of temperature change. This predictor is used in equations for times up to midnight. The choice of predictors from the NWP model forecast fields varies from night to day; the preference is for 1000–850 mb thickness values at night but 1000 mb temperature values during the day (cf. variables for maximum and minimum temperature forecasts in Table II). This effect may be a result of the

Table IV. *Variables used in the prediction equations for temperatures at fixed hours (GMT)*

		Day 0 18	21	Day 1 00	03	06	09	12	15	18	21	Day 2 00	03	06
Day 0 station observations:	12 GMT temperature				H	H							L	L
	14 GMT temperature	L H	L H	L H	L	L	L H	L H	L H	L H	L H	L H	H	
	14 GMT total cloud amount	L H	L H	H										
NWP model variables:	1000–850 mb forecast thickness	L H	L H	L H	L (2) H (2)	L H					H	L H	L H	L H (2)
	1000 mb forecast temperature						L (2) H	L (3) H (2)	L (2) H (2)	L (3) H (2)	L (2) H	L	L	L
	1000 mb forecast wind speed		L H	L H	L H	L H	L H	H			H	H	L H	L H
	700 mb RH							L H	L H	L	L			
	950 mb RH	H	L H	L H	L H	L H	L H				H	L H	L H	L H

L = London Weather Centre, H = Heathrow.

Figures in brackets indicate the number of time levels at which forecast values of that variable are used in the equation.

method used in the NWP model to calculate 1000 mb temperatures from the basic height fields. During the night both the 950 mb RH and 1000 mb wind speed are used. The choice of 950 mb RH can be seen as an approximation to two variables used by forecasters, namely the representative dew-point of the air mass and the average amount of low cloud or fog overnight. The 1000 mb wind speed corresponds to the use by the forecaster of the forecast strength of surface or gradient wind. During the morning hours the importance of the wind speed–relative humidity combination decreases and eventually the forecast 700 mb RH alone is selected, presumably again as an indicator for cloud amount. The respective roles of the relative humidity terms are more apparent when the signs of the coefficients for each term are examined. The 950 mb terms have positive coefficients, high humidities giving higher night-time temperatures (lower radiation loss); the coefficients of the 700 mb RH terms are negative, high values leading to lower daytime temperatures (lower radiation receipt). Similar combinations of predictors are found in the equations for maximum and minimum values.

The variables chosen from the NWP model are usually measured within six hours of validity time, except for the second night when some predictors are valid for 12 or 18 GMT on Day 1. The explanation for this timing anomaly is probably that, without a midday observed temperature for use as a base value, i.e. as for Day 0, some degrees of reliance is put on a notional maximum forecast temperature, i.e. using NWP model values for assessment at 12 or 18 GMT. As an alternative approach, the forecast MOS temperature values for Day 1 at 12 and 15 GMT were offered to the regression model as predictors (cf. the process for maxima and minima beyond Day 1) but they were not selected. The percentage of variance expressed by the equations for the dependent samples ranged from 95% at 18 GMT on Day 0 for both stations to 77% (Heathrow) and 84% (LWC) at the end of the forecast period.

The chosen prediction equations were tested by using as an independent sample the data for October 1980 to March 1981. The performance of the MOS equations can then be directly evaluated against that of the subjective temperature forecasts for LWC, kindly made available by the Principal Meteorological Officer. The r.m.s. errors (Fig. 3) for the MOS forecasts of LWC temperatures are about 0.5 °C lower than those of the subjective forecasts for most of Day 1. By the end of the forecast period this difference has increased to almost 1 °C, e.g. compare 2.5 °C with 1.6 °C at 03 GMT. Indeed, MOS forecasts for 36 hours ahead have similar errors to the subjective forecasts for only 12 hours ahead. The number of large errors (⩾ 3 °C) is correspondingly lower throughout the period for the MOS forecasts (Fig. 4), the number being less than a third of those for the subjective forecasts during the second night, e.g. 44 against 12 at 03 GMT. The r.m.s. errors for the MOS estimates at Heathrow are higher than those for LWC as would be expected with the increased variance in the temperature data, the value at 06 GMT on Day 2 being 2.4 °C. The mean errors (Fig. 5) for both sets of MOS forecasts show a small negative bias, i.e. are too cold, whereas the subjective forecasts for LWC show a very marked diurnal variation in bias together with an increasing negative trend. This feature of small bias strongly reinforces the value of MOS forecasts.

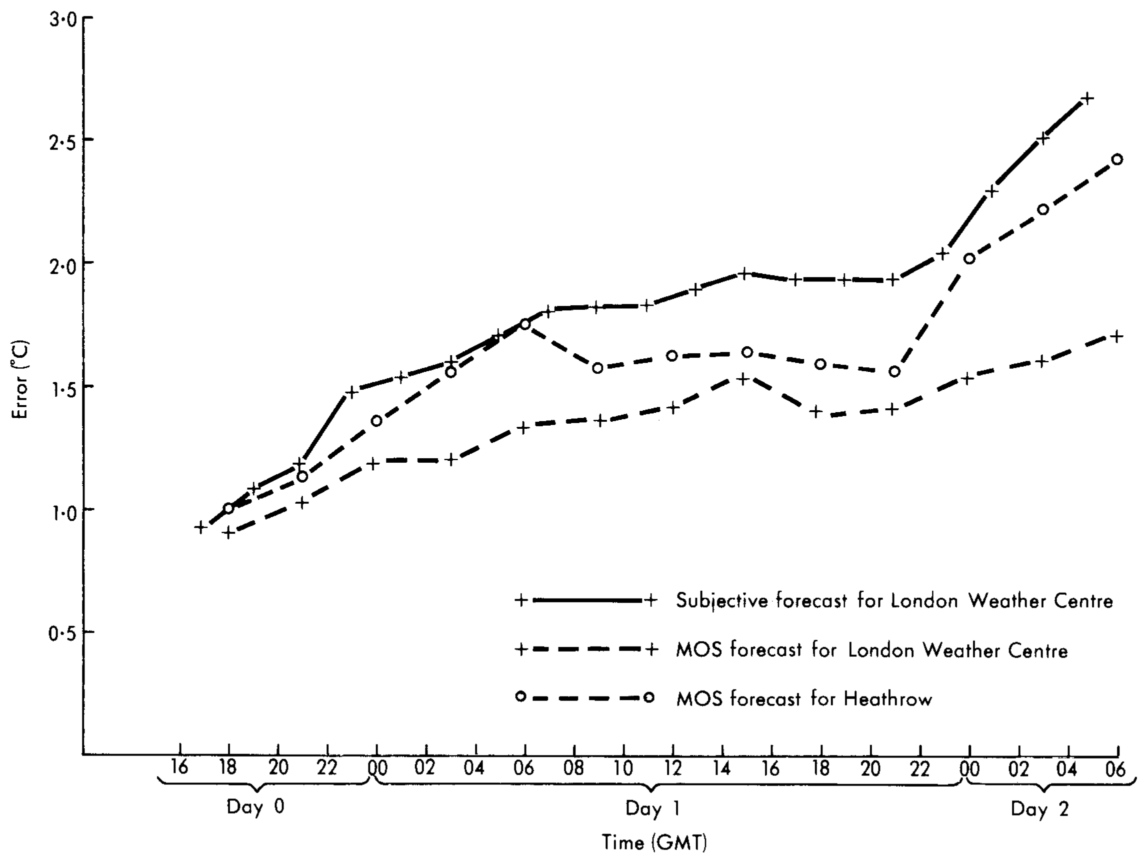

Figure 3. Root-mean-square errors of forecast temperatures for fixed hours, October 1980–March 1981.

(c) *Rationalization of extreme and fixed-hour forecasts*

The separate forecasting of temperatures at fixed hours from that of the extreme values can of course lead to inconsistent forecasts (Carter *et al* 1979), hence a small investigation has been conducted to see whether deriving maxima and minima from the forecasts at fixed hours would entail any loss in accuracy. The dependent data for Heathrow were processed as outlined above to give forecasts at fixed hours. The relevant maximum and minimum values of these forecasts in the appropriate period were then abstracted and compared with observed values. Regression equations for a linear model gave results which indicated a simple mean error correction as the best model to adopt, hence the formulae below were applied to independent data.

Maximum (09–21 GMT) = 1.03 × maximum of fixed-hour forecasts + 0.5 °C
Minimum (21–09 GMT) = 1.01 × minimum of fixed-hour forecasts —0.8 °C

The forecast maxima and minima employing this technique had r.m.s. error values of 1.6 and 1.7 °C respectively, with mean errors of —0.1 and —0.2 °C. A comparison with the results of section 5(b) is not completely valid since data from the coarse-mesh NWP model were used to derive those results. A

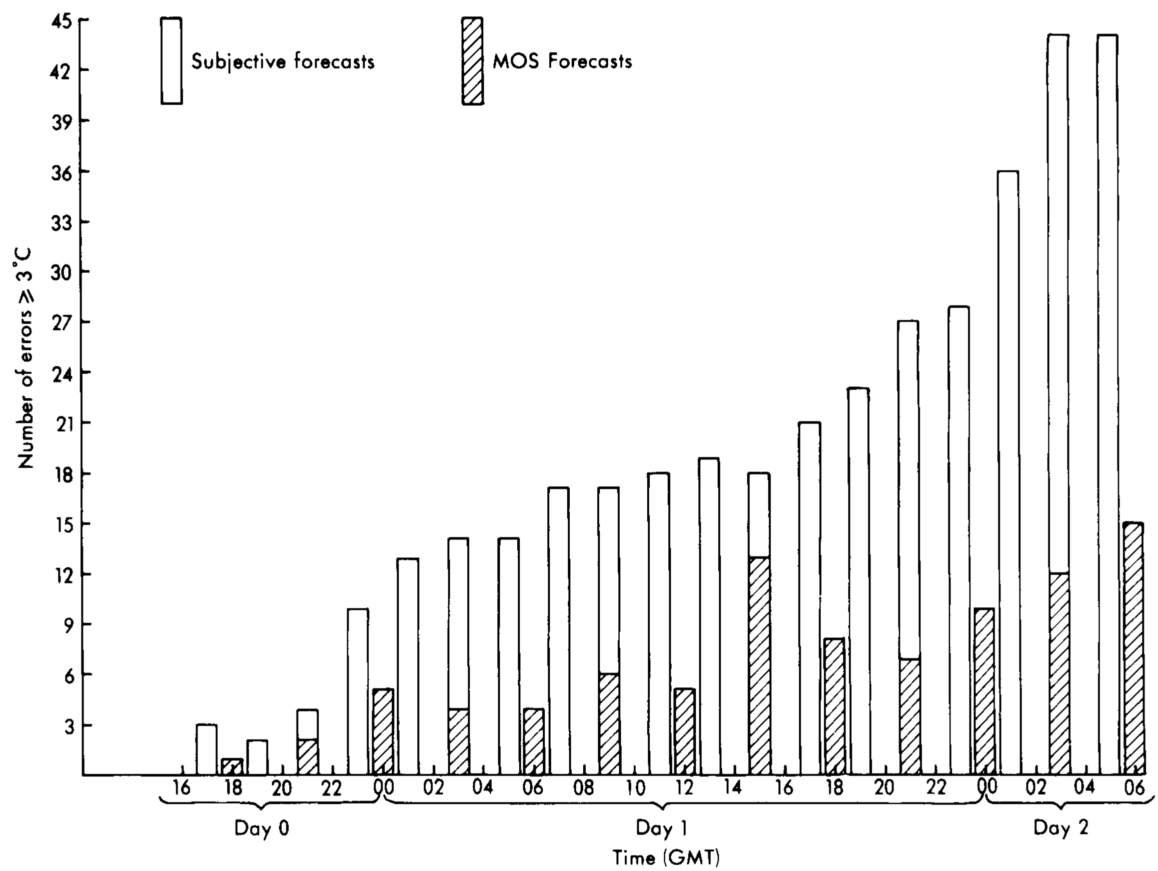

Figure 4. Number of forecast errors ⩾ 3 °C, October 1980–March 1981.

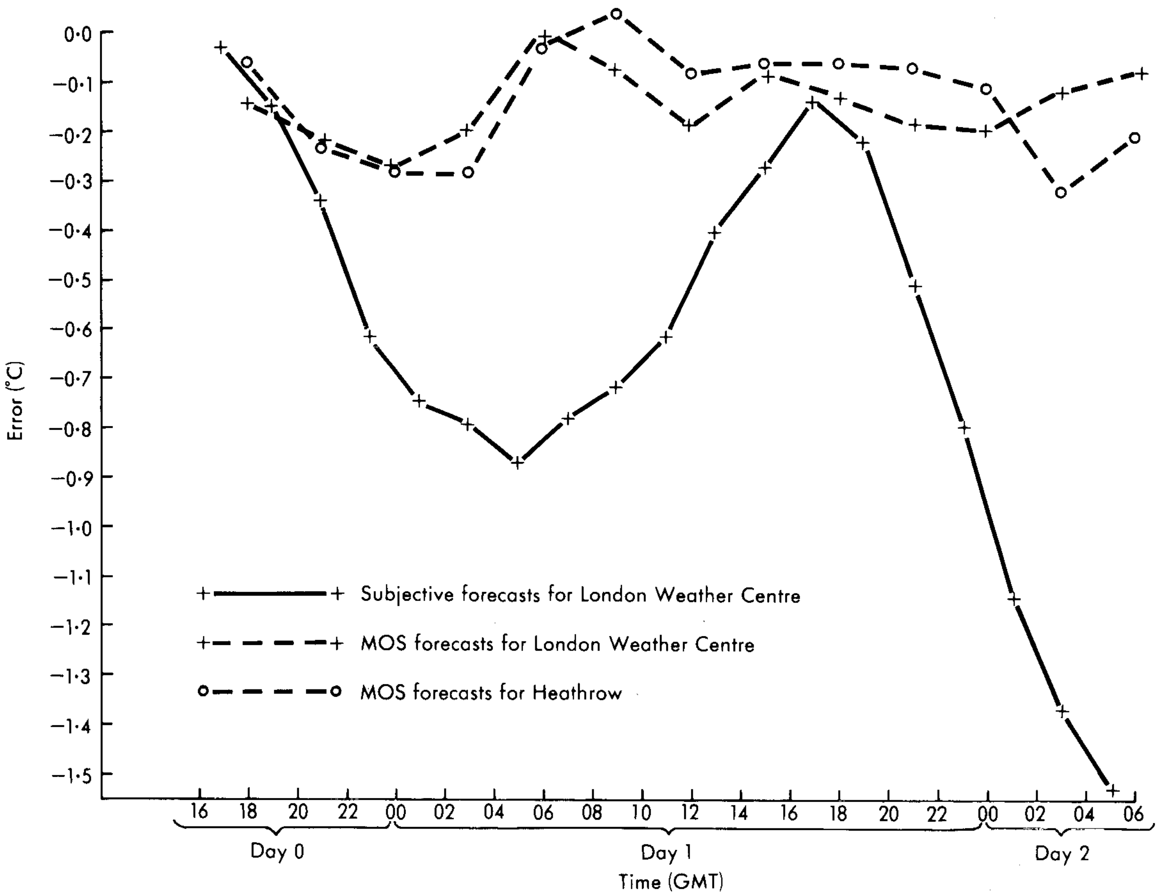

Figure 5. Mean errors (forecast minus actual) of forecast temperatures for fixed hours, October 1980–March 1981.

similar MOS analysis, using fine-mesh NWP model products to yield extreme temperature forecasts directly, produced similar r.m.s. error values, i.e. 1.6 and 1.7 °C. Thus for areas where fixed-hour temperature forecasts are given it would be consistent, and no less accurate, to derive maxima and minima forecasts via this less direct route. An interesting side issue is the higher accuracy of minima forecasts using fine-mesh NWP model data, presumably a result of better forecast fields.

7. Summary and conclusion

It has been demonstrated in this account that forecasts of temperature values for up to five days ahead, during the winter half of the year, can be made with acceptable accuracy using MOS techniques. As the forecast period increases the accuracy of the predicted maximum and minimum temperature values approaches that of a climatological forecast.

Such comparisons with subjective forecasts as can be made indicate that the MOS forecasts are as good as, or better than, the subjective forecasts, at least in terms of r.m.s. error and bias. This is particularly so for the comparisons of forecasts of temperature at fixed hours. A cautionary note is sounded by the relatively higher errors in the MOS forecasts of extreme temperature at Dyce, which suggest that local effects there have a large influence on temperature variation. A possible method of improving MOS forecasts, by accounting for some local effects, is by stratifying the development and test data (e.g. Woodcock 1980). With the limited data available at present a valid test of this approach is difficult to carry out, but a trial experiment based on a stratification by wind direction does appear to show promising results.

The best way forward at present is probably to use MOS forecasts as a guide to the forecaster, rather than as a finished article, in order to ensure the optimum forecast. Such guidance could be produced in the form of a chart of the British Isles with forecast and climatological temperature data for about 20 evenly distributed stations. It is also very desirable to continue the tests on further independent data and to extend the work to cover the summer six months.

References

Carter, G. M., Dallavalle, J.P., Forst, A. L. and Klein, W. H. 1979 Improved automated surface temperature guidance. *Mon Weather Rev*, **107**, 1263–1274.

Hammons. G. A., Dallavalle, J. P. and Klein, W. H. 1976 Automated temperature guidance based on three-month seasons. *Mon Weather Rev*, **104**, 1557–1564.

Klein, W. H. and Hammons, G. A. 1975 Maximum/minimum temperature forecasts based on Model Output Statistics. *Mon Weather Rev*, **103**, 796–806.

Woodcock, F. 1980 On the use of anologues to improve regression forecasts. *Mon Weather Rev*, **108**, 292–297.

551.509.56

A consideration of the effect of 500 mb cyclonicity on the success of some thunderstorm forecasting techniques

By M. N. Pickup

(Meteorological Office, Belfast/Aldergrove Airport)

Summary

Forecasts of thunderstorms were made using as predictors only differences of wet-bulb potential temperature at 500 and 850 mb, and the criterion of cyclonic/non-cyclonic flow at 500 mb. The results were compared with established techniques and these techniques were then tested to see whether they were more successful when they also took into account the curvature of the 500 mb flow.

Introduction

Forecasts of thunderstorms are not only needed by the general public, but also some assessment of the likelihood of lighting is required for specialized jobs such as work by the Central Electricity Generating Board on cables and overhead transmission lines, storage of inflammable materials and gases, and many varied pastimes such as hot-air ballooning, hang-gliding and pigeon racing.

The present techniques used in the Meteorological Office, based upon work by Boyden (1963), Rackliff (1962) and Jefferson (1963), are indices which relate the degree of instability at an upper-air station to various vertical temperature differences with some allowance made for moisture content, but none specifically consider the curvature of the flow.

Inspection of days when thunderstorms were reported at Manchester Airport in 1967, a year selected at random, showed that on almost all the occasions the thunderstorms were associated with cyclonic curved flow at 500 mb, usually ahead of an upper trough or low advancing from the west or south-west. On all these thunder days it was also noted that the wet-bulb potential temperature at 500 mb (θ_{w500}) minus that at 850 mb (θ_{w850}) was less than +3 K. This difference decreases with instability, in contrast to other indices.

Bradbury (1977) has already suggested the use of values of 'potential stability' (the difference between θ_{w500} and θ_{w850}) in combination with surface and upper-air charts to forecast thunderstorms. It was decided to investigate the association of thunderstorms with the curvature of the upper flow, together with the criterion θ_{w500} minus θ_{w850} less than +3 K, and to compare the results with established techniques.

Preliminary study

The study was extended to the summer months (April to September) for the years 1968, 1969 and 1970. The area chosen covered most of Wales and north-west England from 52° to 55°N and from 2° to 5°W. Sferics (atmospherics) data for that period were obtained and, allowing a gap of two days between events to suppress the effect of persistence, a total of 59 'thunder days' emerged. A 'thunder day' was defined as one on which sferics were reported in the area between midnight and midnight. An equal number of non-events was selected by allocating numbers to dates, months and years and selection was made using random numbers. Again, two days were allowed between each non-event. It should be remembered that because cathode-ray direction finding (CRDF) stations operate only for part of each hour, it is possible that, on occasions, thunderstorms may occur without being detected by the CRDF network.

For each of the 'thunder' and 'no thunder' days the following data were extracted from the *Daily Aerological Record:*

(1) A brief description of the 500 mb contour pattern over and near the British Isles at 1200 GMT — noting those days when an upper trough or low was in the area 45° to 60°N and between 0° and 20°W.

(2) The type of flow over this area at 500 mb, designated A, C or N, where
A = Anticyclonic flow,
C = Cyclonic flow, and
N = Neutral flow (indeterminate or 'straight' contours).

(3) The prevailing wind direction over the area 52° to 55°N and 2° to 5°W at 700 mb — this being the 'mid-level' wind of the layer being considered for the present investigation.

(4) The sounding upwind of the area was noted and the following data extracted:

(a) 850 mb temperature, dew-point and wet-bulb potential temperature,
(b) 500 mb temperature, dew-point and wet-bulb potential temperature,
(c) 1000 mb and 700 mb geopotentials, and
(d) 700 mb temperature and dew-point depression.

For each day, the Boyden and Jefferson indices were calculated for the upwind station at both midnight and midday. A 'yes' forecast for thunderstorms was made if either of these was above the relevant threshold limits, and the forecast was correct if sferics were reported in the area during the 24 hours from midnight to midnight.

For a 'yes' forecast of thunderstorms using the present technique the following criteria had to be satisfied:

(a) a 500 mb trough or low in the area 45° to 60°N and 0° to 20°W,
(b) cyclonic curved flow at 500 mb, and
(c) θ_{w500} minus θ_{w850} less than + 3 K at the upwind station.

There are many different formulae from which skill scores are derived to evaluate the success of yes/no categorical forecasts. Johnson (1957) made a comprehensive review of various formulae and concluded that there is no single score which is suitable for all purposes. Some markedly weight 'prefigurance', the probability that an occurrence will be predicted, while others emphasize 'postagreement', the probability that a prediction will be fulfilled. The present study was intended to devise a general technique to give the best results when forecasting both 'thunder' and 'non-thunder' days and therefore Yule's index (Meteorological Office 1975) was used to determine the skill scores as this does not give undue weight to either prefigurance or postagreement.

Given a contingency table of the form:

Observed	Forecast Yes	No	Totals
Yes	*a*	*b*	$(a + b)$
No	*c*	*d*	$(c + d)$
Totals	$(a + c)$	$(b + d)$	$a + b + c + d$

Yule's index is

$$(ad - bc)/ \{(a+b)\ (b+d)\ (a+c)\ (c+d)\}^{1/2}.$$

It varies from −1 for totally wrong forecasts to +1 for perfect forecasts. By adding 1 to the index, dividing the sum by 2 and multiplying by 100, a value emerges which measures what for convenience is called the 'equivalent percentage success', i.e. the success which would be achieved if there were equal numbers of 'yes' and 'no' events actually encountered in the trial.

Table I shows the results obtained from the trial period 1968–70, giving the percentage of correct 'yes' and 'no' forecasts out of the total of 118 occasions, the Yule's index and the equivalent percentage success for each method, associated with suggested critical values of the indices, e.g. Boyden ⩾ 94.

Table I. *Results of preliminary study, related Yule's index, percentage of correct forecasts and equivalent percentage success for each method.*

	Yule's index	Equivalent percentage success	Percentage of correct yes/no forecasts
Pickup	0.528	76.4	76
Jefferson (⩾ 28)	0.467	73.4	73
Boyden (⩾94)	0.472	73.6	72
Boyden (⩾95)	0.435	71.8	69

Using past data it was difficult to determine exactly the nature of the 500 mb flow from only one North Atlantic chart each day, so the next step was to produce forecasts in 'real time' and a comprehensive study was made for the period from April to September 1980.

The 1980 study

From April to September 1980, charts for 850, 700 and 500 mb were plotted every 6 hours, giving a more detailed analysis over the area, and these were used in conjunction with the $T+18$ h forecast charts for these levels to determine the curvature of the flow during the forecast period. On occasions when the flow upwind lay between two radiosonde stations, the data from both were used and, in conditions of light winds, the data from the nearest station, Aughton, were used.

Values of the Boyden, Jefferson and Rackliff indices were calculated for both midnight and 1200 GMT. A forecast of thunderstorms based on the midnight GMT data and the 1800 GMT forecast charts was considered correct if sferics were reported in the area between midnight and midnight GMT, and on the 1200 GMT actual and 0600 GMT forecast charts if they occurred between 1200 GMT and 1200 GMT the next day. For each technique at least two different threshold values were used. A total of 366 forecasts was made.

For the present technique the criteria were reduced to only two:

(a) Cyclonic curved flow at 500 mb over the area at some time during the forecast period, and
(b) θ_{w500} minus θ_{w850} less than +3 K.

Table II shows the results obtained and the related Yule's index for each method. The results varied from an equivalent percentage success of 72 for the present technique down to 60 for Rackliff ($\geqslant$30).

When the Boyden, Jefferson and Rackliff results were modified so that thunderstorms were forecast only when the flow was cyclonic during the period, there was an improvement in the Yule's index varying from 0.05 for Rackliff ($\geqslant$30) to 0.11 for Boyden ($\geqslant$95). The equivalent percentage success improved by 3–6; Boyden ($\geqslant$94) improved to 70, only 2 below the success of the present technique. The results are shown in Table III.

Saunders (1967) has suggested that 'there can be circumstances in which the method to be preferred may not be the one with the highest skill score'. It is a matter of individual choice whether a system which produces a higher percentage success in forecasting 'yes' events is preferred to another which produces more correct 'no' forecasts.

If it is considered more important that the actual occurrence of thunderstorms be forecast with the least number of 'false alarms', an index should be used which weights prefigurance. Peirce's index (Meteorological Office 1975) has this virtue and these values were also calculated, producing similar results to those for Yule's index with an equivalent percentage success for the present technique of 76 down to 65 for the Rackliff ($\geqslant$ 30) results in Table III.

Discussion of the various techniques

Boyden

The Boyden index is given by the formula:

$$I=Z-T-200,$$

where $Z=$ 1000–700 mb thickness in decageopotential metres, and
$T=$700 mb temperature in degrees Celsius.

Table II. *Results obtained and related Yule's index for each forecasting method.*

V = Yule's index. *EPS* = Equivalent percentage success.

Pickup

Observed	Forecast Yes	Forecast No	Total
Yes	45	19	64
No	54	248	302
Total	99	267	366

V = 0.448 *EPS* = 72.4

Boyden (⩾94)

Observed	Forecast Yes	Forecast No	Total
Yes	51	13	64
No	112	190	302
Total	163	203	366

V = 0.326 *EPS* = 66.3

Boyden (⩾95)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	61	241	302
Total	91	275	366

V= 0.234 *EPS* = 61.7

Rackliff ⩾ 29)

Observed	Forecast Yes	Forecast No	Total
Yes	46	18	64
No	134	168	302
Total	180	186	366

V=0.209 *EPS* = 60.4

Rackliff (⩾ 30)

Observed	Forecast Yes	Forecast No	Total
Yes	37	27	64
No	99	203	302
Total	136	230	366

V=0.197 *EPS*=59.8

Jefferson (⩾ 26)

Observed	Forecast Yes	Forecast No	Total
Yes	35	29	64
No	72	230	302
Total	107	259	366

V=0.258 *EPS*=62.9

Jefferson (⩾ 27)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	55	247	302
Total	85	281	366

V=0.258 *EPS*=62.9

Jefferson (⩾ 28)

Observed	Forecast Yes	Forecast No	Total
Yes	25	39	64
No	34	268	302
Total	59	307	366

V=0.287 *EPS*=64.4

Table III. *Results obtained and related Yule's index for each forecasting method associated with cyclonic flow only.*

V = Yule's Index. *EPS* = Equivalent percentage success.

Boyden (⩾94)

Observed	Forecast Yes	Forecast No	Total
Yes	46	18	64
No	67	235	302
Total	113	253	366

$V = 0.409$ $EPS = 70.4$

Boyden (⩾95)

Observed	Forecast Yes	Forecast No	Total
Yes	28	36	64
No	31	271	302
Total	59	307	366

$V = 0.346$ $EPS = 67.3$

Rackliff (⩾29)

Observed	Forecast Yes	Forecast No	Total
Yes	42	22	64
No	88	214	302
Total	130	236	366

$V = 0.290$ $EPS = 64.5$

Rackliff (⩾30)

Observed	Forecast Yes	Forecast No	Total
Yes	34	30	64
No	71	231	302
Total	105	261	366

$V = 0.249$ $EPS = 62.4$

Jefferson (⩾26)

Observed	Forecast Yes	Forecast No	Total
Yes	35	29	64
No	48	254	302
Total	83	283	366

$V = 0.352$ $EPS = 67.6$

Jefferson (⩾27)

Observed	Forecast Yes	Forecast No	Total
Yes	30	34	64
No	38	264	302
Total	68	298	366

$V = 0.335$ $EPS = 66.7$

Jefferson (⩾28)

Observed	Forecast Yes	Forecast No	Total
Yes	25	39	64
No	23	279	302
Total	48	318	366

$V = 0.354$ $EPS = 67.7$

Most thunderstorms are associated with cloud depths greater than 10000 feet, with tops well above 700 mb. Boyden considered only the layer from 1000 mb to 700 mb. When changes are taking place above the 700 mb level, e.g. warm advection or subsidence, no change will take place in the Boyden index.

On 16 June 1980 a thundery trough had moved across the British Isles with a weak ridge moving into Ireland. Warm advection was taking place and, although the midday ascents from Aughton and

Valentia showed the Jefferson index falling from a value of 31 down to 10 and the Rackliff index from 33 to 24, the Boyden index at both stations was the same at 94.

In Table II, Boyden ($I \geqslant 94$) correctly forecast 51 out of the 64 thunder occasions but there were, in fact, a total of 163 'yes' forecasts, i.e. only a third of these forecasts were correct. The number of incorrect 'yes' forecasts was reduced by 40% — from 112 to 67 — when only occasions with cyclonic flow were considered for a 'yes' forecast. When the Boyden criterion was $I \geqslant 95$, the number of correct forecasts (both 'yes' and 'no') increased from 271 to 299 out of the total of 366, but again the proportion of 'yes' forecasts which were correctly forecast was low — being approximately 50%.

Rackliff

The Rackliff index is given by the formula:

$$I = \theta_{w900} - T_{500},$$

where θ_{w900} = 900 mb wet-bulb potential temperature, and
T_{500} = 500 mb dry-bulb temperature.

This technique was the least successful, having only 214 ($I \geqslant 29$) and 240 ($I \geqslant 30$) correct forecasts in Table II, and this increased to only 256 and 265 respectively in Table III. The proportion of correct 'yes' forecasts was only between 25% and 32%.

Jefferson

The Jefferson (1966) index is given by the formula:

$$I = 1.6\theta_{w850} - T_{500} - \tfrac{1}{2}\, T_{d700} - 8,$$

where θ_{w850} = 850 mb wet-bulb potential temperature,
T_{500} = 500 mb dry-bulb temperature, and
T_{d700} = 700 mb dew-point depression.

Although this technique was generally more successful than that of either Boyden or Rackliff, having 304 correct 'yes' and 'no' forecasts in Table III for a critical value of $I \geqslant 28$, the proportion of 'yes' forecasts was low and 39 events were not forecast.

Yule's index was also calculated for either side of the suggested critical values, associated with cyclonic flow. With $I \geqslant 25$ the index fell to 0.286 and to 0.228 using $I \geqslant 29$. In Table III the results were similar for the three criteria considered, and the slight decrease at the mid-point ($I \geqslant 27$) is probably not significant.

Frith (1948) has found that variations of dew-point (frost-point) of as much as 15 K occur over distances of only a few miles, and it is therefore misleading to assume that one ascent is totally representative of an air mass. Values of the Jefferson index could vary by 7 or 8 over short distances. This most probably accounts for the low number of correct 'yes' forecasts.

Present technique

During the 1980 survey this method correctly forecast 293 out of the 366 occasions. Forty-five of the 64 days when thunderstorms were observed were actually forecast out of a total of 99 'yes' forecasts which were made.

When it was decided to forecast thunderstorms only on occasions with cyclonic flow at 500 mb, this was intended to go some way towards highlighting areas of ascending air. Of course, cyclonically curved flow or areas of cyclonic vorticity are not always associated with ascent of air and, ideally, charts showing the advection of cyclonic vorticity and partial or total thickness advection are required (e.g. Morris 1971, 1972). This may account for some of the occasions when sferics were not reported on days when thunderstorms were forecast.

Forecast charts of $\theta_{w500} - \theta_{w850}$ are available, and charts showing these values for 5 June 1980, when thunderstorms were widespread over the British Isles, are shown in Figs 1, 2 and 3, together with the actual 500 mb chart for 1200 GMT on the 5th (Fig. 4).

An area of $\theta_{w500} - \theta_{w850}$ around 0 K moved east across the British Isles ahead of an upper trough, and in the area 52° to 55° N, 2° to 5° W alone there was a total of 414 'flashes' recorded by the CRDF network between midnight and midnight GMT with a maximum in any hour of 62 between 1600 and 1700 GMT. These, of course, were recorded in two 10-minute periods, 1550–1600 GMT and 1620–1630 GMT.

Rainfall totals for the north-west of England for the period from 0900 GMT on the 5th to 0900 GMT on the 6th showed that parts of the Manchester area recorded almost 2 inches of rain. During the afternoon of the 5th, 1.69 inches of rain was reported in one hour at Eccleshall in Staffordshire, with hailstones observed up to 20 mm in diameter.

Conclusion

None of the 64 occasions (midnight to midnight GMT or 1200 to 1200 GMT) when thunderstorms were reported during the period from April to September 1980, were associated with marked anticyclonic flow although 5 were classified as 'neutral' and 2 as 'slightly anticyclonic'.

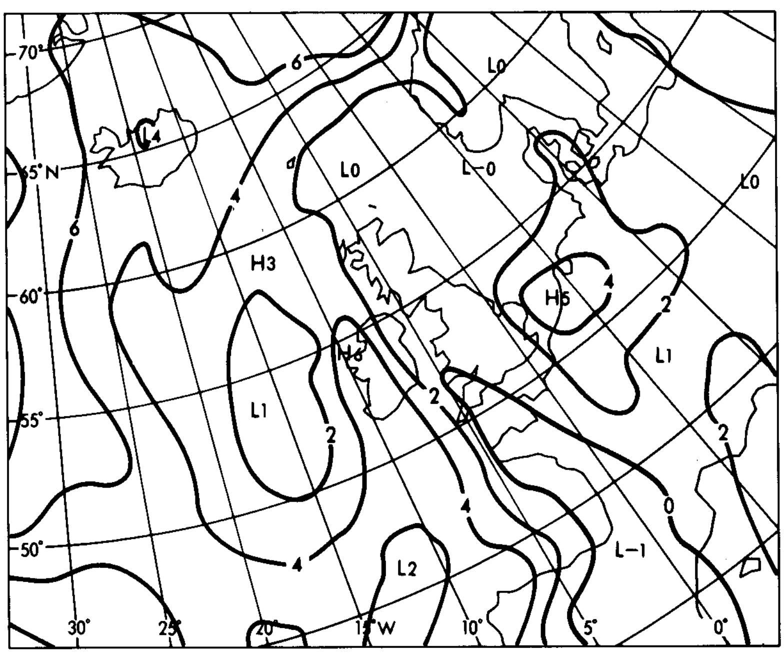

Figure 1. Wet-bulb potential temperature difference (500–850 mb) 6-hour forecast for 0600 GMT, 5 June 1980.

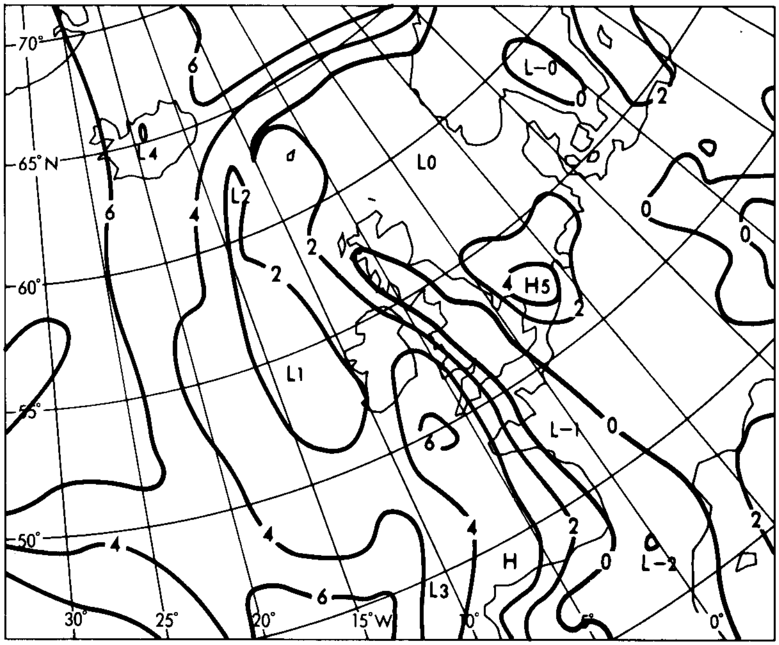

Figure 2. Wet-bulb potential temperature difference (500–850 mb) 12-hour forecast for 1200 GMT, 5 June 1980.

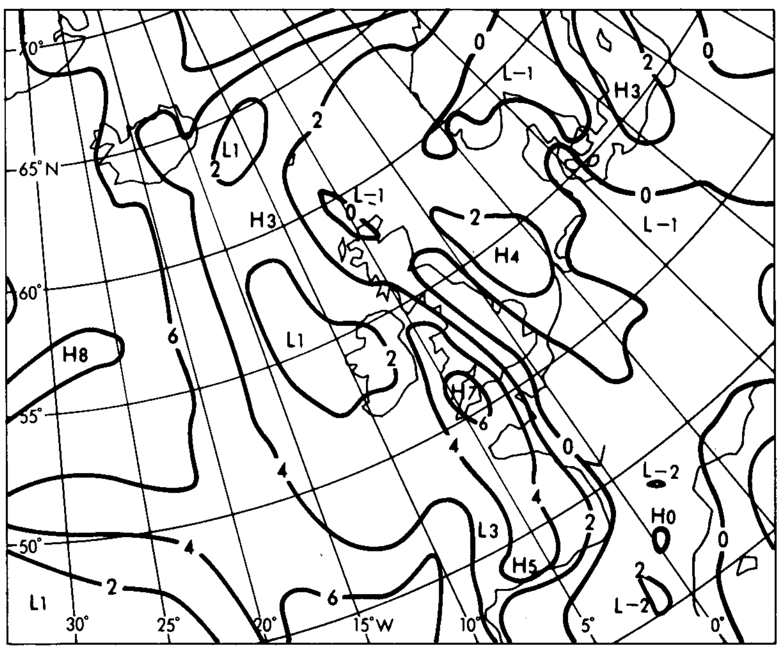

Figure 3. Wet-bulb potential temperature difference (500–850 mb) 18-hour forecast for 1800 GMT, 5 June 1980.

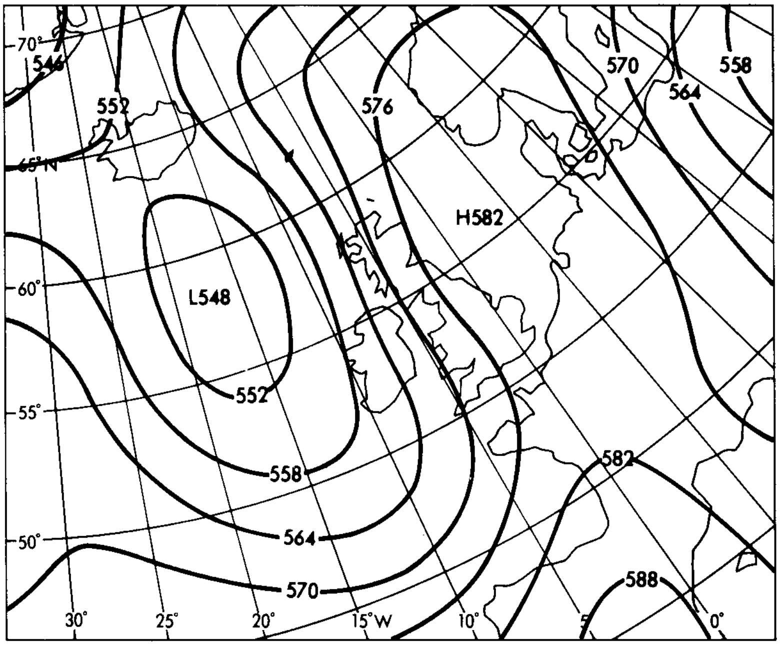

Figure 4. Central Forecasting Office 500 mb analysis for 1200 GMT, 5 June 1980. Values in geopotential metres.

Improvements have been made when using the Boyden, Jefferson and Rackliff indices if thunderstorms are forecast only when the values are above the critical limit, together with marked cyclonic flow. Large dew-point depressions in middle levels do not preclude the possibility of thunderstorms if the air mass is potentially unstable.

The present technique, using differences in wet-bulb potential temperature between 500 mb and 850 mb associated with cyclonic flow, showed the highest equivalent percentage success during the 1980 survey. As values of $\theta_{w500} - \theta_{w850}$ decreases to or below 0 K the intensity of thunderstorms increases, provided they are not associated with anticyclonic flow. Computer charts of forecast vertical motion in mid-troposphere and of wet-bulb potential temperature differences could be used to highlight the most likely areas for thunderstorm activity.

References

Boyden, C. J. 1963 A simple instability index for use as a synoptic parameter. *Meteorol Mag*, **92**, 198–210.

Bradbury, T. A. M. 1977 The use of wet-bulb potential temperature charts. *Meteorol Mag*, **106**, 233–251.

Frith, R. 1948 Small scale temperature and humidity patterns in the free air. (Unpublished, copy available in the National Meteorological Library, Bracknell.)

Jefferson, G. J. 1963 A modified instability index. *Meteorol Mag*, **92**, 92–96.

1966 Letter to the Editor. *Meteorol Mag*, **95**, 381–382.

Johnson, D. H.	1957	Forecast verification: a critical survey of the literature. (Unpublished, copy available in the National Meteorological Library, Bracknell.)
Meteorological Office	1975	Handbook of weather forecasting (Chapter 24). (Unpublished, copy available in the National Meteorological Library, Bracknell.)
Morris, R. M.	1971	A case study of the spectacular developments and movement of a February storm. *Meteorol Mag*, **100**, 14–27.
	1972	The trowal, an important feature of frontal analysis. *Meteorol Mag*, **101**, 150–153.
Rackliff, P. G.	1962	Application of an instability index to regional forecasting. *Meteorol Mag*, **91**, 113–120.
Saunders, W. E.	1967	Tests of thunderstorm forecasting techniques. *Meteorol Mag*, **96**, 204–210.

551.5(09):551.501.9

Auxiliary Reporting Station Gorleston

By C. S. Broomfield

(Meteorological Office, Bracknell)

The closure of Auxiliary Reporting Station Gorleston (03497) in October 1981 brought to an end 114 years of synoptic reports from the district.

Synoptic reports from Yarmouth started in 1867 and were made by Mr T. Robinson, a telegraphic clerk. The reports, with those of five other stations, were sent daily to M. Le Verrier for publication in the daily bulletin of the Observatoire Impérial, Paris. In return M. Le Verrier supplied the Meteorological Committee with daily reports from six continental stations. The observations were also included in the Daily Weather Chart when it was first issued in 1872.

On the death of the observer in 1872 the commitment was taken over by the Secretary of the Sailors' Home, Yarmouth. An anemometer was erected a few feet above the roof of the Home and figured prominently on picture postcards of the era. (See Fig. 1) In 1873 the reports and those of two other stations were supplied to the Swedish Meteorological Service in exchange for reports from four Swedish stations.

In 1907 HM Coastguard assumed responsibility for the reports. A Dines pressure-tube anemograph was installed on the Brush Pier, Gorleston, in 1908 to test the exposure of the Robinson anemometer on the Sailors' Home. The Dines anemograph was 42 feet above the pier and not surprisingly showed much stronger winds than those from the Robinson just above roof level.

During World War I the station was taken over by the Royal Navy but with the posting of the Chief Petty Officer observer the routine was transferred to the War Signals Station, Gorleston, in 1915. The Town Council made available a site for an instrument enclosure in a public garden which was near to the Signals Station.

After the War the coastguards resumed observations. Replanning of the public garden in 1924 led to the instrument site being moved about 400 yards from the Coastguard Station. (See Fig. 2)

During an air raid on 24 June 1941, six bombs fell within 15–35 yards of the anemograph. For six days the coastguards had to pass within 30 yards of an unexploded bomb while making the observation. A fragment of metal or shrapnel was found buried in one of the copper tubes of the anemograph and caused the instrument to under-record by 8 mph.

Figure 1. Telegraphic Reporting Station Yarmouth. Anemometer on top of Sailors' Home, 1896.

Figure 2. Auxiliary Reporting Station Gorleston. Instrument enclosure, with vandal-deterrent fence, at climatological site in public park.

War-time HM Coastguard duties eventually meant it was no longer possible to make frequent visits to the enclosure, and a screen was erected on the roof of the coastguards' lookout. Visits to the public garden site were then restricted to 0900 and 2100 GMT only. Naval ratings assisted with the observing program during and immediately after World War II.

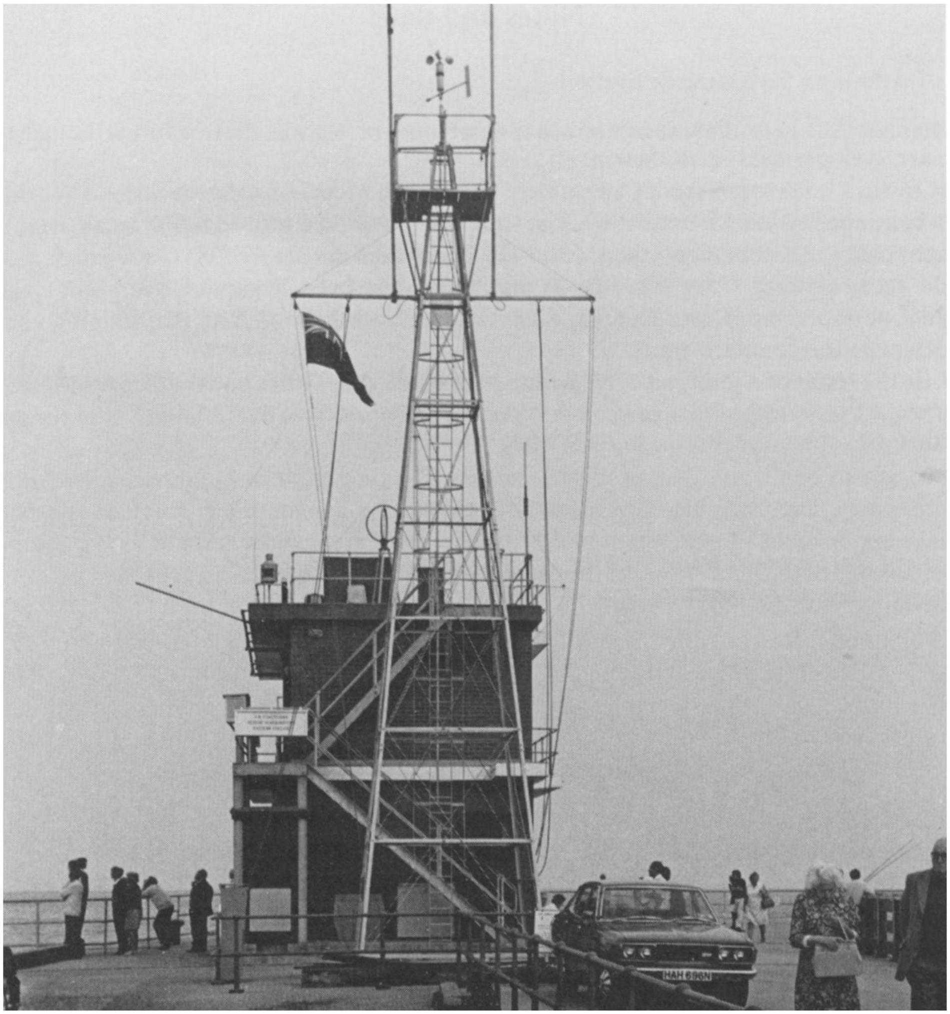

Figure 3. Auxiliary Reporting Station Gorleston. Anemometer and balcony screen at synoptic reports site on South Pier, 1976.

The pressure-tube anemograph was wrecked by a lorry in 1958 and was replaced by an electrical anemograph (Fig. 3) the following year.

In 1981 HM Coastguard moved most of their staff to a seven-storey office block at Havenbridge House, Great Yarmouth. The new location formed the nerve centre of a communications network which covered the coastline from Berwick-upon-Tweed to Orford Ness. Advanced equipment was available for gathering and displaying information on marine activities for the whole coastline and for 40 miles out to sea. The site, alas, was unsuitable for weather observing, and further reductions in the manning of the lookout meant observations coming to an end in October 1981. For a while, at least, anemograph records will continue as will 0900 GMT climatological readings from the site in the public garden.

Synoptic observations from the upper-air station at Hemsby (03496), which started in June 1978, now fill the gap which would otherwise be created by the closure of Gorleston.

Notes and news

Opening of Athalassa Rawinsonde Station

On 17 October 1981 in brilliant sunshine at a site just south of Nicosia, the first formal launch took place from a smart, well-planned, new station.

The first rawinsonde ascents from Cyprus were made from Nicosia during the Second World War and the station continued to launch until 1969. The equipment was then moved to Paramali, near Episkopi, on the south coast and ascents continued until 1976. From then until early 1981 Graw-sonde ascents only were made each evening from Akrotiri. Hence there has been a gap of over four years in the measurement of upper winds over Cyprus, other than by pilot balloon, and in obtaining values of the other variables at the standard times.

In 1978, as the result of a joint initiative by the Meteorological Office and the Cyprus Meteorological Service, a project to re-establish a rawinsonde station in Cyprus was put in hand under the auspices of the Voluntary Co-operation Program of WMO.

The Government of Cyprus has provided the site, the fine modern buildings, services, furniture, ancillary equipment and staff. The Government of the United Kingdom has provided specialist advice and training, major items of equipment and a two-year supply of consumables. The smooth progress of the project is one of the many fruits of the close relationship which has always existed between the two meteorological services.

Mr K. Philaniotis, Head of the Cyprus Meteorological Service, made brief introductory remarks, thanking everyone concerned for their individual contributions, and introduced Sir John Mason. The Director-General spoke of the enormous advances made in the science of weather forecasting, stressing, to a large and mainly professional audience, that no amount of modelling skill and computing power could succeed without high-quality data of the sort now available at Athalassa.

Dr Andreas Papasolomontas, Director-General of the Ministry of Agriculture and Natural Resources, a well-known plant pathologist, made the address of thanks and formally inaugurated the station.

After the ceremony the Minister of Agriculture and Natural Resources (Mr N. K. Pattichis), who had been unable to attend the ceremony owing to a Cabinet Meeting, entertained a party, including Sir John Mason, the Minister of Telecommunications and Building, the UK High Commissioner and Dr Papasolomontas, to lunch.

Honours

The award of the Imperial Service Medal to Mr E. J. Perrow, Radio Operator, was announced on 17 December 1981.

In the New Years Honours List for 1982 it was announced that Mrs J. M. Cowlard, (Higher Scientific Officer), Information Officer in the National Meteorological Library, had been appointed a Member of the Order of the British Empire.

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NOTICES

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

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