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Long-Range Forecasting and Climate Research

Prospects for Long-Range Forecasting for the United Kingdom

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Summary

After a brief review of the recent history of long-range forecasting for the UK (to about summer 1987), we summarize the recent levels of skill using a variety of methods to assess the forecasts for their accuracy. Future plans are discussed in some detail. Most emphasis is placed on monthly forecasts for the UK, but the potential of, and reasons for, research into seasonal forecasting are mentioned, including seasonal forecasts for other regions of the globe.

1. INTRODUCTION

The public service of monthly forecasts for the UK published in "Monthly Weather Survey and Prospects" was discontinued at the end of 1980 as was a limited consultancy service for seasonal forecasts, including other parts of Europe. A much simplified forecasting system began in January 1981 organised around a conference held at half-monthly intervals at which forecasts for the UK for the periods 1-5 days ahead, 6-15 days ahead and next half-month were produced. During the ensuing period forecasts have been issued to around 10-20 consultancy customers for a nominal fee.

Analogue techniques were abandoned in 1982 due to a lack of staff. Two new statistical techniques replaced all prior statistical techniques, neither of which worked with acceptable reliability until June 1982. One of these, the multivariate forecasting technique (MVA) (Maryon and Storey (1985)), has tended to dominate the forecasts since that time. Subjective synoptic climatological experience also plays a role, which can be crucial when the predictions are contradictory. The other technique, the surface pressure eigenvector regression (SPEVR), has had little attention since it was developed in 1978-1982. Dynamical forecasts have been used irregularly throughout the period. Early forecasts in winter using a 5-level GCM (Corby et al, 1977) appeared to be slightly useful. The first real-time ensemble forecast was produced in late 1985 using an 11-level GCM (Slingo, 1985). This year, dynamical long-range forecasts have been more prominent but often for days 1-15 only. The CFO 5-day and ECMWF 10-day forecasts are extensively used early in the forecast. Folland and Woodcock (1986a) give the most recent detailed description.

There has been a major change in the structure of the forecasts since 1980. Five-day, next 10-day and last half month surface pressure and surface weather forecasts are made separately and the remaining forecasts, including that for the monthly mean, are objectively calculated from the three constituents. Automated temperature and rainfall data for the ten forecast districts was not available until 1982, since when it has been steadily improved. Recently, highly skilful objective equations have been developed using this data that predict district temperature and rainfall anomalies from forecast circulation patterns and current local sea surface temperature anomalies. Some reduction in the subjective input to the forecasts has resulted.

Looking to the future, it is expected that the role of dynamical forecasting will become increasingly important. The replacement of the Cyber 205 in the second half of 1988 by an ETA-10 computer eight times more powerful will allow ensembles of dynamical forecasts to be run on a regular basis for consideration at all future conferences. This will have a significant impact on the organisation of the conferences and, according to results of recent investigations, should lead to a perceptible increase in forecast skill in the period 6 to 20 days ahead, especially for temperature.

2. PERFORMANCE OF ISSUED FORECASTS

The forecasts are issued and assessed in two forms: (a) "best estimate" forecasts of temperature anomaly or rainfall percentage for each district which are also converted into the appropriate quint or terce category; (b) as a set of forecasts for each district of the probability of each quint or terce category. It is much easier to judge the skill of the forecasts as measured by a pre-defined statistic than to gauge "usefulness". However by measuring skill in several ways, progress can be adequately monitored. Note that the "anomaly correlation" assessment technique is used in section 5 but not section 2.

2.1 Skill of temperature and rainfall forecasts Jan 1983-Sept 1987

Figure 1 shows the skill of the temperature and rainfall forecasts for days 1-5, 6-15, 1-15, 16-30, 6-30 and the complete month. The Folland-Painting (FP) scoring system (Folland et al (1986)) is applied to rainfall terces and temperature quints and also to forecasts where only the sign of the forecast and observed anomalies about the climatological median for 1951-80 is compared. The stars above the median skill histograms denote statistical significance at better than the 5% level. The narrow bars represent the FP quint or terce skill that would have resulted from persisting the forecast anomaly made for days 1-5 ahead throughout the whole forecast. The black regions represent the extra skill of the forecasts over and above that which would arise if their skill was merely the time-weighted average of the skill of forecasts for their constituent sub-intervals. Black regions are possible for days 1-15, 6-30 and one month.

It is clear that:

(a) the best skill, as expected, is for days 1-5; the values are so high that they, and experience, indicates that the forecasts are clearly "useful";
(b) the lowest skill depends on the measure used, but tends to be for days 6-15;
(c) the skill for days 6-30, ie beyond the medium range, is small but positive;
(d) the skill represented by the black regions for days 1-15, 6-30 and the month (there are no relevant examples where this additional skill is completely absent) is sometimes quite large compared with total skill;
(e) if persistence of the forecast anomaly for days 1-5 ahead had been used to make forecasts for remaining periods, forecast skill would generally have been better, except for days 16-30 (temperature). Similar statistics for median sign skill (not shown) also give generally higher values than those for issued forecasts.

The reason for the black regions is not totally clear but this tendency is seen in individual years. One possible reason is that if the constituent sub-periods within a month are not of equal length then the monthly skill may not in principle be given by the average skill of the constituent sub-periods weighted according to their lengths. If we use the correlation between observed and forecast conditions as our measure of skill, the skill of the shortest sub-period has a larger weight than would be expected from the length of the sub-period alone. Thus if forecasts and observations for the first five days were always perfectly correlated but five day averages were uncorrelated thereafter, the expected correlation between monthly mean forecasts and observations would be close to 0.40 for normally distributed data.

2.2 Longer term skill

Figures 2a and 2b are updated versions of diagrams published by Folland et al (1986) but incorporate improvements to the quints and terces giving small changes in skill throughout the period since 1964. On a four-year running mean time scale, Figures 2a and 2b indicate that the improved skill shown in Folland et al (1986) is being maintained. Comparison of Figures 1, 2a and 2b suggests that the FP skill for days 6-30 in Figure 1 (i.e. for recent years) is similar to that for the month as a whole for the period of the public issue of the forecasts (1964-1980). A t-test indicates that there has been a statistically significant increase in the skill of rainfall forecasts (at the 5% level) when the period January 1983-September 1987 is compared with the period of public issue of the forecasts (1964-80). The change in the skill of temperature is clearly less and only just statistically significant at the 10% level.

2.3 Probability forecasts

Folland and Varah (1988) give a fuller description of the assessment of probability forecasts for their skill. Figure 3a shows the relation between forecasts of the probabilities of quints 4/5 together (warm) and 1/2 together (cold) and the proportion of the time that the outcome was in the given forecast category. Thus we might hope that a set of forecasts which state that warm is likely to occur with a probability of 0.6 will be followed 60% of the time by a warm outcome. The "ideal" relationship between the forecast and observed probabilities is given by the thin line. Figure 3b gives similar statistics for terce 1 (dry) and terce 3 (wet). The above probability forecasts approximately follow the ideal relationship, though confident forecasts of "cold" fail too often (Figure 3b).

Figure 3c shows that no relationship between forecast and observed probabilities exists for forecasts of terce 2. This is also true for forecasts of quint 3 (not shown). Not surprisingly forecasts of these categories also have no skill, however measured. This inability to forecast near average conditions is the experience in the USA (Gilman, 1986) where nowadays forecasts of the probability of the near average category of temperature or rainfall in any region of the USA is fixed at its climatological value.

3. **AUTOMATION**

The organisation of the long-range forecast conferences (LRFC) revolves around the use of paper charts. These consist of computer generated forecasts and a range of background information. They are coloured by hand and displayed on walls and boards in the conference room. The amount of information that can be examined at each LRFC is therefore limited by the available manpower and by the amount of free wall space.

During the conference, forecast MSLP charts are drawn and modified by hand after assessing the merits of the forecasts produced by the different prediction systems. Rainfall and temperature forecasts are then derived from these MSLP charts using a combination of subjective and objective techniques.

Although the Meteorological Office mainframe computer system is used to provide the basic MSLP forecasts and to derive objective rainfall and temperature forecasts from regression equations, much of the current system could be further automated with consequent savings in staff effort and increased effectiveness. This, however, will only be possible with the help of a powerful graphics workstation. It is hoped that a suitable graphics system will be installed during 1988. Once the appropriate software has been written, it will enable the range of data considered at the LRFC to be greatly increased. At the same time it will free staff to concentrate on the forecast itself rather than the mechanics of its production.

The role of the workstation will be to provide interactive facilities to do the following:

(i) review all the MSLP forecast information, superimpose charts, do weighted averages of selected forecasts and, as a final step, adjust contour values. Since this data is held on computer, rainfall and temperature forecasts can then be generated automatically using the existing techniques;
(ii) display information on the past and current performance of the different forecasting systems being considered;
(iii) display historical information on the synoptic climatology of the current forecast period.

Although the use of a graphics workstation will be of immediate benefit, it becomes of greater importance when future plans are considered. The introduction of a new more powerful supercomputer during 1988 will mean that, for the first time ever, ensembles (of up to 9) dynamical forecasts can be run in real time for consideration at each LRFC. This will lead to a massive increase in the amount of forecast data to be reviewed at a conference. The use of a graphics workstation will allow this data to be automatically displayed without the extra staff effort that would be required if more traditional methods are used. New ways of analysing, interpreting and presenting this data can then be developed using this technology (for example by showing time-lapse pictures of individual integrations), so that the full potential of dynamical forecasting can be quickly and successfully realized.

Until recently, long range forecasts were issued at half monthly intervals just before the 1st and 16th of each month. This orientation around calendar months was historical and had evolved naturally from using prediction methods which were tied to the seasons. The proposed introduction of real-time ensembles of dynamical forecasts into the long range forecasting system has made it advisable to realign the forecast conference onto a 2-weekly cycle so that they are held every other Monday. This is because the computational cost of ensemble forecasting is very large and will be more easily managed at weekends when there is less pressure on the computer system. A second reason for holding the LRFC on Mondays is that forecasts will be aligned to the working week, which is seen as advantageous in attracting commercial customers.

4. CURRENT DEVELOPMENTS IN FORECASTING FOR 1 MONTH AHEAD

4.1 Regression equations

Until 1985, rainfall and temperature forecasts were derived from MSLP forecasts by purely subjective methods. More objective techniques based on surface pressure analogues were introduced then, but only recently have adequately objective methods based on multiple regression equations been introduced. Experience shows, however, that some subjective modification is still needed. The regression equations have been produced for each half month and for each of the 10 areas into which the UK is divided. They relate the two surface weather variables to functions of the forecast MSLP patterns, averaged over 5, 10 and 15 days. The functions are the zonal and meridional geostrophic wind components, the geostrophic vorticity and the mean pressure. In addition, for temperature, sea surface temperature anomalies upwind and sometimes 500 mb-1000 mb thickness are included in the regression equations. In practice, 500 mb-1000 mb thickness is only predicted by dynamical forecasts and can only be used when these products are available though they can be used routinely.

The mean multiple correlation obtained when the regression equations are tested on dependent data (1951-80) over a 15-day mean period is currently .78 for rainfall and .91 for temperature when thickness, is included. Without thickness the temperature multiple correlation reduces to .77. Rainfall is most closely related to vorticity and mean pressure; for temperature the largest partial correlation is with the 500 mb-1000 mb thickness field.

4.2 Comparison of forecasting methods

Figures 4 and 5 show the skill obtained, measured by time series correlation, when these regression equations are retrospectively applied to (a) the MSLP fields produced by the LRF conferences for a recent 4-year period and (b) to the MSLP and 500 mb-1000 mb thickness fields derived from a set of 48 dynamical forecasts run for the same 4-year period. The dynamical forecasts were produced using the Met O 20 11-level climate model after subtracting estimates of the systematic seasonal error. Figures 4 and 5 also give the skill of the issued temperature and rainfall forecasts.

It can be seen that in all of the forecast periods, except in days 1-5, the best rainfall forecasts were produced by the regressed dynamical forecasts, although the statistical significance of these improvements is difficult to assess because of the different selection of cases. The additional skill of the issued forecasts over the regressed dynamical forecasts for days 1-5 is undoubtedly due to the use of operational medium range products. The differences between the three systems of forecasting are more marked for the temperature forecasts (Figure 5), partly because the dynamical products forecast 500 mb-1000 mb thickness and the statistical products do not. This result alone holds out a clear hope of some modest improvement in forecasting skill in the near future, especially for the period 6-15 days ahead.

4.3 Intrinsic skill of dynamical forecasts

In general, systematic errors develop during dynamical model integrations as the model climate drifts away from the climate of the real atmosphere towards its own internal equilibrium state. The estimate of the systematic error in the forecast MSLP and thickness fields, used in Section 4.2 has been calculated from the same set of 48 forecasts. One important question is therefore whether the skill scores for the dynamical forecasts shown in Figures 4 and 5 are over optimistic, since the estimate of systematic error was not calculated from independent data.

Figure 6 compares the skill of regressed dynamical temperature forecasts derived with and without the systematic MSLP and thickness errors removed. The effect of the systematic MSLP error is clearly negligible. This is an interesting result, since other evidence suggests that the effect of removing the systematic error on the skill of the MSLP forecasts themselves is more marked (Murphy and Dickinson (1988)). A possible reason is that the derived quantities used in the regression equations, such as the direction of the geostrophic wind, are better forecast than is the absolute value of MSLP.

In contrast, the impact of the systematic error in 500 mb-1000 mb thickness on the forecast temperature skill is quite large and its removal appears to be beneficial at all forecast periods. This is because the forecast thickness fields have a large negative bias as illustrated by Figure 7. The cause of this bias appears to be an underestimation of 500 mb height, and may be a result of inaccuracies in the technique used to derive height from values held at model levels. Although this error is unsatisfactory, it is quite clearly systematic and its calculation from dependent data should not lead to too large an overestimation of the forecast temperature skill.

Having reviewed the impact of model systematic error, we can now look at the mean level of predictability we might expect from individual dynamical model integrations. Figure 8 compares the forecast skill for temperature averaged over all forecasts and 10 districts with that of (a) persistence and (b) a measure of random forecast skill, calculated by using temperature forecasts for the same day but different years. This shows that for 10-day mean fields positive skill is maintained out to 20 days and beyond. The equivalent set of graphs for rainfall predictions (not shown) show a slightly reduced level of skill, probably because the regression equations used for rainfall are intrinsically less skilful than those used for temperature where these of course include 500 mb-1000 mb thickness. Nevertheless, these results indicate the potential of dynamical forecasting using a model which, by current medium range forecasting standards, is of relatively low resolution. It also indicates that there may be some additional reward in forecasting for other periods, say days 11-20, once dynamical models become a regular feature of the long range forecasting conference.

4.4 Ensemble forecasting and prediction of skill

As mentioned elsewhere in this paper, the main techniques for exploiting dynamical forecasting at extended range will be based on the analysis of an ensemble of forecasts initialised at successive data times leading up to the first day of the long range forecast period. An example of the technique is discussed by Palmer and Murphy (1986).

Two main features of ensemble forecasting are:

(i) it provides a framework for applying methods for predicting the skill of a set of integrations in advance. Several techniques for relating skill to the spread of the ensemble have been developed (Murphy, 1988). These are based on measures of the statistical significance of the difference between the spread of the ensemble and the variance of the model climate. Other techniques, which measure the extent to which members of the ensemble are correlated with each other, are under development;

(ii) use of the ensemble mean can lead to a significant enhancement in skill when the individual forecasts are themselves skilful. This is demonstrated by Figure 9, which compares the skill, in terms of MSLP anomaly correlation over the UK, of a set of eight 7-member ensembles, where the criterion for a skilful forecast is that the average individual score of an ensemble is greater than zero. Notice that the ensemble mean can sometimes lead to less skilful forecasts as is demonstrated by the set of ensembles where the average individual score is negative.

A priori prediction of skill is a crucial part of the long range forecasting process, since the current levels of skill at extended range are still quite low and variable. Investigations of possible relationships between forecast skill and low frequency atmospheric events or particular flow regimes is an increasing part of the work of the Synoptic Climatology Branch which it is hoped will eventually lead to techniques for identifying "predictable" atmospheric states. Some attempt is already made at the long range forecasting conference to predict the skill of the forecast by assigning a confidence letter varying from A (highest confidence) to E (lowest confidence) which is based on the mutual consistency of the indications from the several forecasting methods used. Confidence classes are currently limited to C, D and E. Figure 10 shows that for all periods, issued C confidence forecasts show a much higher level of skill than all issued forecasts taken as a whole. Significance testing of the monthly scores, done separately for rainfall and temperature, has confirmed that a quite highly significant difference exists between the skill of C forecasts and the skill of D and E forecasts (December 1982-September 1987).

4.5 Statistical forecasting techniques

A revised multivariate forecasting technique is currently being developed. This includes:

(i) a revised set of surface pressure data (removing a recently discovered hemispheric-scale inhomogeneity before and after 1965);
(ii) a revised procedure for selecting past data to be included in the linear discriminant prediction equations;
(iii) some improvements to the sea surface temperature data.

Fairly soon, a more radical revision of the predictor and predicted atmospheric eigenvectors will be incorporated. The existing "principal component" type patterns will be replaced by "varimax" rotated patterns because they appear to be substantially more meaningful in a synoptic sense. The SPEVR technique will be replaced by the new multiple regression version of MVA which could include 500 mb-1000 mb thickness predictions if sufficient effort was available.

Further developments in the objective equations that predict district temperature and rainfall are planned, especially to identify the spatial scale of the surface pressure fields that best relate to the district anomalies. The scales for temperature and rainfall are likely to differ. The effect required for this last step is quite significant.

5. SEASONAL FORECASTS

Substantial effort is being put into a long-term project to explore scientifically the nature of low frequency variability in the tropics and then the extratropics and its predictability on seasonal and longer timescales. The key tools are versions of the 11-level GCM and worldwide sea surface temperatures. Statistical techniques for predicting tropical seasonal rainfall, and also sea surface temperature, for a season ahead are also important. Recent work on the relatively good predictability of interannual variations of rainfall in the Sahel (Folland et al (1986), Owen and Folland (1987), Parker et al (1988)), NE Brazil (Ward et al (1987)) and now the coastal region of Kenya rainfall, indicate the potential of this work in the tropics. Seasonal tropical prediction could be of substantial value not only to the countries concerned but also to the UK-based multi-national companies and financial institutions especially in regions influenced by El Nino. The emerging prospect of skilful predictions of tropical Pacific Ocean temperatures for months ahead using dynamical models of the ocean circulation adds impetus to this approach. Prospects for seasonal prediction in the extratropics are less clear but merit substantial study. Sufficient skill in seasonal tropical and extratropical prediction could be of especial interest in the insurance, futures and agricultural markets. Very recently four skilful dynamical forecasts (hindcasts) were made in Met O 13 for the Sahel for over three months ahead for four separate years (1950, 1958, 1983 and least skilfully 1984) using persistence of the SST anomalies alone (Owen, Folland and Bottomley (1988)).

6. DISCUSSION

The preceding sections have discussed the current state of long range forecasting and Met O 13's plans for the future. Over the next few years there appears to be a distinct possibility of increased skill through the regular use of dynamical forecasts, particularly in the period up to 20 days ahead. Practical application of techniques to predict the skill of forecasts in advance also appears likely. Increasingly difficult decisions about the relative research efforts into dynamical and statistical monthly forecasts for the UK are likely to be needed. Prospects for seasonal forecasting in some parts of the tropics look promising but require substantial effort in modelling and in further development of the sea surface temperature data set. The problem of extratropoical seasonal forecasting is unexplored but the tools exist if staff can be found. A CASE studentship now underway with Lancaster University is expected to make a substantial contribution to work with the sea surface temperature data set that can be applied to the seasonal forecasting problem.

Many of the above plans can only be implemented with a significant increase in computer resources. It is estimated that something like 10 times our current allocation of Cyber 205 time is required to support ensemble forecasting on a 2-weekly basis. This assumes a modest increase in model resolution and a number of supplementary forecasts to provide improved estimates of the nature of the models systematic error. The amount of data produced by the ensemble forecasting technique is large and it will only be possible to fully utilize it in real time through the use of a graphics workstation.

As forecast skill increases and customers become dependent on the forecasts, the status of the UK long range forecasts may need to be raised to a more operational level. This will have an impact on staff resources. Changes to the forecasting system will need to be monitored and checked more thoroughly before being incorporated into the operational suite to prevent errors or failures in the system, staff will have to be on call in case of problems when running the suite, planned annual leave of key members of staff will be affected and there may be a need for working outside normal hours in order to fully prepare for a conference. These points will need serious consideration if long range forecasts are going to become an integral part of the operational products of the Meteorological Office.

REFERENCES

1 Corby, G.A., Gilchrist, A. and Rowntree, P.R. (1977) The United Kingdom Met Office 5-level general circulation model. Methods Comp. Physics, 17, 67-110.

2 Folland, C.K. and Woodcock, A. (1986) Experimental monthly long-range forecasts for the United Kingdom. Pt.I. Description of the forecasting system Met. Mag., 115, pp 301-318.

3 Folland, C.K., Woodcock, A. and Varah, L.D. (1986) Ibid. Pt.II. Skill of the monthly forecasts. Met. Mag., 115, pp 377-395.

4 Folland, C.K. and Varah, L.D. (1988) Probability forecasts of monthly mean temperature and rainfall for the United Kingdom, 1979-1987. To be submitted to J. Clim.

5 Folland, C.K., Palmer, T.N. and Parker, D.E. (1986) Sahel rainfall and worldwide sea temperature 1901-85. Nature, 320, pp 602-607.

6 Gilman, D.L. (1986) Expressing uncertainty in long range forecasts. Namias symposium, Ed: J. Roads, pp 174-187. Scripps Inst. of Oceanography, Ref Series 86-17.

7 Murphy, J.M. (1988) The impact of ensemble forecasts on predictability. To appear in Q.J. Roy. Met. Soc.

8 Murphy, J.M. and Dickinson, A. (1988) Extended range prediction experiments using an 11-level GCM. To appear in Met. and Atmos. Physics.

9 Murphy, J.M. and Palmer, T.N. (1986) Experimental monthly long-range forecasts for the United Kingdom Part III. A real time long range forecast by an ensemble of numerical integrations. Met.Mag., 115, 337-349.

10 Owen, J. and Folland, C.K. (1987) Modelling the influence of sea surface temperatures on Sahel rainfall. Proc. Int. Geog. Union Study Group on Recent Climate Change, Aug 24-27, 1987. Sheffield, England. Ed: S. Gregory Belhaven Press. (in press).

11 Owen, J., Folland, C.K. and Bottomley, M. (1988) Numerical simulations of seasonal Sahel rainfall in four past years using observed sea surface temperatures. LRFC 15, Met Office, Bracknell, England.

12 Parker, D.E., Folland, C.K. and Ward, M.N. (1988) Sea surface temperature anomaly patterns and prediction of seasonal rainfall in the Sahel region of Africa. Ibid (in press).

13 Slingo, A. (1985) Handbook of the Meteorological Office 11-layer atmospheric general circulation model. Volume 1 model description. Dynamical Climatology Tech Note No 29, Met Office, Bracknell, England.

14 Ward, N., Brooks, S. and Folland, C.K. (1988) Predictability of seasonal rainfall in the N. Nordeste region of Brazil. Ibid (in press).

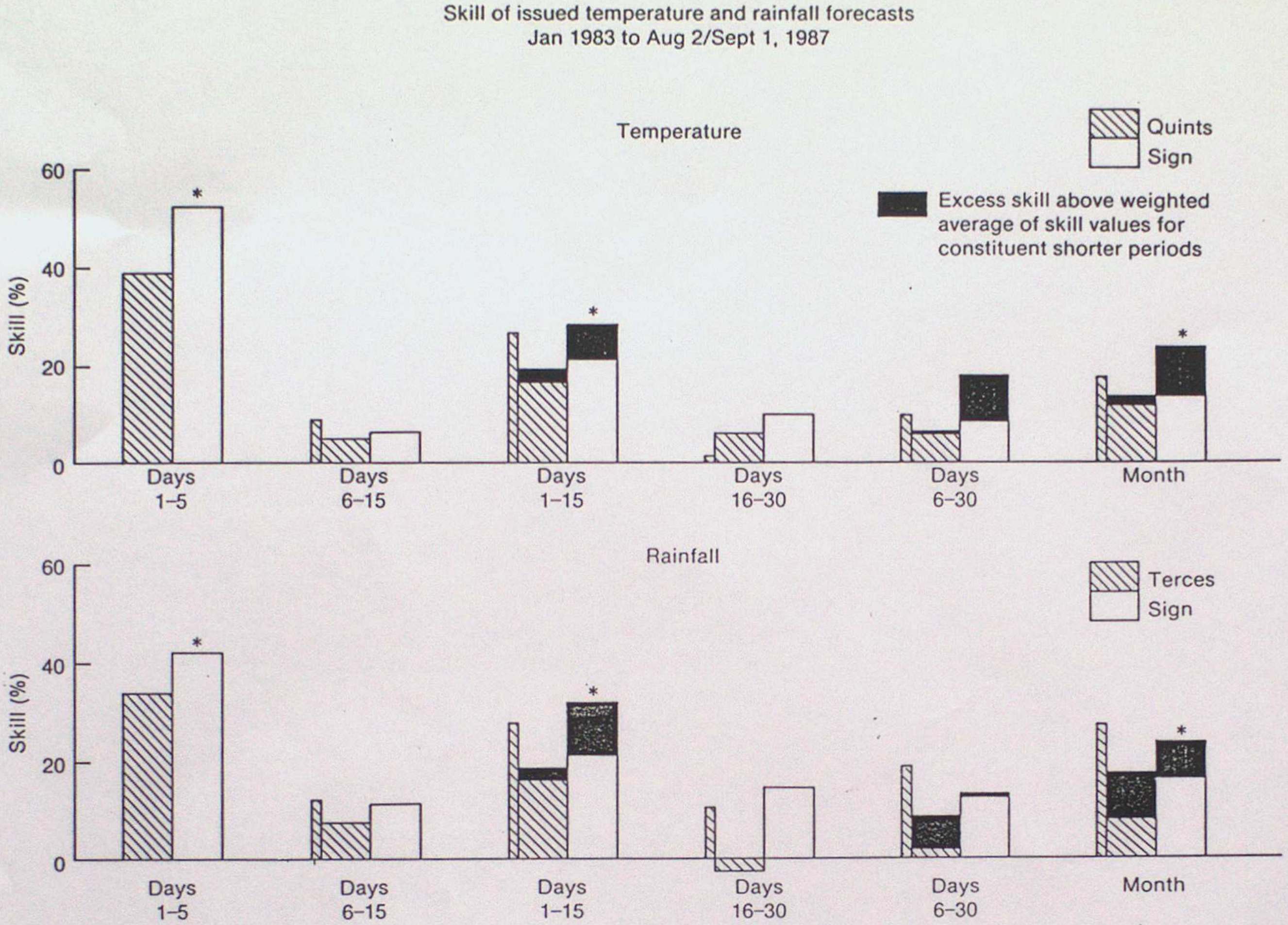

Figure 1. Skill of issued temperature and rainfall forecasts (January 1983 to September 1987).

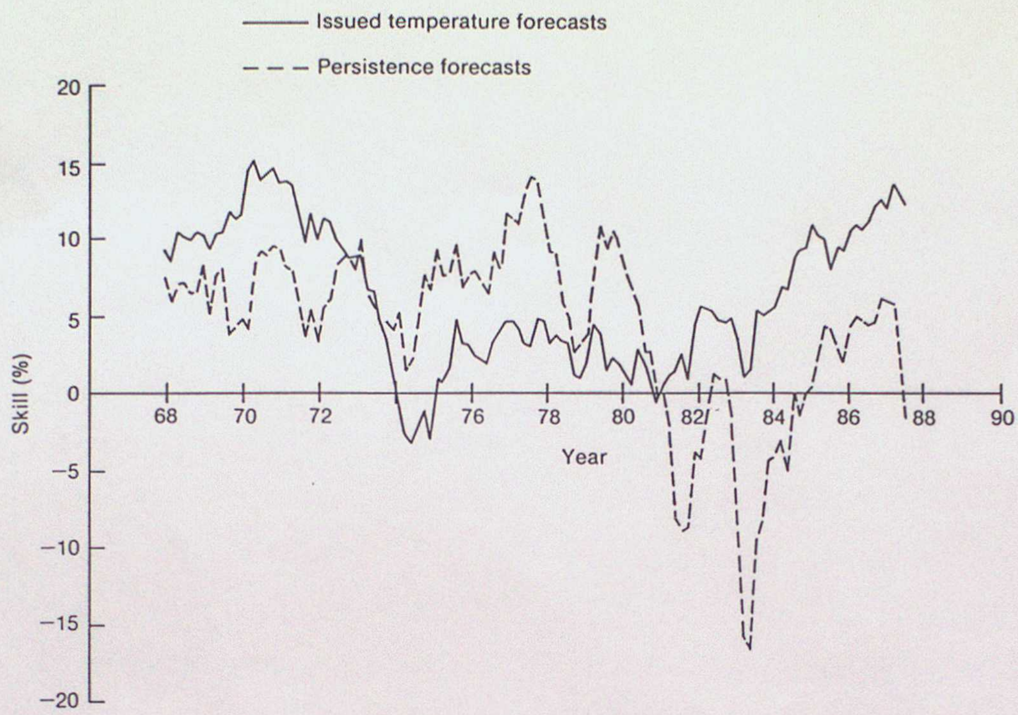

Figure 2a. Four year running mean skill using Folland-Painting score of issued temperature forecasts averaged over the 10 UK districts for days 1-30.

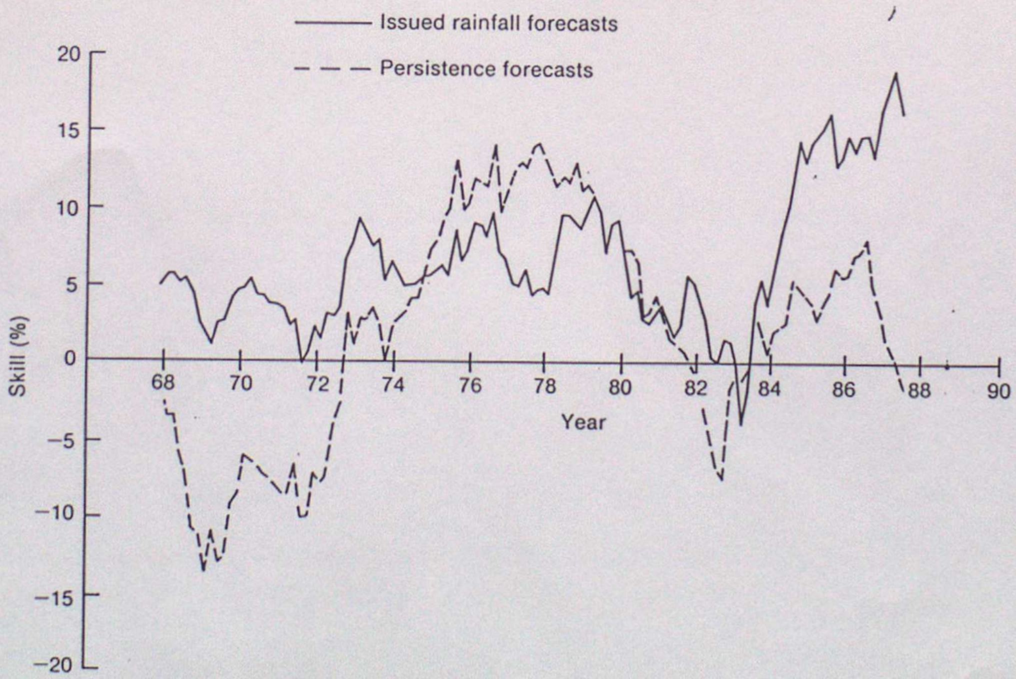

Figure 2b. As figure 2a, but for issued rainfall forecasts.

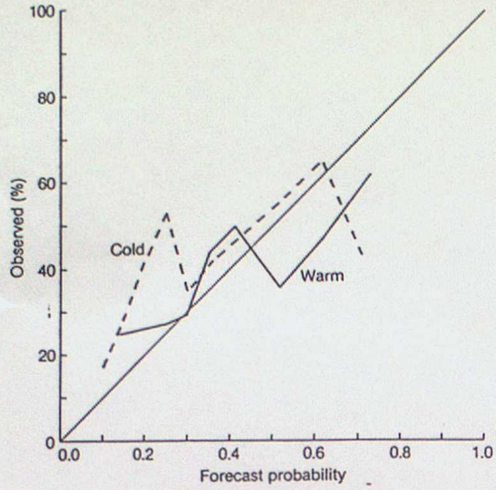

Figure 3a.
Forecast probability allocated to (a) "warm" and (b) "cold" categories versus percentage of outcomes corresponding to these probabilities. Warm is quints 5 and 4 together, cold is quints 1 and 2 together. The thin line is the "ideal" relationship between forecast probabilities and % outcomes.

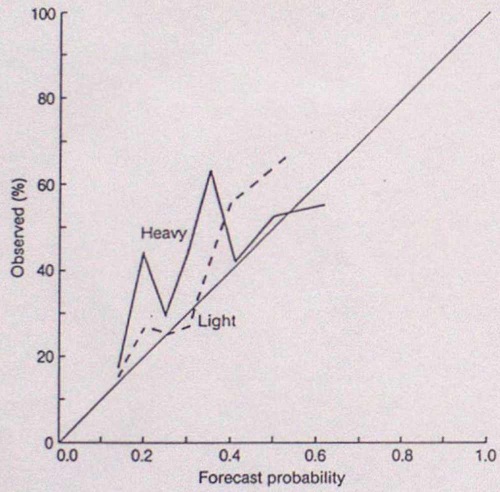

Figure 3b.
As figure 3a, but for (a) heavy rainfall (terce 3) and (b) light rainfall (terce 1).

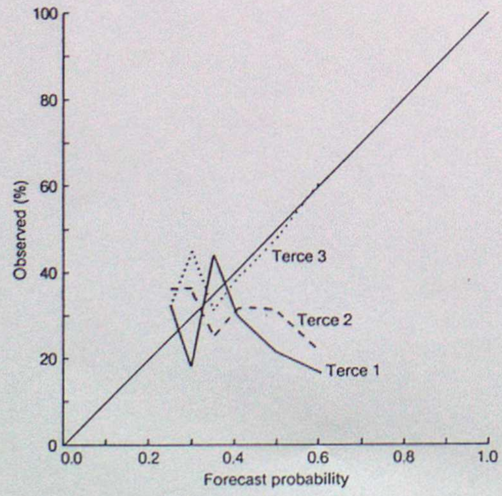

Figure 3c
As figure 3b but for average rainfall (terce 2) (dotted line). Also shown are the percentages of observed categories of terces 3 and 1 for various forecast probabilities of terce 2. The thin line is the "ideal" line for terce 2 outcomes, whereas for terce 1 and terce 3 outcomes the ideal line is parallel to the X axis.

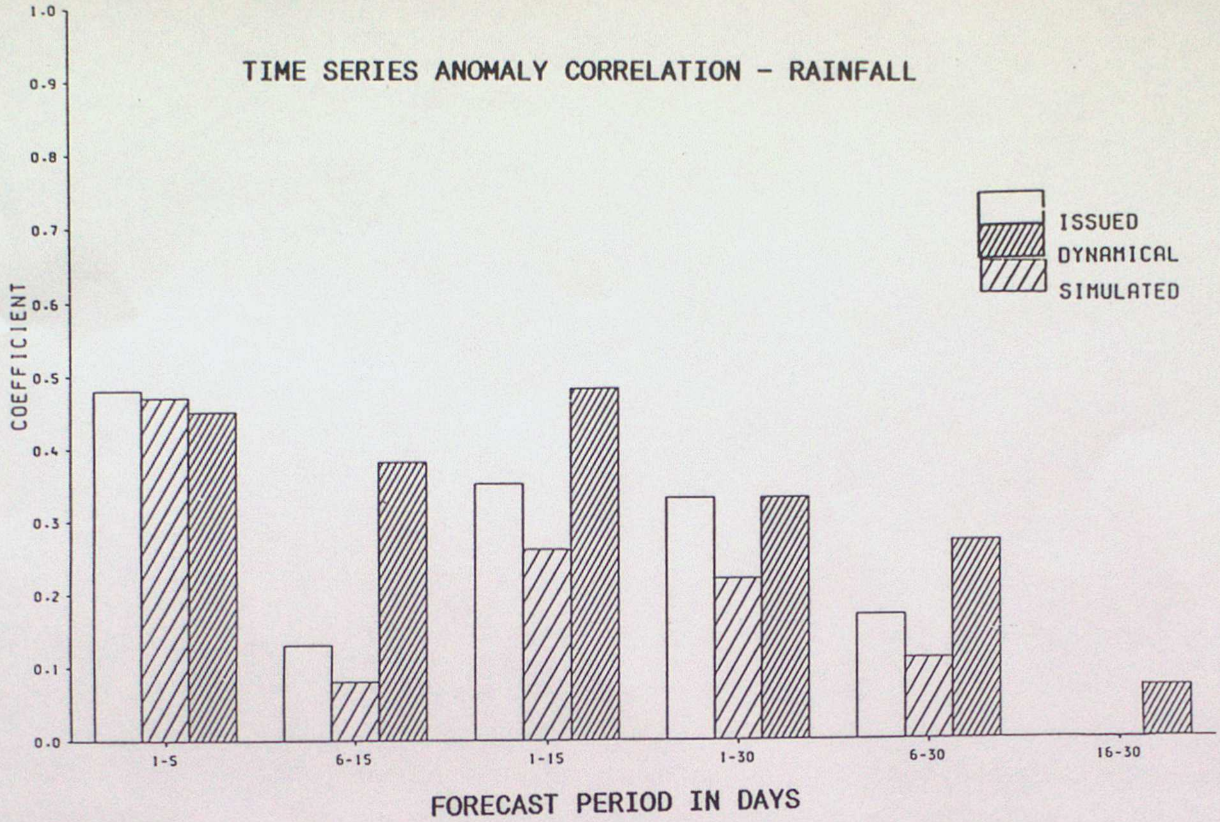

Figure 4. Forecast time series anomaly correlation for rainfall averaged over the 10 UK districts and all forecasts. [ ] As issued at LRF conferences from Feb 1983 - Jan 1987. [////] Applying regression equations to MSLP fields derived at LRF conferences from Feb 1983 - Jan 1987. [////] Applying regression equations to MSLP fields for 48 11-level model forecasts with SE subtracted for initial dates within period Dec 1982 -Jan 1986.

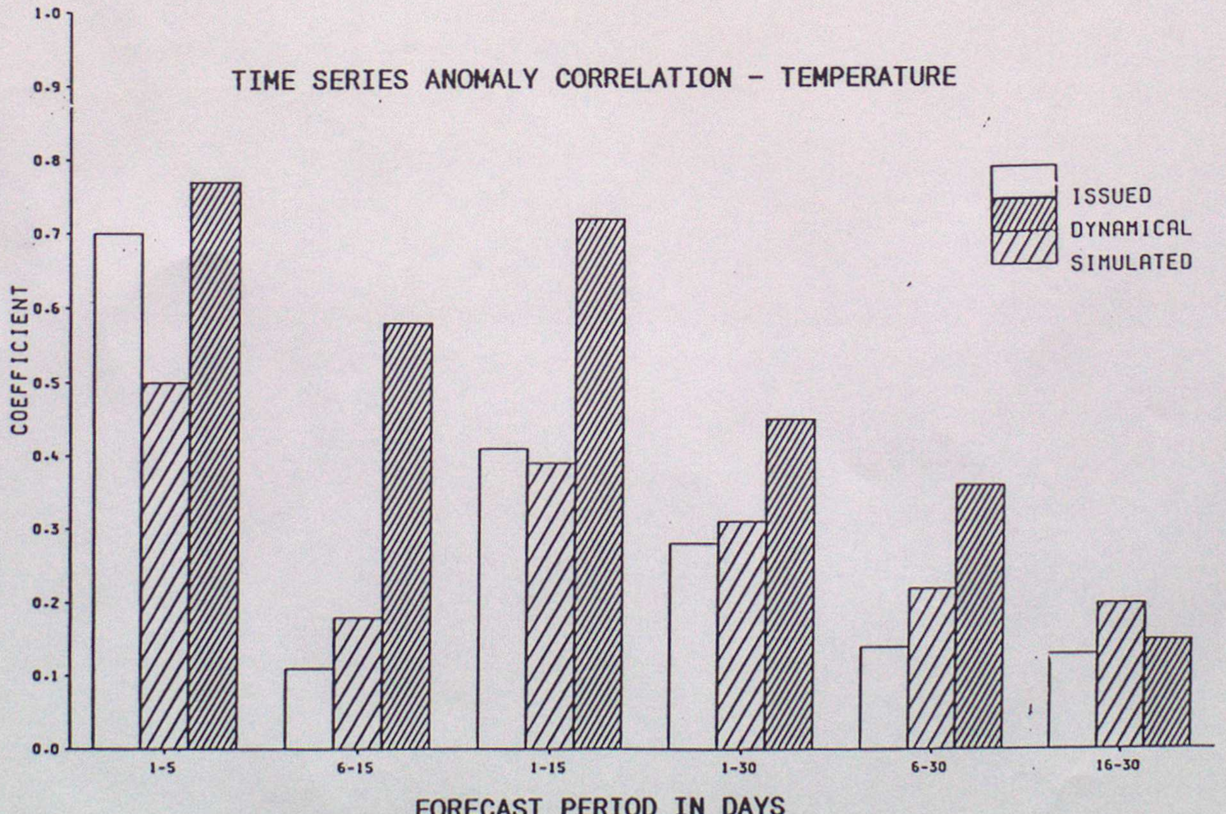

Figure 5. Forecast time series anomaly correlation for temperature averaged over the 10 UK districts and all forecasts. [ ] As issued at LRF conferences from Feb 1983 - Jan 1987. [////] Applying regression equations to MSLP fields derived at LRF conferences from Feb 1983 - Jan 1987. [////] Applying regression equations to MSLP and 1000mb-500mb fields for 48 11-level model forecasts with SE subtracted for intial dates within period Dec 1982 -Jan 1986.

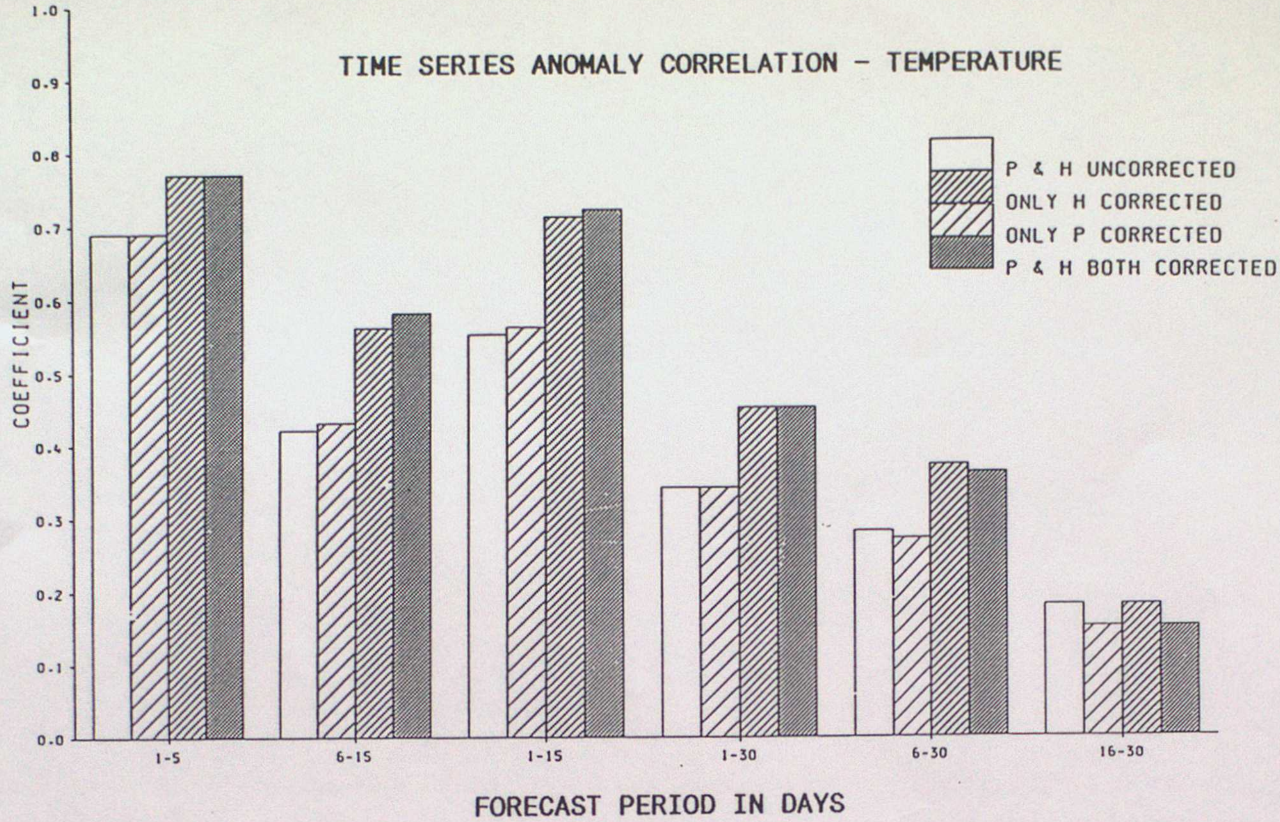

Figure 6. Forecast time series anomaly correlation for temperature averaged over the 10 UK districts and all forecasts. These have been derived by regressing the MSLP and 100mb-500mb thickness fields for 48 11-level model forecasts run from initial dates within the period Dec 1982 - Jan 1986. [ ] No systematic error (SE) removed. [///] MSLP SE removed. [///] Thickness systematic error removed. [■] MSLP and thickness SE removed.

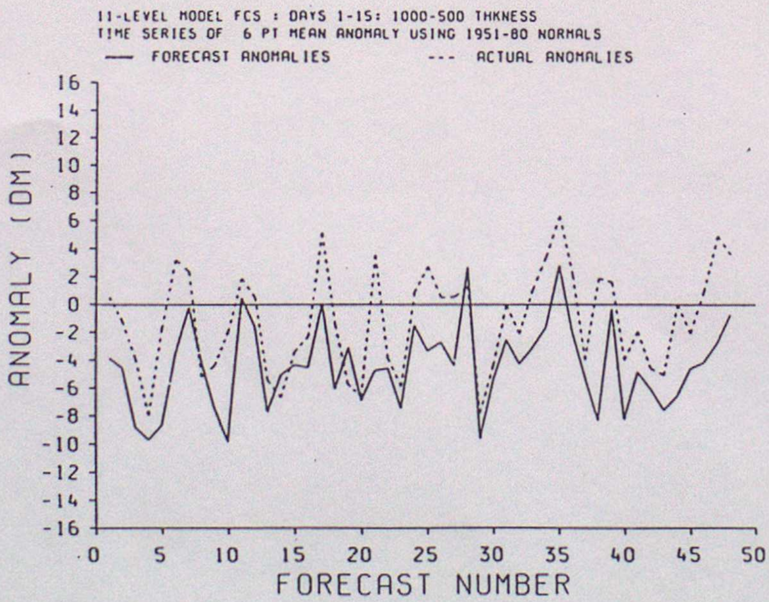

Figure 7. Time series of 15-day mean forecast (____) and observed (----) 1000mb-500mb thickness anomalies. The forecast values are derived from 48 11-level model integrations with no SE removed and are an average of the 6 grid points covering the UK.

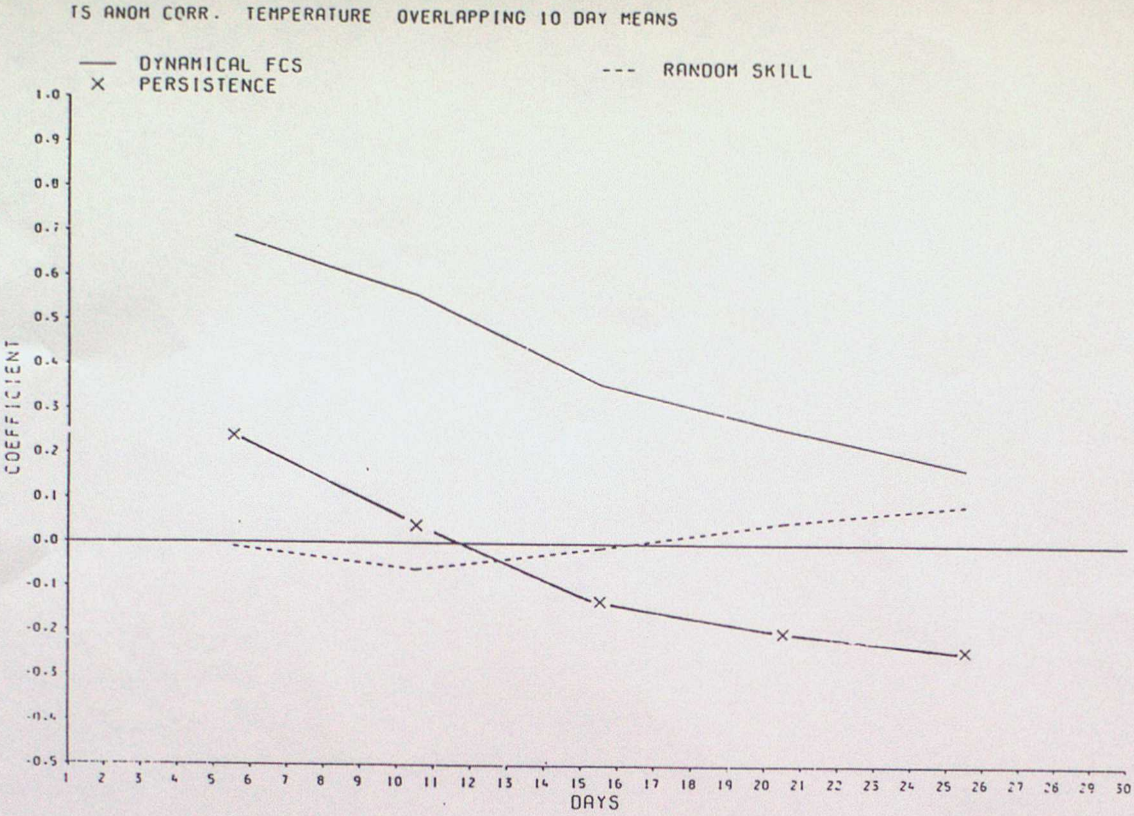

Figure 8. Overlapping 10-day means of forecast temperature averaged over the 10 UK districts as regressed from 48 11-level model forecasts run from initial dates within the period Dec 1982 - Jan 1986. (____) Model forecasts with systematic error removed. (----) Random forecast skill constructed by verifying forecasts for other years but the same season. (-x-x) Persistence.

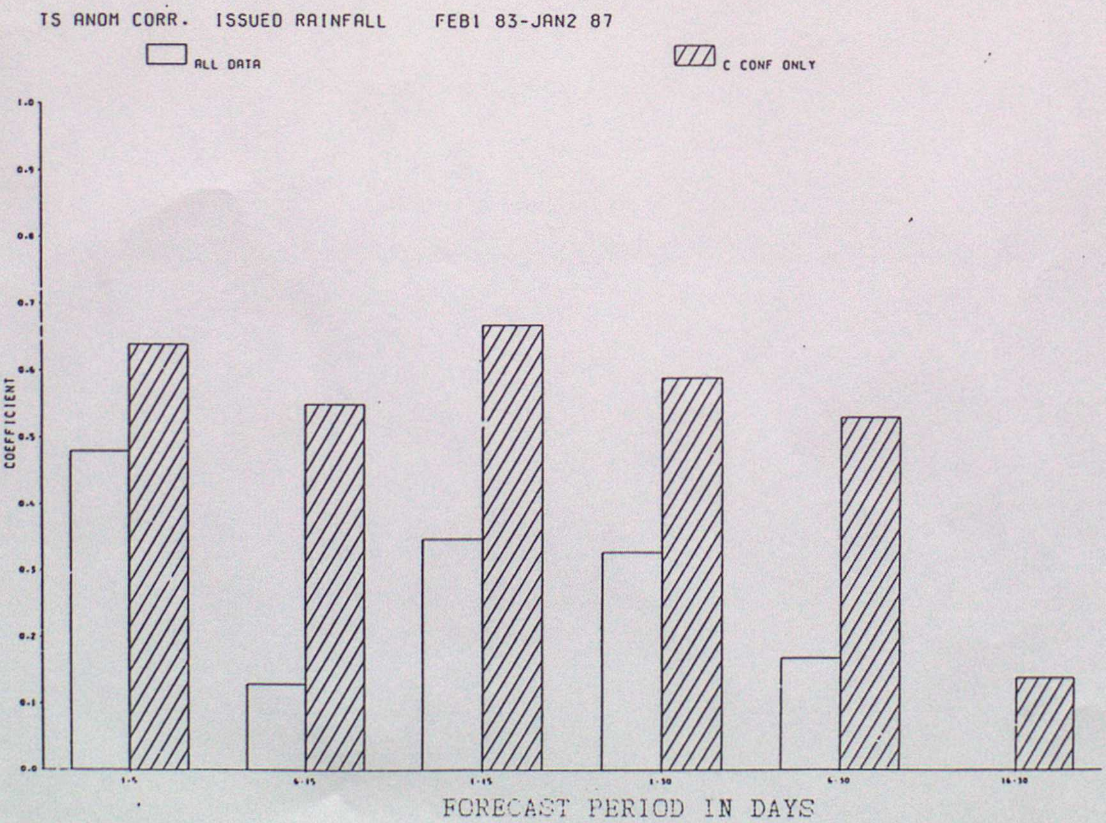

Figure 9. Forecast time series anomaly correlation for rainfall averaged over the 10 UK districts and all forecasts. ☐ as issued at LRF conferences for Feb 1983 - Jan 1987. ▨ Those forecasts between Feb 1983 and Jan 1987 given C confidence markings (22 in all).

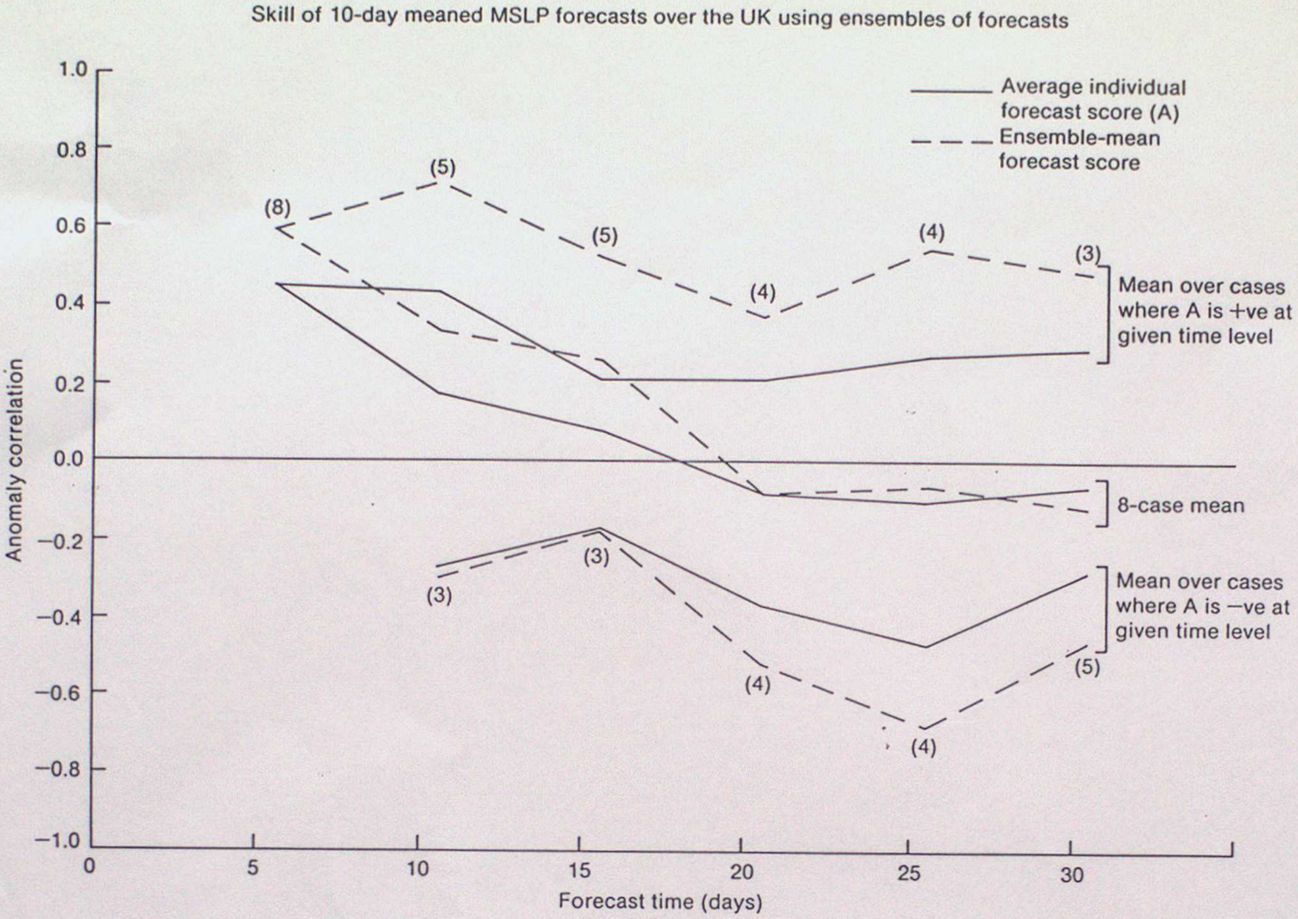

Figure 10. Skill of overlapping 10day mean MSLP forecasts over the UK in terms of anomaly correlation. Results are based on 8 independent sets of ensembles of 7 members each. The values in brackets represent the number of ensembles being considered at each point of the graph.

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