THE USE OF ENSEMBLE FORECASTING TECHNIQUES AT THE UK METEOROLOGICAL OFFICE, NOW AND IN THE FUTURE

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1. INTRODUCTION

The current status of ensemble prediction at the UK Met Office (UKMO) is assessed in this paper, covering both research and forecasting aspects. Options for the future development of ensembles are outlined.

The potential benefit of forming joint ensembles by combining the ECMWF ensembles with ensembles run using the UKMO model is being studied in collaboration with ECMWF. In a detailed study of 38 cases covering Winter 1994/5 the benefit of the joint system over either single model system was demonstrated using a range of diagnostics. Additional ensemble integrations were made for two cases to examine the relative effect of model and analysis differences on the joint ensemble results. The main conclusions of this research are summarised in section 2.

Ensemble products are now becoming an integral part of the medium-range forecast process in the Central Forecast Office. As well as the standard disseminated EPS products a number of tailored products are produced in-house from EPS data to provide the forecasters with additional information.

For the past year, a UKMO working group has been examining all aspects of ensemble prediction from development of forecasting techniques to provision of forecasts to end users. The group has produced a report for UKMO management, and conclusions and recommendations are presented.

2. MULTI-MODEL ENSEMBLES

Medium-range ensemble forecasts are run regularly at the UKMO, initialised from UKMO analyses for 12 UTC every Saturday and Sunday. The initial perturbations are the singular vector perturbations produced daily at ECMWF for their operational Ensemble Prediction System (EPS). A total of 38 cases were run during winter 1994/5, during which formulation of both models and perturbations remained fixed. In spring 1995 both the ECMWF and UKMO models were upgraded and the resolution of the singular vector calculation was increased from T21 to T42. A preliminary analysis of the 50 or so joint ensembles produced since then show similar benefits to those found for the winter cases. The main conclusions from the set of 38 cases are summarised briefly below. A more detailed discussion and further results are presented in Harrison *et al.* (1995).

The skill of the joint ensemble mean is on average greater than that of the single model ensembles for all regions of the northern hemisphere, extending the predictability limit (point where the anomaly correlation falls below 0.6) by around half a day (Figure 1). The spread of the ensemble is also improved within the joint system, so that there is a substantial drop in the number of observations falling outside the ensemble distribution compared to ensembles formed from either single model. If only 16 members are used from each model the benefit to skill is undiminished; the improvement to the spread is reduced compared to the full joint ensemble but is still better than either single-model ensemble.

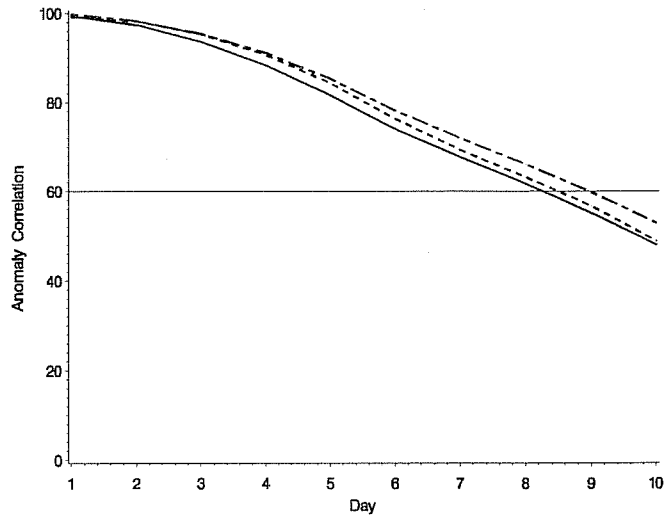

Figure 1. Anomaly correlations (×100) of single-system and joint ensemble means over the Northern Hemisphere: solid - UM, dashed - EC, chained - joint.

Across individual cases a wide range of behaviour was found. On many occasions both systems demonstrated comparable performance (Figure 2a), including examples where both systems failed to capture the observed evolution (Figure 2b). It should be noted that even when forecast quality (e.g. as measured by anomaly correlation scores) is similar, there can be distinct differences between the forecast fields of the two models, and the probability distribution of the joint ensemble may contain improved information over single-system probabilities. The most obvious benefit from the joint ensemble occurs on occasions when one model ensemble performs noticeably better than the other (Figure 2c,d). Either system may be the more successful in a particular case; however the joint ensemble skill is generally close to that of the most skilful system on that occasion.

A number of analyses were carried out for probabilistic predictions of 500hPa anomalies exceeding one standard deviation. All of these indicated improved performance for the combined ensemble. For example, at day 7 the reliability of probability forecasts of anomalies greater than one standard deviation above normal is better overall than that of either single system (Figure 3a). The performance of probabilistic predictions in terms of hit and false alarm rates can be illustrated using the relative operating characteristic (see Harrison et al., 1995 for details). Again the joint ensemble performs better in general than the single systems (Figure 3b for day 7 anomalies one standard

deviation above normal).

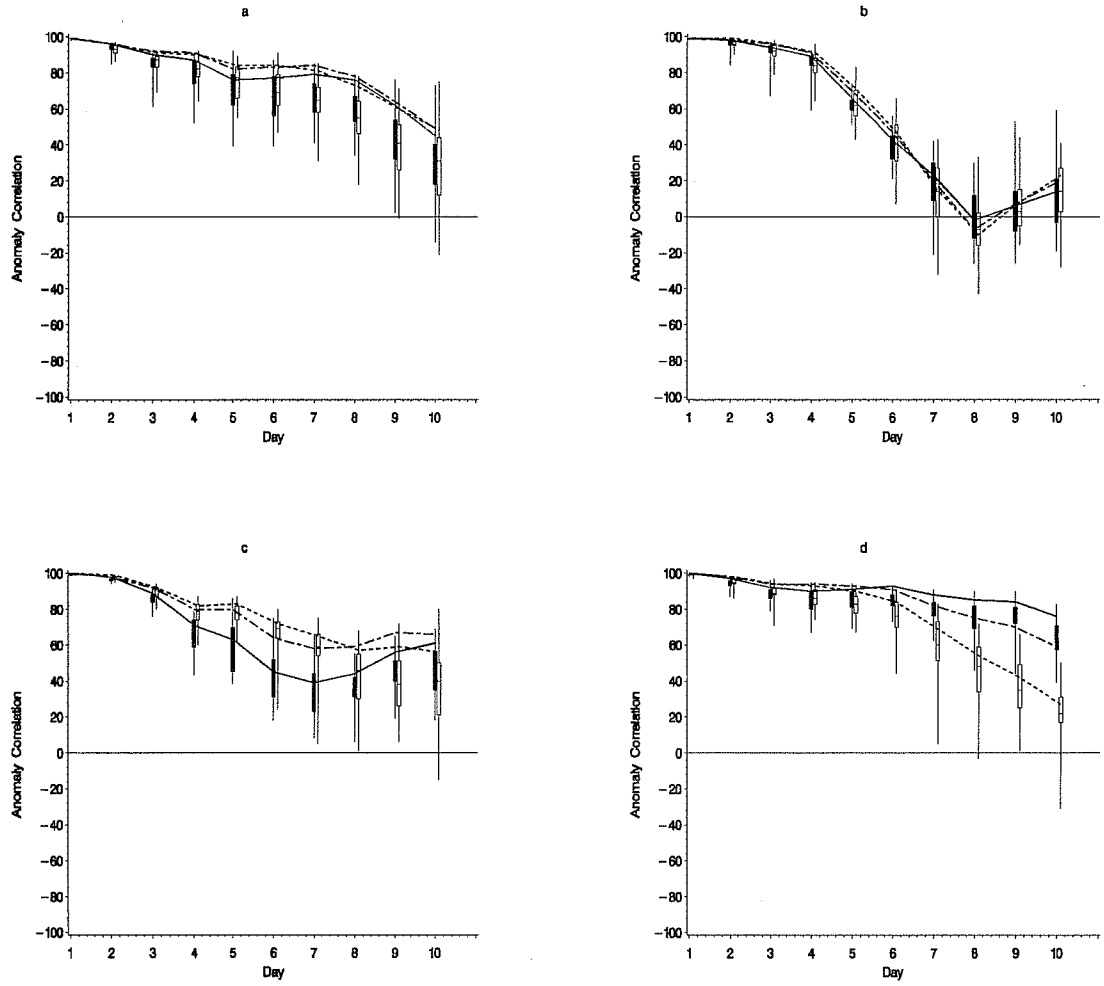

Figure 2. Examples of anomaly correlations over the north Atlantic/Europe for ensembles initialised on individual days: a) 18 December 1994; b) 25 December 1994; c) 17 December 1994; d) 27 November 1994. Box and whisker plots indicate medians, quartiles and ranges for UM (solid) and EC (open). Lines are for ensemble means: solid - UM, dashed - EC, chained -joint.

The relative effect of model and analysis differences was examined in two cases for which 'hybrid' ensembles were constructed by running each model initialised from the other centre's analysis. In these two cases it was found that both model and analysis differences affected the predictions. The relative effect of the two differences varied both geographically and with forecast range. Clear differences in skill due to both model and analysis differences were found for different regions (Figure 4). More detailed analysis of these 'hybrid' ensembles clearly demonstrates that overall the model

differences had the greater effect (Harrison et al., 1995).

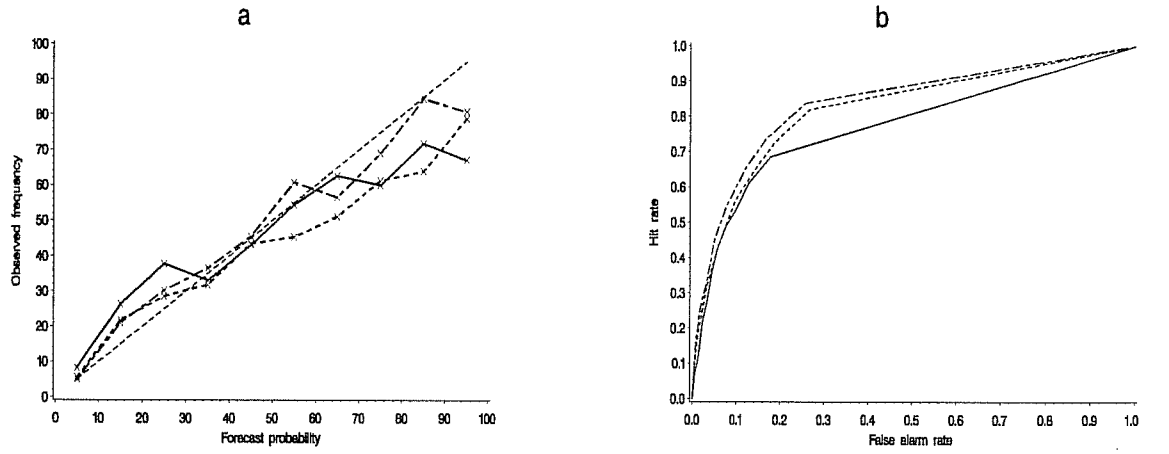

Figure 3. (a) reliability and (b) relative operating characteristic curves at day 7 for predictions of positive 500 hPa height anomalies exceeding 1 standard deviation. Solid line - UM; dashed line - EC; chain dashed line - joint; diagonal dashed line - perfect reliability.

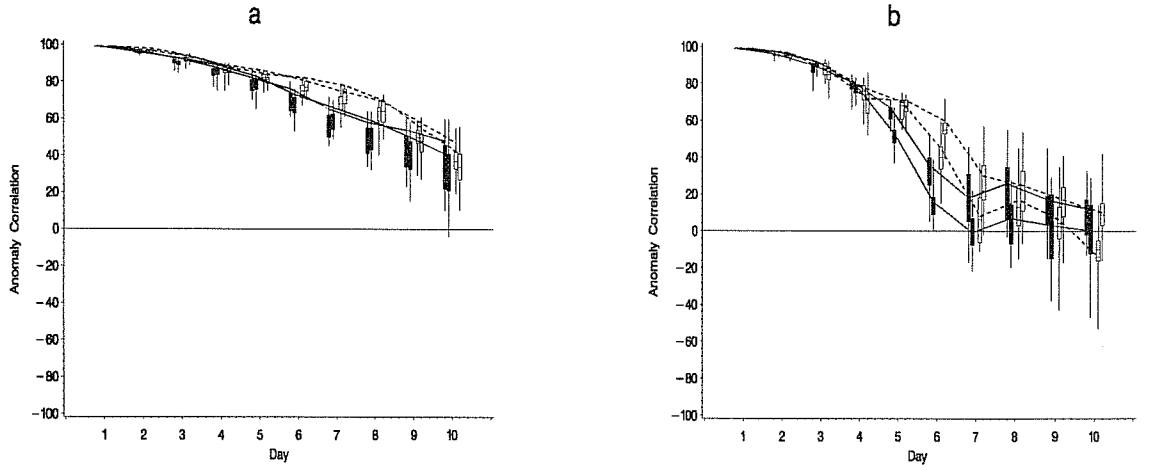

Figure 4. Distributions of anomaly correlations for the 'hybrid' ensembles initialised on 18 December 1994. Box and whisker plots indicate medians, quartiles and ranges for UM (filled) and EC (open) ensembles. The central two boxes are from the ECMWF analysis, the outer two from the UKMO analysis. Lines are for ensemble means: solid - UM, dashed - EC. a) Northern Hemisphere; b) Asia 40°E to 160°E.

3. OPERATIONAL USE OF ENSEMBLE PRODUCTS

At present UKMO ensembles are not produced in real time and so are not available to forecasters. However, data from the ECMWF EPS is provided to the Central Forecast Office (CFO). Forecasters receive the standard fax charts issued by ECMWF together with charts produced from the disseminated products (cluster charts, etc.). In addition, a number of ensemble fields are retrieved by UKMO from the MARS archive as soon as they become available. Retrieval of these extra data allow further processing at UKMO, and several additional products are provided to CFO. Processing of the data at UKMO allows production of products tailored to the requirements of the CFO medium-range forecasters. The ability to hold the raw data on line potentially allows the forecaster to examine the ensemble interactively and gain a much greater understanding of the variety of information contained within the ensemble than is possible with a fixed set of charts (interactive facilities are being developed within UKMO, but are not yet available in CFO). At present northern hemispheric fields of sea-level pressure and 500 hPa height are retrieved for each ensemble member every 12 hours out to forecast day 10. Among the charts produced are sequences (every 12 hours) of charts of the ensemble mean and of probability of 1000-500 hPa thickness being below 528 dam (an indicator, in the UK, for snow). Currently the threshold is fixed, but this can easily be changed. An interactive display would give greater flexibility by allowing the forecaster to select any threshold.

All ensemble products are available to CFO only and are not supplied to other forecast offices. The EPS has now become the main basis of the 6-10 day forecast guidance issued by CFO. Currently the main guidance is provided in deterministic form and the starting point for the forecast is the ensemble mean. In some cases of high spread the ensemble mean is clearly not appropriate and an alternative forecast perhaps based on a cluster mean must be chosen. Forecasters' experience is that the ensemble mean is more skilful at this range than the single high resolution operational run.

Forecasters have also been undertaking a trial of probability forecasts using input from the ensemble. Expression of the forecast in probabilistic terms is the most natural way to present the information from the ensemble, explicitly recognising the inherent uncertainty in medium-range prediction. A reliable probability forecast will also be more valuable than a deterministic prediction in which an unjustified certainty in the outcome is implied.

4. UKMO WORKING GROUP CONCLUSIONS AND RECOMMENDATIONS

The Working Group for the Development and Use of Ensemble Forecasting (WGDEF) was set up within the UKMO to consider all aspects of ensemble prediction from development of forecasting

techniques to provision of forecasts to end users. The aim was to produce a report to senior management recommending actions needed to allow full advantage to be taken of the availability of ensemble forecasts, focusing on the medium range. Members of WGDEF were drawn from across the Office, representing research, operations, forecasting, training and business interests.

The main conclusions from WGDEF are summarised below. Based on research results and on forecaster experience, WGDEF concluded that substantial benefits to forecasting are provided by use of ensembles. Used deterministically the ensemble has improved skill over single integrations (even of higher spatial resolution) in the medium range. Additionally, the ensemble provides useful information on possible alternative developments and can be used as the basis for probability forecasts, which provide more information than equivalent deterministic predictions. The introduction of ensemble forecasts allows both an increase in the number of skilful forecast products available in the medium range and an opportunity to provide increased automation of forecasts.

Research on the relationship between ensemble spread and forecast skill has so far been inconclusive and the operational prediction of forecast skill is not yet fully feasible. Current clustering techniques do not adequately capture the significant meteorological differences within the ensemble and more work on clustering is necessary if this is to be used in practice.

An important aspect to recognise is that the use of ensembles introduces new perspectives into forecasting and imposes a change in culture on the forecaster. Education for all those involved, from forecaster to end user, is an essential requirement for the successful introduction of ensembles. The operational implementation of ensemble forecasts in the UKMO will require a substantial increase in resources; however the potential benefits fully justify this initial investment.

WGDEF's main recommendation was to make ensemble forecasts operational at UKMO. To achieve this successfully, WGDEF recommended the introduction of an education programme for forecasters, sales and marketing staff, and customers. More work is also needed to determine how best to present probabilistic information to users. Finally, WGDEF recommended that operational ensembles should be extended to cover other time ranges.

5. FUTURE PLANS

A number of cases studies are being prepared in collaboration with ECMWF to examine the effects of having more ensemble members and/or increasing the resolution of the forecast

model used for the ensemble predictions. For these case studies the UKMO model will be run at operational resolution, the first time that ensembles will be available using exactly the same model configuration as is currently used in the Central Forecast Office. As in the previous studies, the benefits of using the multi-model approach will be assessed and 'hybrid' ensembles will be used to examine the model and analysis effects.

A number of new fields will be retrieved from the EPS MARS archive and processed at UKMO to provide additional information to forecasters. Initially rainfall and 850 hPa temperature are being added; visualisation will include charts of probabilities of these parameters exceeding various threshold values. Development of interactive displays of ensemble information will continue. The WGDEF recommendation to implement ensemble forecasts operationally in the medium range is now under consideration by management. A project to implement this proposal may be set up during the coming year.

6. REFERENCE

Harrison, M.S.J., T.N. Palmer, D.S. Richardson, R. Buizza, T. Petroliagis, 1995: Joint ensembles from the UKMO and ECMWF models. Proceedings of the 1995 ECMWF Seminar on Predictability, 4-8 September 1995, ECMWF.