Development Plans for the ECMWF Ensemble Prediction System

by

T.N.Palmer, J. Barkmeijer, R.Buizza, D. Richardson

ECMWF

Below are briefly summarised plans for the development of the ECMWF Ensemble Prediction System (EPS), focussing mainly for the period 2000-2001.

1. INTRODUCTION

The EPS has become an established and integral part of the ECMWF operational forecast system. The EPS recognises the inevitable uncertainty that exists, both in the initial state, and in the model equations themselves, and provides flow-dependent probability forecasts of relevant meteorological variables, for the medium range. As such, the ensemble system necessarily benefits from development in the operational model, and in the data assimilation system. Below developments that relate specifically to changes to the operational EPS itself are outlined, focussing on the period 2000-2001.

2. DEVELOPMENTS

2.1 Reduced-rank Kalman filter singular vectors for initial perturbations

Ever since its inception, the EPS initial perturbations have been based on the dominant singular vectors of the short-range forecast flow. The philosophy underlying this can be summarised briefly (though see, for example, Palmer, 2000). For a probability forecast system to be useful, it must have "resolution", that is to say, there must be sufficient circumstances where ensemble dispersion is reasonably small. On such occasions, deterministic forecasts should be reasonably reliable. On the other hand, there are many unquantified uncertainties in the process of data assimilation, and it is therefore difficult to determine reliably a probability density function (pdf) associated with error in the initial state. In addition, with an ensemble size that is very much smaller than the dimension of phase space, small ensemble dispersion may not be a reliable indication of forecast quality, but rather an indication of an inadequate sampling of a poorly known pdf. To overcome uncertainty in sampling, a "conservative" strategy has been adopted whereby initial perturbations project onto the dominant finite-time instabilities (singular vectors) of the flow.

On the other hand, it is necessary to ensure that these singular vector perturbations are not inconsistent with possible analysis error. A sophisticated but practical methodology to ensure this has been developed at ECMWF, it is known as the reduced-rank Kalman filter

(RRKF; Fisher and Courtier, 1995). Essentially the analysis error covariance matrix is given by the (inverse) Hessian, or second derivative, of the cost function of variational data assimilation. In conventional 3D and 4D var, the background error covariance matrix is not flow dependent. In RRKF, the background is propagated in time, in the space of dominant singular vectors. Conversely, the inner product on the space of dominant singular vectors is defined by the time-propagated analysis error covariance matrix. This synergistic approach means that the RRKF is able both to define a more accurate initial analysis for the deterministic forecasts, and to give a set of singular vector perturbations that are more consistent with our knowledge of analysis error.

Initial results using the RRKF, both in terms of deterministic forecast scores, and EPS scores are very encouraging. It is therefore likely that the RRKF will be implemented operationally within the period 2000-2001.

2.2 High resolution EPS vs larger ensemble size

A number of ensemble integrations have been studied comparing the effect of higher horizontal resolution (TL255) against larger ensemble size (100 members). For users requiring reliable low-probability forecasts (eg when their cost/loss ratio is small, so that default action is always to take precautionary action), then there is demonstrable benefit in doubling the size of the ensemble. On the other hand, forecasts of intense rainfall amounts are undoubtedly improved by running with higher resolution, and, on balance the benefits of higher horizontal resolution appear to outweigh the benefit of higher ensemble size. As a result, it is planned in the second half of 2000 to increase EPS resolution to TL255. An increase in effective ensemble size may occur in the following year by running from twice-daily analyses.

2.3 Addition of tropical singular vectors to EPS.

With the introduction of diabatic processes in the forward and adjoint tangent models, it is possible to determine singular vectors for situations where diabatic physics may be important in producing perturbation growth. Difficulties that arise in computing tropical singular vectors are associated with spurious upper-tropospheric perturbation growth which arise from inertially-unstable basic states. Their effect can be minimised by targeting onto the lower troposphere. The dominant targeted singular vectors for tropical cyclones show resemblance to fast-growing structures found for idealized vortices (Barkmeijer et al, 2000).

In the past year, a detailed study of ensembles of tropical cyclone tracks has been performed (Puri et al, 2000). Results have shown that adequate spread in the cyclone tracks can only be achieved using targeted diabatic singular vectors. Inclusion of stochastic physics generates a realistic spread in the depth of the tropical cyclone. It is planned to implement initial perturbations in the tropics into the EPS using diabatic singular vectors, targeted on individual ocean basins.

2.4 Multi-centre ensembles

The performance of the EPS has been compared with that of a number of alternative configurations which incorporate information from additional analyses or an additional model or both (Richardson, 2000). Each configuration is approximately equivalent in size, resolution and computational cost and could therefore in principle provide an alternative operational EPS. A multi-centre ensemble system (MC EPS) was constructed by replacing half of the EC EPS with integrations of the UK Meteorological Office (UKMO) model perturbed about the UKMO analysis. Two additional configurations are constructed using the ECMWF model only, but adding information available from four other operational analyses. A "consensus" ensemble (CONS EPS) is generated by adding the operational EC EPS perturbations to the mean of the available analyses (the consensus analysis); a multi-analysis ensemble (MA EPS) is generated by combining smaller ensembles of EC model integrations perturbed about each of the available operational analyses. The different systems are compared over a large sample of 60 cases covering the period October 1998 to July 1999.

Without correcting for model bias, for 500 hPa height the MC EPS is consistently the most skilful configuration, but for 850 hPa temperature the MC and MA systems are equivalent. The CONS EPS is generally less skilful than the other two alternatives. The benefit of the MC EPS over the MA EPS for 500 hPa height can be attributed to the combination of different models within the MC EPS. However, it is shown that application of a simple bias correction to the ensemble members removes the advantage of the MC EPS. It is also noted that, by construction, the MC and MA systems have larger initial spread than the EC and CONS configurations. It is demonstrated that increasing the amplitude of the initial perturbations of the CONS EPS improves the performance of this configuration to be comparable to the MC and MA systems. It is concluded that the benefit of a MC EPS can be realised using a single-model EPS incorporating information from additional operational analyses (provided that the issue of model bias is addressed), thus avoiding the technical difficulties of maintaining more than one model in an operational EPS.

2.5 A random walk approach to stochastic physics

The scheme implemented to simulate random model errors (Buizza et al, 1999) has been modified to be able to simulate model errors with two different spatial and temporal scales. More specifically, in the new scheme model tendencies due to paranetrized physical tendencies are perturbed by two stochastic terms. Each term includes a time auto-correlation term (Markov chain). A check has been introduced to limit the maximum value of the ralative change of the model tendencies to 100% (this term is now necessary in case of a non-zero time auto-correlation term).

The first term is characetrized by a small spatial scale (7.5 degrees), a short time scale (random numbers are re-sampled every 6 hours), a small autocorrelation (Tcorr=0.5) and a large amplitude (A=0.5). This term should simulate large (up to 50% in amplitude), small-scale errors. It can also thought as a way to simulate sub-grid scale uncertainty.

The second term is characetrized by a large scale (22.5x15 degree), a long time scale (24 hours), a high autocorrelation (Tcorr=0.95) and a small amplitude (0.1). This term should simulate small (up to 10% in amplitude), large-scale errors.

The new scheme has been applied to single deterministic forecast. Preliminary results obtained for January 1999 have indicated that the new scheme is more capable of simulating large-scale, systematic model errors. Experimentation is under way to test the impact of the new scheme in the EPS.

2.6 Use of higher resolution singular vectors.

At present the singular vector computations are performed at T42 resolution. With the development of the semi-Lagrangian version of the tangent model, tests will be performed assessing the impact of higher resolution singular vector computations.

References

Barkmeijer, J., K. Puri, T.N. Palmer, R. Buizza and J.-F Mahfouf, 2000: Diabatic singular vectors and tropical cyclone ensemble forecasting. Q.J.R.Meteorol.Soc. submitted.

Buizza, R., M.J.Miller and T.N.Palmer, 1999: Stochastic simulation of model uncertainties in the ECMWF ensemble prediction system. Q.J.Meteorol.Soc., 125, 2887-2908.

Fisher, M. and P. Courtier, 1995: Estimating the covariance matrices of analysis and forecast error in variational data assimilation. ECMWF Technical Memorandum No 220. ECMWF, Shinfield Park, Reading RG2 9AX, UK.

Palmer, T.N., 2000: Predicting uncertainty in forecasts of weather and climate. Rep.Prog.Phys., 62, 1-47.

Puri, K., J. Barkmeijer and T.N.Palmer, 2000: Ensemble prediction of tropical cyclones using targeted singular vectors. Q.J.R.Meteor.Soc., submitted.

Richardson, D.S., 2000: Ensembles using multiple models and analyses. Q. J. R. Meteorol. Soc.