LAGGED AVERAGE FORECASTS AND MONTE CARLO EXPERIMENTAL FORECASTS AT NMC

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1. INTRODUCTION

It is clear now that beyond medium range forecasting, single deterministic forecasts are not appropriate (see *Boyer*, 1991 for a comprehensive review of recent research in this area). At NMC, this has been recognized in the plans for the forthcoming supercomputer which should arrive in 1993: the highest resolution global model will be run for detailed daily aviation and medium range forecasting purposes (3 and 7 days respectively), and beyond a week, ensembles of T62 forecasts from a T62 analysis cycle will be performed.

In this paper we briefly review the status of several research projects ongoing at NMC, aimed at the development of an efficient method of ensemble forecasting that could become operational in 1993. Two of the purposes of ensemble forecasting, both Monte Carlo and Lagged Average (or Lagged Analysis) Forecasting, are to improve the skill of the forecast, and to predict its skill to the extent possible. In addition, the ensemble of forecasts should be useful as a basis for the formulation of probabilistic forecasts, but in this paper we will not address this third application. Section 2 has a discussion of the advantages of LAF vs MC and a simple new variation on LAF, Section 3 a review of the status of the quasi-operational scheme to predict medium range forecast skill, and in the main new section 4, preliminary results of a new type of efficient method for the selection of MC members.

2. MONTE CARLO AND LAGGED AVERAGE FORECASTING

The choice of initial perturbations for ensemble forecasting is of utmost importance for both improving the forecast and predicting its skill. A truly random MC selection will provide no relationship between forecast spread and error at short range, because the perturbations are random (*Barker*, 1991). Moreover, too many ensemble members will be needed to filter the unreliable components of the forecast through ensemble averaging. This has led to several efforts to find optimal perturbations from the fastest growing eigenmodes of the model (e.g., *Molteni*, 1991, *Mureau*, 1991, this volume, *Tribbia*, pers. comm.). An alternative efficient method to select "promising" fast growing MC perturbations is offered in section 4.

LAF (*Hoffman and Kalnay*, 1983), on the other hand, is a simple method to produce realistic perturbations obtained as short range forecast errors, and therefore represent actively growing error modes corresponding to the "flow of the day". A disadvantage of LAF, compared to MC, is that the perturbations are not of similar size, with those corresponding to "older" forecasts being too large. This naturally limits the size of the ensemble, unless the members of the ensemble are carefully weighted (*Dalcher et al*, 1987). A simple modification of LAF to eliminate this problem was suggested and tested with excellent results by *Ebisuzaki and Kalnay* (1991). In this method, 8 short range forecasts of length 6, 12,..., 48 hours, verifying at the latest analysis time, are linearly combined with the latest analysis, in order to create 8 forecasts with the same (6 hours) "equivalent age". For example, the 12 hour old forecast is averaged with the latest analysis, the 18 hour old forecast is combined with the analysis with weights of 1/3-2/3, etc. In addition, the perturbations equivalent to a 6-hour forecast can also be used with their opposite sign, thus obtaining sets of 16 perturbed initial conditions, in addition to the control forecast from the latest analysis.

In every one of the 5 ensemble average forecasts that were tested, the modified LAF was better than the control even at 12 hours, whereas with conventional LAF methods, the errors of the older forecasts make the LAF forecast inferior to the control for the first few days. Ebisuzaki (personal communication) also obtained a good relationship between forecast agreement and skill at least for the first five days.

A similar result should be obtained by combining older analyses with the current analysis so as to construct "equivalent age" analyses (*Kalnay*, 1990). For example, to create a set of lagged analyses equivalent to six-hour old analyses, the 12-hour old analysis is averaged with the 0-hour analysis with equal weights, the 18-hour old analysis is averaged using weights of 1/3, 2/3, etc. In addition, the perturbations obtained in this way can also be used with a negative sign, equivalent to an extrapolation of the analyses 6 hours into the future.

3. FORECAST OF THE SKILL USING OPERATIONAL MODELS FROM MULTIPLE CENTERS

A "poor person" Monte Carlo method for forecasting the skill is being tested in a quasi-operational mode at NMC (*Wobus and Kalnay*, 1991, *Kalnay and Ham*, 1989, *McCalla and Kalnay*, 1988). The main predictor for the NMC medium range forecast (MRF) is the forecast agreement between the MRF and an ensemble of 4 additional operational forecasts produced from 12 hour older initial conditions: the global forecasts from ECMWF, UKMO, JMA, and an average of the MRF and the previous day MRF. This predictor is combined, by means of multiple regression based on the last 60 days of data, with two other potential predictors, forecast persistence and rms amplitude of the anomaly. Based on the 60 day training period, forecast agreement is chosen as a prediction 100% of the time over Europe and North America, whereas the other two predictors are chosen only about 40% and 60% of the cases respectively. The output is the predicted evolution of the MRF anomaly correlation (AC) for 0.5-5.5 day forecasts (and its expected error), for regions of 60° longitude and 30° longitude. Regional anomaly correlations are more sensitive to forecast errors in synoptic scales than hemispheric AC, which are dominated by planetary waves. Fig. 1 presents the last 3 months (July, August and September 1991) of predicted and observed AC for the 5.5 day forecast over "North America" and "Europe". The results for the previous year are presented in *Wobus and Kalnay (1991)*. Additional predictors of the skill for this range of forecasts, including regime and regional baroclinic instability indexes, were tested but not found skillfull (*Kalnay and Ham*, 1989). However, other predictors may be added based on the results of the experiments of next section. The prediction of the skill of the 6-10 day average forecast is now under preparation.

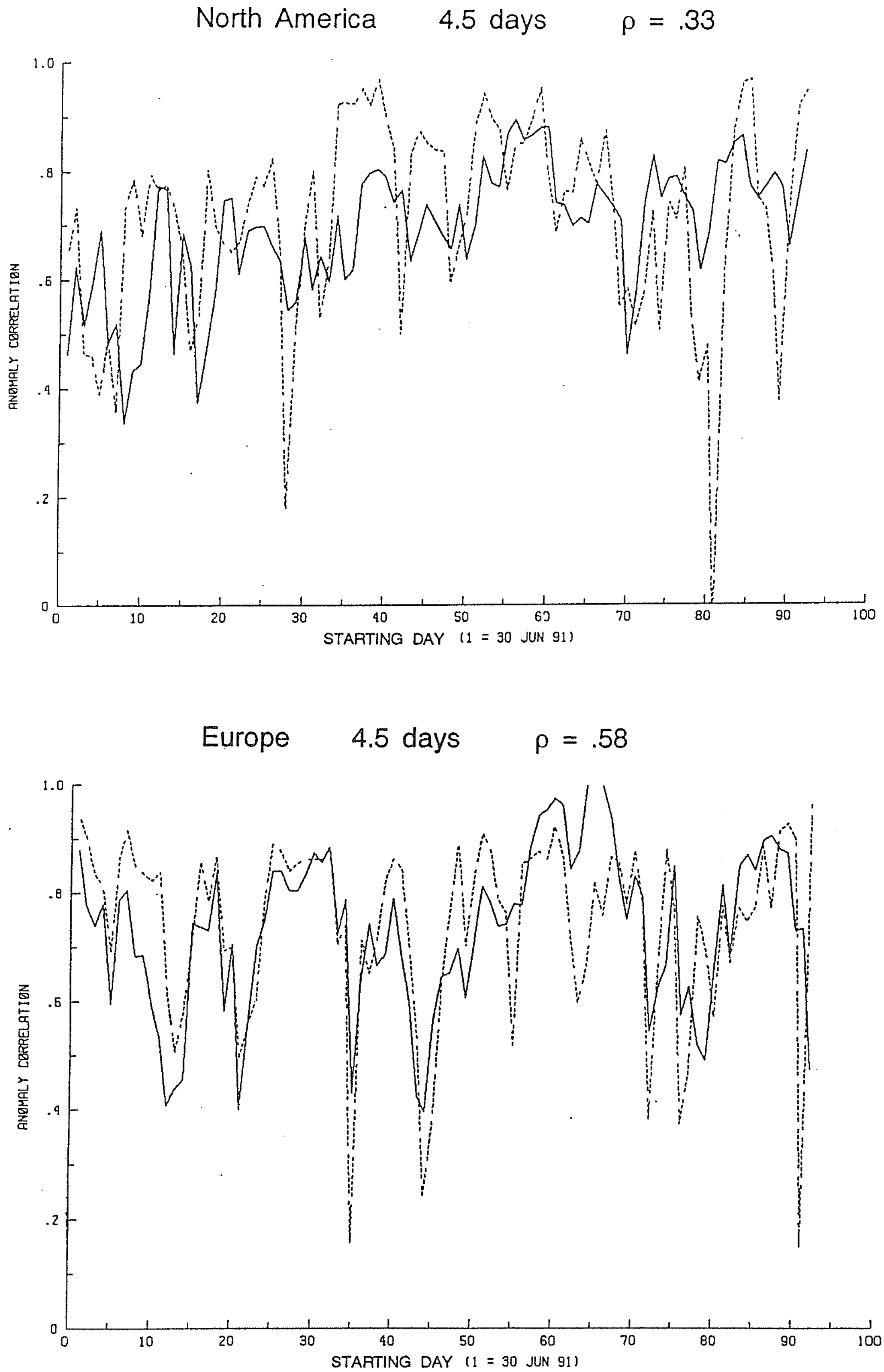


Fig. 1: Predicted (solid) and observed (dashed) anomaly correlation of the 4.5 day NMC global forecast over "North America" (30° N - 60° N, 60° W- 120° W) and "Europe" (30° N - 60° N, 0° E - 60° E).

4. EFFICIENT SELECTION OF MC FORECAST ENSEMBLE MEMBERS

In this study (*Toth and Kalnay*, 1991), an efficient approach is offered to select the fastest growing perturbations. A large number (100-1000) of randomly selected perturbed initial conditions are integrated forward for a single time step to find the "most promising" (fastest growing) members for a subset of longer ensemble integrations.

4.1 Random perturbations

Our goal is to create plausible 3 dimensional flow patterns that are close to the control analysis field (within the estimated analysis error) and hence could well be the outcome of our analysis procedure. To arrive at these fields we add different perturbations to the control analysis. The perturbations (X_n, n = 1 to 1000) are linear combinations of archived quasi-independent analysis fields (a_j, j = 1 to 40) from the same season, but from all the years available (4 so far):

$$X_n = A_n \sum_{j=1}^{40} w_j \, (a_j - c)_{st}$$

where w_j is a random weighting factor and c is the climatological average. In the procedure, first the anomaly fields (a_j - c) are standardized, and then after introducing the random weights, a final coefficient A_n is introduced so as to set the size of the anomaly at the 10% level of the average (a_j - c) on the 500 hPa streamfunction field, in an RMS sense.

4.2 Selection of the fastest growing perturbations

* For each perturbation we compute one time derivative and advance one time step, using the full forecast model:

$$(X_o + X_n) + 2\Delta t \, \delta \, (X_o + X_n) \, / \, \delta t$$

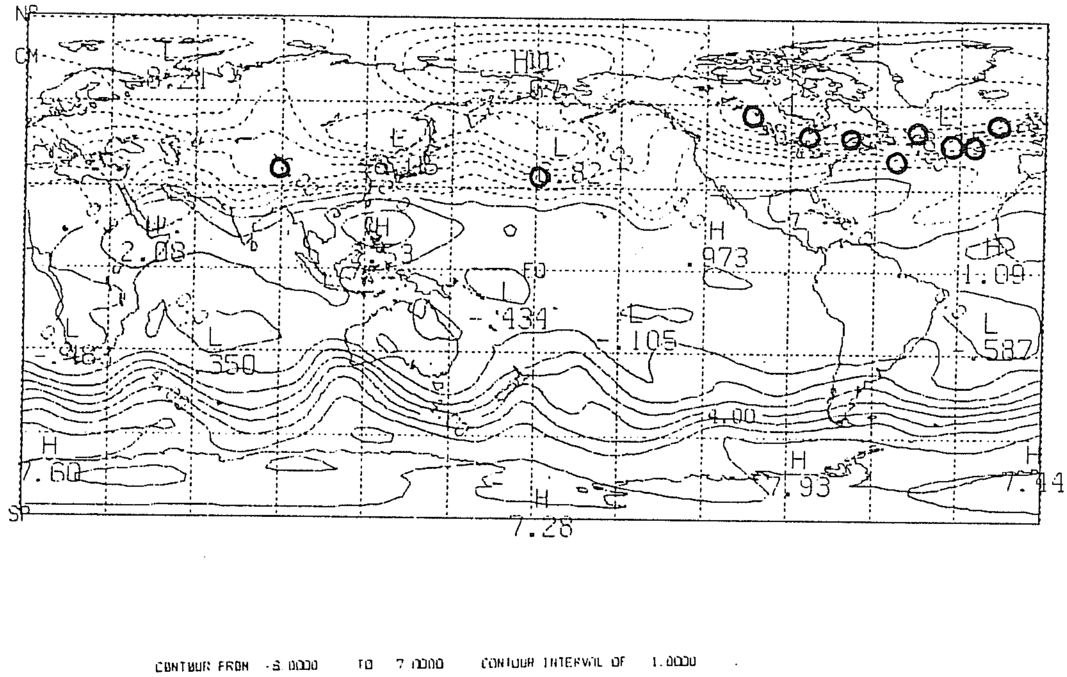
* From this field, we can compute the growth rate for each perturbation X_n, for each basic state X_o:

$$G_n = \| \delta(X_o + X_n)/\delta t - \delta(X_o)/\delta t \|$$

We want to use a norm that represents true weather growth, not gravity waves, convection, etc., i.e., a norm that represents the growth rate for the slow weather modes. One way would be to compute the quasi-geostrophic available potential energy plus kinetic energy, but this is difficult to do on a primitive equations model. In this study we use rotational kinetic energy as a norm $K(X)$, as well as the RMS distance on the streamfunction field.

4.3 Preliminary results

So far we have completed 1-day integrations for 100 perturbations for two selected cases, one with high and one with low forecast skill. We computed the correlation between G_n for one time step and for 24 hours. The correlation values for both cases are around .8, showing that we can successfully select the fastest growing modes on the basis of one time step integrations, at about one hundredth of the cost. We also found that the one time step average value of the tendency of the kinetic energy, for both the basic state and



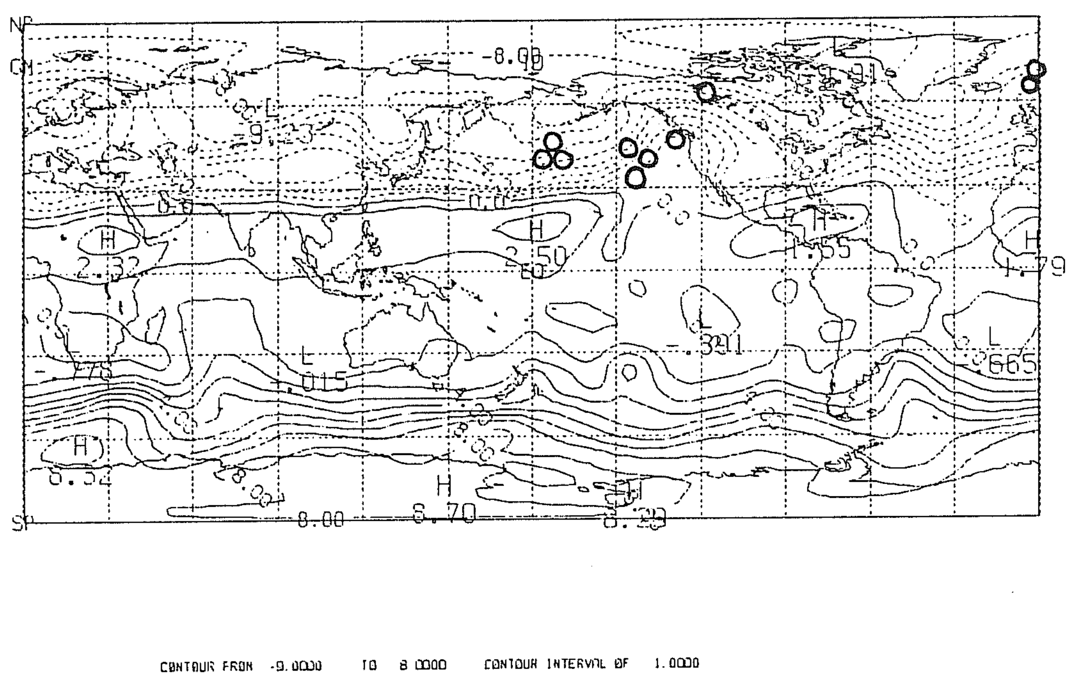


Fig. 2a and b: Streamfunction at the 9th sigma level (~ 500hPa) for the two days tested (2 Jan. 1991 and 17 Jan. 1991), which had relatively high and low forecastability respectively. The circles represent the location of the largest "error" in the tendency for each of the ten fastest growing modes on the first timestep.

the perturbations,

$$K\left[\delta(X_o)/\delta t\right] \text{ and } K\left[\delta(X_o + X_n)/\delta t\right]$$

which are an inverse measure of persistence, are considerably larger for the case with low skill, suggesting that they may be a useful predictor of short range skill. It should be noted, however, that although all the perturbations had the same size in the sense of the RMS of the streamfunction (for the Northern Hemisphere), they had somewhat variable initial rotational kinetic energy, and that this initial value was also strongly correlated with the growth rate.

It is also interesting to note that the geographical location of the local maximum of the growth rate of rotational kinetic energy, tends to cluster in well defined regions, as shown in Fig. 2, presumably the same regions where the fastest growing unstable modes would appear.

4.4 Future applications

Ensemble integrations based on the selection of fastest growing modes described above should provide a very good prediction of skill breakdown, especially in the short range forecasts (≤ 3 days). Experiments are also planned to explore whether, apart from the prediction of skill, the ensemble based on the fastest growing modes (with both positive and negative perturbations) results in more successful forecasts than purely random perturbations would.

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