ENSEMBLE GLOBAL WEATHER FORECASTING AT CPTEC

Antônio Marcos Mendonça and José Paulo Bonatti
Center for Weather Forecast and Climate Studies (CPTEC) – INPE
Rodovia Presidente Dutra, Km 40, Cachoeira Paulista, SP, 12630-000, Brazil
Tel.: +55 12 5608531 Fax: +55 12 5612835
mendonca@cptec.inpe.br, bonatti@cptec.inpe.br

1. Introduction

In October 2001, the Center for Weather Forecast and Climate Studies (CPTEC) started operationally the ensemble weather forecast. Zhang and Krishnamurty (1999) developed the technique used to generate the perturbed initial condition for hurricane forecasting and adapted for global weather forecasting at CPTEC by Coutinho (1999). The CPTEC ensemble prediction system (EPS) uses the global spectral model, run since 1994 for deterministic forecasting, and has 15 members, being one from the initial condition without perturbations (control forecast) and 14 from perturbed analysis in a T062L28 resolution.

Essentially, the method consists of: 1) add random perturbations to traditional initial condition (control); 2) integrate the model for 36 h starting from the control and from the perturbed initial conditions, and saving results each 3 h; 3) construct a time series formed by the successive differences between forecasts started from control and perturbed analysis; 4) perform a empirical orthogonal function (EOF) analysis for the time series of difference fields over the interest region in order to obtain the fastest growing perturbation (considered as the eigenmode associated to the largest eigenvalue) and normalize the eigenmode to pre-fixed amplitudes for each variable; 5) the ensemble of initial conditions is generated by adding (subtracting) these EOF-based perturbations to (from) the control analysis. Some characteristics of the method were modified in order to apply it for operational weather forecasting at CPTEC. In the original version, Zhang and Krishnamurty perturbed the initial hurricane position, however, in the version implemented at CPTEC no perturbations in relation to the position of meteorological systems was done. The region of perturbation used by Zhang and Krishnamurti (1999) was the neighborhood of the hurricane, however, Coutinho (1999) found that the use of the region 45S to 30N and 0E to 360E produces better results than the use a specific region, such as, a region over South America.

Several products can be produced from the EPS. The ensemble mean is one of the simpler and easier interpretation products because it consists just in performing an average of the several ensemble members. In a deterministic approach, the ensemble mean may be considered the best estimate of the future atmosphere (Toth and Kalnay (1993) and Molteni et al (1996)), especially for medium range weather forecasting. Another useful information, derived from the EPS, is the uncertainty of forecast estimated from the ensemble spread. Low spread is associated with high confidence of forecast and high spread with low confidence of forecast.

In this work we have evaluated the performance of the ensemble mean in order to compare it with the performance of the control forecast and we have investigated the relationship between ensemble spread and skill of the ensemble mean for the CPTEC EPS.

2. Methodology

The CPTEC EPS is evaluated daily by statistical indexes, such as, anomaly correlations, root mean square, ensemble spread, etc. In this paper we have used anomaly correlations (SK) to compare the skill of the ensemble mean and the skill of the control forecast. Moreover, we have used the ensemble spread (SP) to investigate the relationship between performance of the ensemble mean and high/low spread. The statistical indexes used in here were calculated for 500-hPa geopotential height over the South America region (101W to 11W and 60S to 15N).

The ensemble mean (EM) for each model grid point (j) is

$$EM_j = \frac{1}{N}\sum_{i=1}^{N} F_j^i, \qquad (1)$$

where F_j^i represents the forecast of each EPS member (i) and N is the number of members of the ensemble.

The skill of the ensemble mean and the control forecast (CF) is defined as anomaly correlation

$$SK = 100 \times \frac{\sum_{j=1}^{J}\left[\left(F_j - C_j\right)' \times \left(A_j - C_j\right)'\right] \times W_j}{\left\{\sum_{j=1}^{J}\left[\left(F_j - C_j\right)'^2 \times W_j\right] \times \sum_{j=1}^{J}\left[\left(A_j - C_j\right)'^2 \times W_j\right]\right\}^{\frac{1}{2}}}, \qquad (2)$$

where $(\,)'$ means deviation in relation to spatial average, j is the index for each grid point, J is the number of grid points, W_j is the area weight, F_j is the field (EM or CF), A_j is the analysis field, C_j is the climatological field.

The ensemble spread is given by

$$SP = \frac{\sum_{j=1}^{J}\left[\frac{1}{N}\sum_{i=1}^{N}\left(F_j^i - EM_j\right)^2\right]^{1/2} \times W_j}{\sum_{j=1}^{J} W_j}, \qquad (3)$$

where indexes and terms have been described previously.

3. Results

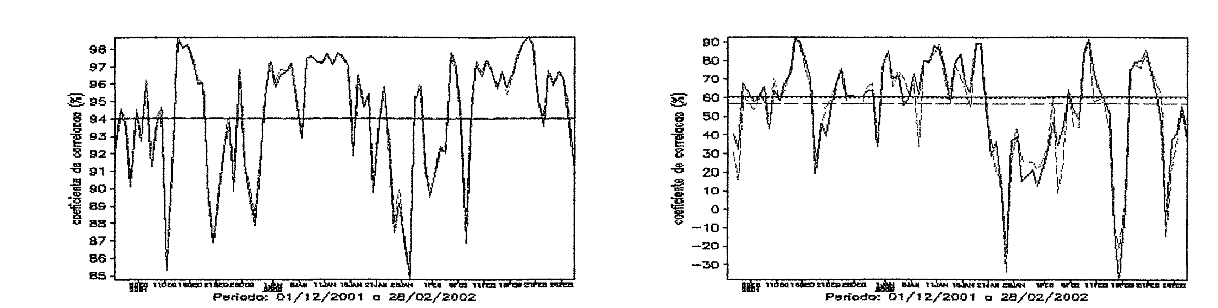
3.1 Control versus Ensemble Mean

The comparison between EM and CF was carried through anomaly correlations (*SK*). Only the graphs for 48 and 168 hours predictions are presented (Figure 1).

The performance of ensemble mean and control forecast for the first days of integration are similar. The time average of both forecasts is very closely, about 98 % in 24 hours, 94 % in 48 hours and 90 % in 72 hours. In this period, is interesting to observe that until 72 hours both forecasts can be considered useful (above 60%) all the time.

In 96 hours meaningful differences are observed between the performance of both forecasts, and the time average skill of the ensemble mean becomes greater than that one of the control forecast. It can observed that the ensemble mean tends to be better than the control forecast as the lead time of forecast increases.

A particularly interesting result can be observed in the Figure 1b, the time average performance of the control forecast is below the useful forecast limit, about 58 %, while the time average performance of the ensemble mean is slightly above 60 %. Generally, the anomaly correlations of the 500-hPa-geopotential height on a determined region are considered as reference to establish the term of predictability of numerical models. Although more episodes of summer were needed in order to infer the predictability of the forecasts, these results suggest that the predictability of the ensemble mean is almost one day greater than predictability of the control for this season.



a) 48 hours b) 168 hours

Figure 1 – Anomaly correlations for 500-hPa geopotential height. Daily values from 01 December 2001 to 28 February 2002 of the control forecasting (blue dashed curve) and of the ensemble mean (red continuous curve). The blue dashed and red continuous lines denote the time average skills of the control forecast and of the ensemble mean, respectively. The black dotted line denotes the useful forecast limit (SK = 60 %).

3.2 Skill and Spread

In this section is investigated the relationship between skill of the ensemble mean and the ensemble spread, evaluating the coefficient of correlation for daily series of skill of the ensemble mean and ensemble spread for the three months considered in this work. The coefficient of correlation (r) is evaluated as

$$r = \frac{1}{K}\frac{\sum_{k=1}^{K}\left(SP_k - \overline{SP}\right)\left(SK_k - \overline{SK}\right)}{\left[\sum_{k=1}^{K}\left(SP_k - \overline{SP}\right)^2 \sum_{k=1}^{K}\left(SK_k - \overline{SK}\right)^2\right]^{\frac{1}{2}}}, \qquad (4)$$

where K is the number of pairs of statistical indexes, SP and SK are, respectively, spread and skill of forecast, and the bar means time average.

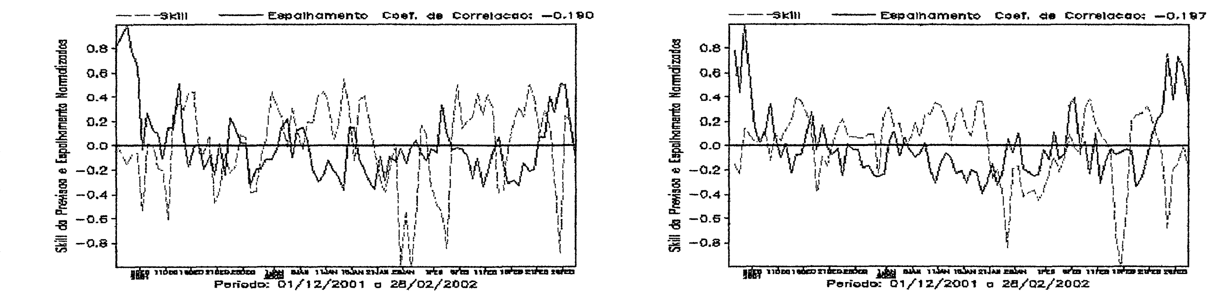
If the numerical models were perfect and if the mechanisms of generation of the perturbed initial conditions could represent completely the uncertainties of the meteorological observations, is probable that correlation between ensemble spread and skill of forecast would be greater. But, because of deficiency of models and problems to represent all possible atmospheric states of initial conditions, this correlation is small.

The coefficients of correlations between spread and skill of the ensemble mean for each lead time of forecast are presented in Table 1. It can be noted that in 24 hours, r is very small and positive what suggest that the spread is not a good indicator of forecast uncertainty. For 48 hours r is still very small, however its value is negative, indicating a possible inverse relation between spread and skill. From 72 to 168 hours r assumes negative values and the module of its magnitude is about 2 times bigger than the one in 48 hours and 45 times bigger than the one of the 24 hours. These results suggest that there is some correlation between spread and skill of forecast, however it is still small.

Table 1 – Coefficient of correlation between *SP* and *SK* for DJF (2001-2002).

	Lead time of forecast (days)						
	1	**2**	**3**	**4**	**5**	**6**	**7**
r	0.004	-0.089	-0.168	-0.190	-0.165	-0.147	-0.197

The Figure 2 presents the spread (red continuous line) and the skill (blue dashed line) normalized by maximum deviation, for 96 and 168 hours prediction. Negative coefficients of correlation between *SP* and *SK* suggest that when the spread is bigger than the time average on the considered period, the skill of ensemble mean is smaller than the time average of skill, and vise-versa.



a) 96 hours b) 168 hours

Figure 2 – Spread (red continuous line) and anomaly correlation (blue dashed line) normalized by maximum deviation of period (01 December 2001 to 28 February 2002) for 500-hPa geopotential height over the South America region.

4. Discussion

The CPTEC ensemble prediction system began operationally, in October 2001. Daily several statistical indexes are calculated such as anomaly correlations root mean square, bias and spread in order to evaluate the performance of the ensemble. In this study it is used anomaly correlations and ensemble spread of December 2001, January and February 2002 in order to evaluate the performance of the ensemble mean in relation to the control forecast and to evaluate the relationship between skill of the ensemble mean and ensemble spread in this period.

For anomaly correlations we have obtained that the ensemble mean shows better performance than the control forecast, especially, after 3 or 4 days. The biggest difference found for the 500-hPa geopotential height was the increase of the predictability by almost one day.

The results of item 3.1 have shown that there is some negative correlation between spread and skill of the ensemble mean in the considered period however it is still small especially in 24 and 48 hours. Despite the low values of correlation obtained it seems that the spread can be used to infer the uncertainty of the forecast.

The performance of the ensemble mean and the relationship between spread and skill of the CPTEC EPS present results that are encouraged, and suggest that EOF-based perturbation method can be applied successfully for ensemble global weather prediction. However, other experiments are necessary in order to evaluate some features that are not considered in this study and to improve the performance of the system.

5. References

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