

Quantifying the Predictability of Low-Resolution Medium-Range Weather Forecasts

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LONG-TERM GOALS

To predict the probability distribution function (pdf) of medium range weather forecast errors as accurately as possible.

OBJECTIVES

Objective 1: To compare the Bishop et al.'s (2001) recently developed Ensemble Transform Kalman Filter (ET KF) ensemble generation technique against the breeding of growing vectors (BGV) technique (Toth and Kalnay, 1993, 1997) in a GCM.

Objective 2: To compare simplex and symmetric ensemble centering techniques

Objective 3: To develop statistical “dressing” techniques that ensure that the difference between any two members of an ensemble is statistically indistinguishable from the difference between any one ensemble member and the truth.

APPROACH

Users of weather forecasts with non-linear cost/loss functions can benefit from details of the probability distribution function (pdf) of future atmospheric states given past and current observations, a data assimilation scheme and forecast models. The above objectives represent sub-goals aimed at the overarching aim of providing users with detailed and reliable probabilistic forecasts of future atmospheric states. Our test-bed is NCAR's community climate model (CCM3) run off NCAR/NCEP reanalysis data.

WORK COMPLETED

Considerable progress has already been made in all of the above objectives. Xuguang Wang, the Penn State PhD student who is paid by this ONR grant, has developed numerical tools to run and test T42 CCM3 ensemble forecasts off the NCEP/NCAR reanalysis data set on 8 PCs each with dual 1 GHz processes running Linux. As a result of this work, one paper (Wang and Bishop, 2003) entitled “A comparison of Breeding and Ensemble Transform Kalman Filter Forecast Schemes” appeared in the Journal of Atmospheric Sciences earlier this year while another (Wang et al., 2003) entitled “Which is better, an ensemble of positive/negative pairs or a centered spherical simplex ensemble?” has been submitted for publication in the Monthly Weather Review. A third paper is currently being prepared for submission to the Quarterly Journal of the Royal Meteorological Society on the subject of statistical “dressing” techniques that ensure that the difference between any two members of an ensemble is statistically indistinguishable from the difference between any one ensemble member and the truth.

MAIN RESULTS

See Wang and Bishop (2003) for results on “A comparison of breeding and ensemble transform Kalman filter ensemble forecast schemes”. Results for the “Which is better, an ensemble of positive/negative pairs or a centered spherical simplex ensemble?” can be found at <http://www.essc.psu.edu/~xuguang/publications.html>. Here we focus on our recent results regarding the statistical augmentation of ensemble perturbations.

Statistical post-processing with the dressing technique

To account residual errors, one way we can try is to add statistical perturbations to each of the dynamical ensemble members in the post-processing. This idea is first tried by the best member dressing technique by Roulston and Smith (2003). In the best member dressing method, the statistical perturbations are from archived historical best member errors. The best member is defined as the closest to the verification in the full space including all spatial locations, all quantities and all forecast lead times. Our first concern about this best member dressing method is that since the error statistics of each member should be similar on average one should not expect the first, the second and the even the worst member to be significantly different measured in full space. Secondly, since identification of the best member is time consuming, one would choose a subspace. Then the selection of the best member is dependent on the choice of subspace. Third, Roulston and Smith (2003) shows that using too low dimensional space will very likely misidentify the true best member defined in full space and it will underestimate the errors associated with each forecast. But is it possible that the selection of the best member in very high dimensional space will overestimate the errors?

With these questions in mind we propose another dressing kernel. The basic idea is to choose the statistical perturbations that will make the dressed ensemble members indistinguishable from the verifications under the second moment measurements. Mathematically,

$$\left\langle (\mathbf{y}_p^f - \mathbf{y}_q^f)(\mathbf{y}_p^f - \mathbf{y}_q^f)^T \right\rangle = \left\langle (\mathbf{y}_p^f - \mathbf{x}^t)(\mathbf{y}_p^f - \mathbf{x}^t)^T \right\rangle$$

where $\mathbf{y}_p^f$ and $\mathbf{y}_q^f$ are two randomly picked dressed ensemble members. $\mathbf{x}^t$ is the verification. $\langle \rangle$ is the seasonal average. Then the dressing perturbation $\mathbf{e}$ satisfies

$$\langle \mathbf{e}\mathbf{e}^T \rangle = \left\langle (\bar{\mathbf{y}} - \mathbf{x}^t)(\bar{\mathbf{y}} - \mathbf{x}^t)^T \right\rangle - \mathbf{S}_e^2$$

where $\bar{\mathbf{y}}$ is the undressed ensemble mean and $\mathbf{S}_e^2$ is the seasonally averaged undressed ensemble covariance.

Our proposed method has shown better results relative to the best member method when we test with single variable of interest (see fig.16, 17 and 18). We have developed a mathematical tool to extend the dressing to more variables, in which case the covariance between different elements need to be considered. Work is underway to test this tool.

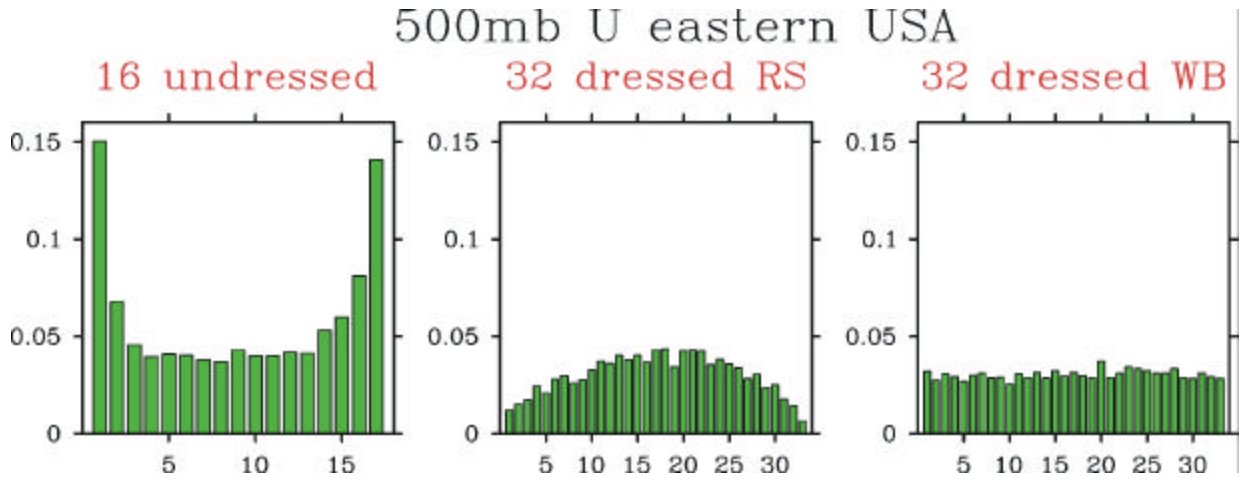


Fig. 16 Test of the two dressing technique. RS: best member method. WB: proposed method. The undressed ensemble is 16 member ETKF ensemble. 2 dressing perturbations are added to each of the 16 ETKF ensemble members. The single variable considered are 500mb U at Eastern USA. In the best member method, the best member is defined from a very high dimensional subspace: 200mb, 500mb and 850mb U,V, T throughout 1 to 10 day forecast lead times. What's shown are rank histograms for the 16 member undressed ETKF ensemble, 32 member dressed or proposed dressing method shows more reliable.

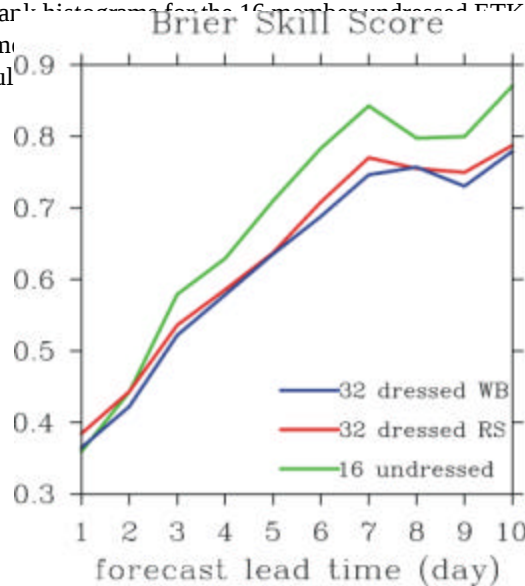


Fig. 17 Brier skill score measurements on the three ensembles in fig. 16. Our proposed method shows smaller BSS.

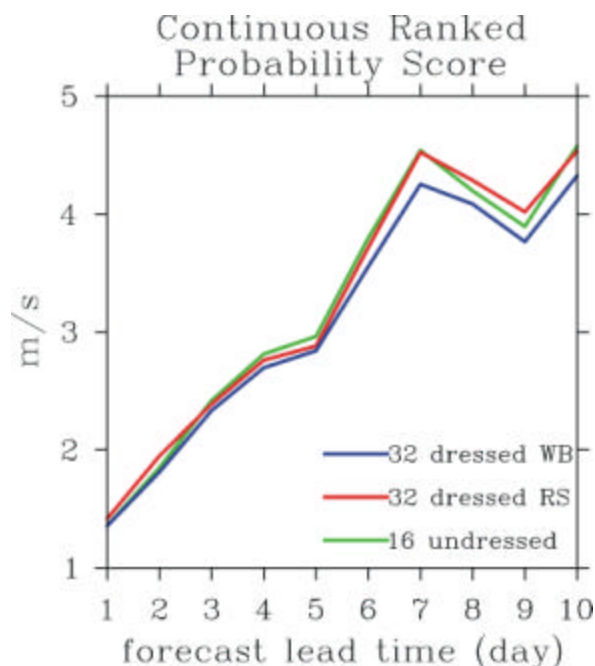


Fig. 18 Continuous ranked probability score measurements on the three ensembles in fig. 16. Our proposed method shows smaller CRPS.

IMPACT/APPLICATIONS

At NRL Monterey, research is being conducted to improve FNMOC's (bred vector) ensemble forecasting capabilities. Because of the positive results found in our preliminary tests, the ETKF ensemble generation scheme and other schemes will be tested at NRL to determine their suitability for transition into operations at FMNOC. Zoltan Toth and Mozheng Wei of the National Centers for Environmental Prediction (NCEP) are also preparing to test versions of the ETKF ensemble generation scheme to determine its suitability as a replacement to their current bred vector scheme.

TRANSITIONS

NCEP, in collaboration with former Post-doctoral fellow Sharanya Majumdar, graduate student Brian J. Etherton and undergraduate student Jonathon Moskaitis, is currently applying the ETKF to a combined ECMWF/NCEP ensemble to determine where aircraft should fly in the ongoing NOAA Winter Storms Reconnaissance program.

RELATED PROJECTS

The NSF grant ATM-98-14376 "Adaptive Sampling with the Ensemble Transform Kalman filter" enabled tests of the ability of the ETKF to predict reductions in forecast error variance due to targeted

observations. See <http://www.met.psu.edu/dept/faculty/bishop.htm> and <http://orca.rsmas.miami.edu/~majumdar/> for details.

SUMMARY

In order to more accurately represent the uncertainty in weather forecasts a new, computationally inexpensive method has been devised for generating multiple forecasts whose differences reflect weather forecast uncertainty. Our tests indicate that the method is superior to the breeding technique that is currently used by the federally funded civilian and Naval weather forecasting agencies. In addition new ensemble statistical techniques have been introduced that augment dynamical ensemble members with statistical members. These dressed ensembles are designed so that the difference between any two dressed ensemble members is statistically indistinguishable from the difference between any one ensemble member and the verifying observation. Thus, the statistical augmentation technique greatly enhances the value of the ensemble forecast to users with non-linear cost functionals.

REFERENCES

Bishop, C. H., B. J. Etherton and S. J. Majumdar, 2001: Adaptive sampling with the ensemble transform Kalman Filter. Part I: Theoretical aspects. *Mon. Wea. Rev.*, **129**, 420-435.

Wang, X. and C.H. Bishop, 2003: A comparison of Breeding and Ensemble Transform Kalman Filter Forecast Schemes. *J. Atmos. Sci.*, **60**, 1140-1158.

Wang, X., C.H. Bishop and S.J. Julier, 2003: Which is better, an ensemble of positive/negative pairs or a centered spherical simplex ensemble? (Submitted to *Mon. Wea. Rev.*)

Buizza, R., and T. N., Palmer, 1995: The singular vector structure of the atmospheric general circulation. *J. Atmos. Sci.*, **52**, 1434-1456.

Daley R., 1991: *Atmospheric Data Analysis*. Vol. 2. Cambridge University Press, 457 pp

Houtekamer, P.L. and H.L. Mitchell, 1998: Data assimilation using an ensemble Kalman filter technique. *Mon. Wea. Rev.*, **126**, 796-811.

Houtekamer, P.L., L. Lefaivre and J. Derome, 1996: A system simulation approach to ensemble prediction. *Mon. Wea. Rev.*, **124**, 1225-1242.

Molteni, F., R. Buizza, T. N. Palmer, and T. Petroliajgis, 1996: The ECMWF ensemble prediction system: Methodology and validation. *Quart. J. Royal Meteor. Soc.*, **122**, 73-119.

Smith, L. A., 2001: *Nonlinear dynamics and statistics (chapter 2)*, Alistair I. Mees (ed.), Birkhauser.

Toth, Z., and E. Kalnay, 1993: Ensemble forecasting at NMC: The generation of perturbations. *Bull. Amer. Meteor. Soc.*, **74**, 2317-1330.

3/4, and —, 1997: Ensemble forecasting at NCEP and the breeding method. *Mon. Wea. Rev.*, **125**, 3297-3319.