Determination of Mesoscale Predictability Limits with Respect to Uncertainty in the Larger-Scale Environment

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LONG-TERM GOALS

Our goal is to determine the limits of predictability inherent in atmospheric forecasts due to uncertainty in their initial conditions. These uncertainties are a consequence of inaccuracies of observational data and the algorithms that produce 3-dimensional analysis. Even if a model can simulate atmospheric behavior perfectly, since atmospheric flows exhibit instabilities leading to chaos, any errors in a forecast's initial condition will tend to grow, until information content of the forecast is negligible. The result is a limit to predictability.

This predictability limit has been known for some time (Lorenz, 1963), although it continues to be ignored by some who make very optimistic claims (see Errico and Baumhefner, 1987 for some examples). Its character, especially regarding how various types of errors influence the predictive skill of various fields on various scales, has only been superficially explored to date (Lorenz, 1969; Errico et al., 1995). Since characterization of this limit has crucial implications regarding forecast reliability and possible observation system impacts, its determination is critical (Tribbia and Baumhefner, 1988).

OBJECTIVES

Our objective in this particular study is to determine the predictability limits of meso-α scale events imposed by inaccuracies in the initial conditions at larger scales. Predictability measures will explicitly consider the quantitative prediction of precipitation. Although the predictability limit for forecasting 50 kPa geopotential height anomalies may by as long as 8 days with present observing

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systems, it is likely considerably shorter for forecasts of the small scale processes that generate precipitation. Yet for many purposes, cloud generation and precipitation are of paramount interest.

Energy and variances of fields are much greater at synoptic and planetary scales than at mesoscales. Initial conditions for forecast models therefore also tend to have errors that dominate at these larger scales. It has been argued that mesoscale errors grow more rapidly or, alternately, that they are more predictable, but these have been on heuristic grounds, using either simple models (Lorenz, 1969) or flawed experimental designs (Anthes et al., 1985). Our attempt will be to perform careful experiments using the highest resolution, most realistic global model we can presently afford to use.

APPROACH

We assume a perfect model. For this reason, it must be carefully verified with regard to its abilities to both forecast weather and simulate climate. A good candidate is version 3 of NCAR's Community Climate Model (Hack et al.,1993).

Initial condition perturbations are created by randomly sampling from an error probability distribution that has some expected characteristics of analysis errors. We can only base this on "expected" characteristics, because very limited effort has been applied to revealing these. Estimated analysis errors reported by Daley and Mayer (1986) and from examination of differences between analysis produced at NCEP and ECMWF are used as guidance, along with knowledge about the current observation system and intuition regarding the behavior of data assimilation systems.

For selected forecast periods, ensembles of randomly perturbed forecasts are created. They are then examined using standard forecast verification tools as well as statistical tests on all the pairs of forecast differences. Scales are distinguished using spherical harmonics and normal modes as basis functions. Other techniques will be applied as well, as required.

Adjoint sensitivity analysis and singular vectors will be determined on selected cases if possible and if a suitable adjoint model is available. One possible model is version 2 of NCAR's Mesoscale Adjoint Modeling System System (MAMS2, Errico et al., 1994; Errico and Raeder, 1999). Examples of related applications of MAMS2 appear in Errico (1997) and Langland et al. (1995, 1996). See also Gelaro et al. (1997).

WORK COMPLETED

Over the past year we have concentrated our efforts on the infrastructure development aspects which were outlined in our proposal. These development activities included (1) testing and evaluating predictability error growth in a hierarchy of global models ranging in resolution from T42 to T106, (2) testing and refining our analysis error simulation perturbation to include more scale and regional sensitivity, and (3) evaluate our current limited area model for high resolution studies.

Under item (1), we undertook an extensive study to ascertain the minimum horizontal resolution sufficient to adequately capture error growth rate in synoptic scales. This research led us to investigate two versions of the NCAR CCM, CCM2 and CCM3, at both T42 and T63 resolutions. CCM3 had slower characteristic growth than CCM2 at comparable resolution. In order to gauge which version was most representative of the atmosphere, we examined the asymptotic limit of this growth, which reflect the climatological transient variance in each of the model configurations.

Under item 2 we have been re-examining our earlier perturbation generation technique in order to ensure it adequately reflects current estimates of initial data uncertainty. In addition, a revision was necessitated because of some inconsistencies at small scale we noted when our previous scheme was examined at higher resolution. In order to accommodate the vertical and horizontal inhomogeneity that clearly is evident in the statistical diagnoses of the differences in operational NCEP and ECMWF analyses, we have focussed our efforts on reproducing these spatial differences first in physical space. This is achieved using a white noise (i.e., uncorrelated from point to point) generation on the model grid. The standard deviation of this noise is modulated in the vertical and horizontal to reflect the larger expected errors near the jet stream and over the oceans. This error is then spectrally transformed and the energy in each wavenumber band is re-weighted so that a representative horizontal spatial correlation length for error is achieved. A similar procedure is used to ensure vertical correlation scales are modeled by our procedure.

The third item which we have examined is the applicability of the MAMS2 for use in locally high resolution prediction/predictability studies. This model had not been previously tested at high vertical and horizontal resolution. Unfortunately, our testing has revealed troubling aspects of the model at such resolutions. An orographically locked instability occurs, which can be controlled only with heavy horizontal damping. We had planned to use this model because of its associated tangent linear and adjoint versions, but this may not be possible as planned. Possible fixes are still being tested and alternative models are being considered. An alternative is to use a T170 version of the CCM3.

MAMS2 has been used at lower vertical and horizontal resolutions to examine atmospheric stability on small synoptic scales. Singular vectors have been determined for a diverse set of synoptic situations for 24 hour periods. The standard energy norm has been considered along with a variant that measures only the energy of geostrophic components at selected scales. Stability has been examined in a dry model context as well as in a moist model context, the latter including convection and large scale precipitation.

RESULTS

Comparison of the CCM2 and CCM3 results indicates that the magnitude and spatial distribution of variance of 500 mb geopotential height in a 2.5-10 day bandpass is similar in the storm tracks for both models at T63 and quite similar to the NCEP analyzed values. A critical difference in the 0-2.5 day bandpass variance exists, however, which we have noted is strongly related to the early error amplification behavior of the models. We suspect that the error growth properties of CCM2 are not converging toward an appropriate asymptotic level as the resolution is increased, while CCM3 is demonstrating convergence. We are currently verifying this hypothesis in a T106 version of CCM3.

The new perturbation generation algorithm is almost complete. Most of the problems in our previous generator have been corrected. The imposition of vertical correlations and an inhomogeneous distribution of variance is completed. What remains is the tuning of parameters to obtain appropriate horizontal length scales and an approximate dynamic balance.

The singular values computed for the MAMS cases reveal that only a few percent of possible modes are growing ones. For random perturbations whose distributions are white with respect to the norms examined, the expectation is that decay of the norm will be observed over the first 24 hours of a forecast. Although the singular values are larger when moist physics is considered, the spectra of values appears to asymptote to those determined for the dry model. Just 30 singular vectors explain more than 10% of the total variance of perturbations at hour 24.

IMPACTS/APPLICATIONS

NCAR's CCM3 appears to be suitable as a forecast model, with comparable skill to ECMWF and NCEP models at the same resolutions when measured using rms 500 mb geopotential height errors. This model, at T106 resolution, therefore can be used to perform state of the art predictability studies. Its behavior at T170 must still be investigated.

Our new perturbation generator can be tuned to yield reasonable initial condition errors that would be produced by a real data assimilation system with the current observational network. We are also investigating how to build flow-dependent errors into the perturber.

MAMS2 adjoint and tangent linear versions perhaps can still be used at lower vertical resolutions to help our interpretation of comparable resolution (T106 or T170) CCM3 results. An alternative may be to use the NRL's NOGAPS adjoint system, for which a moist version is currently being developed.

The MAMS2 singular value results are still being interpreted, but those results appear consistent with results from the few meso-α scale predictability studies performed in the past. The geostrophic norm used in these studies is described in a work in press.

RELATED PROJECTS

1. Work on various aspects of singular vectors is being performed in collaboration with Kevin Raeder at NCAR, Martin Ehrendorfer at the University of Vienna, Austria, and Carolyn Reynolds and Ron Gelaro at NRL, Monterey.

2. Luc Fillion (AES, Montreal, Canada) is visiting NCAR for one year assisting in research regarding data assimilation systems.

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