Research at NCAR on the Topics of Data Assimilation Singular Vector Analysis, and Some General Adjoint Applications

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LONG-TERM GOALS

This proposal covers some broad topics that are of mutual interest to scientists at NCAR and NRL Monterey. The research topics include aspects of data assimilation, singular vector analysis, and more general adjoint model development and applications. The work is being coordinated with NRL staff so as to augment, rather than duplicate, what is being done by them. The emphasis at NCAR will be on fundamental aspects of the problems, including, but not limited to: characterization of error statistics and implications of non-normal distributions, development of appropriate mesoscale balance conditions, development of norms that measure moisture for defining singular vectors, and parameterization of model Jacobians for efficient and effective tangent linear and adjoint calculations. Much of what is done is instructional. The support provided by ONR augments work being performed at NCAR and allows continuation of extensive collaborations between the P.I. and NRL staff.

OBJECTIVES

The new science this year was concerned with 4 different scientific questions: (1) Why are the rates of backward sensitivity growth greater for sensitivities of barotropic vorticity than for precipitation? (2) How must the NOGAPS PBL scheme be modified in order to render its corresponding adjoint version numerically stable? (3) What are the statistics of differences between NCEP and ECMWF re-analysis, and what do they imply about analysis error statistics? (4) What is an appropriate algorithm for constructing random, statistically significant realizations of analysis error?

Development work consisted of porting the MAMS2 software to new hardware. This was motivated by the forthcoming removal of CRAY machines from NCAR and by the porting of this software to the University of California at Los Angeles, the Desert Research Institute (in Reno), the University of Wisconsin, and perhaps the University of Arizona.

APPROACH

The primary tool for backward sensitivity analysis is NCAR's Mesoscale Adjoint Modeling System (MAMS2, Errico et al. 1994; Errico and Raeder 1999). This is a limited area, meso-α scale, primitive equation model that includes a complete physics package except for above-surface radiation effects. It also includes a vertical mode initialization package. It is the only model with complete (not simplified)

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14. ABSTRACT
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physics that has corresponding tangent linear and adjoint versions with demonstrated utility (Errico and Raeder, 1999).

The primary technique for examining numerical stability of the NOGAPS and MAMS2 PBL schemes uses a tool developed by R. Errico. It produces an explicit Jacobian of linear or nonlinear models, for which eigen-solutions are then obtained. Atmospheric profiles from a NOGAPS simulation were provided by T. Rosmond of NRL. N. Nichols of the University of Reading, England served as an applied mathematics consultant.

The ECMWF and NCEP reanalysis are obtained on pressure surfaces. Some horizontal interpolations and spectral filtering are required to get them on the same grid so that consistent differences can be taken. Statistics of these differences are then analyzed for single winter and summer seasons. Some of these are expressed in terms of power spectra of spherical harmonic coefficients.

The perturbation technique developed for NRL is based on Errico and Baumhefner (1987). The initial perturbations are produced randomly, consistent with estimates of local analysis error variance produced by NAVDAS and consistent with assumptions made about shapes of vertical and horizontal correlations of analysis error.

WORK COMPLETED

The result that backward (i.e., adjoint-derived) sensitivities of precipitation have very different temporal behavior than those of vorticity, even when both measures are made within the confines of the same extra-tropical cyclone, had been obtained the previous year in ONR-supported work by this P.I. Additional experiments and analysis were performed this year to investigate the causes for this behavior. One new set of experiments concerned changing the specific location over which precipitation was measured in the examined winter cyclones. Additional analysis included examining correlations of sensitivity fields. This work was conducted with the support of Kevin Raeder at NCAR and has been submitted to Tellus.

A very detailed investigation of the behavior of the MAMS2 vertical diffusion and planetary boundary layer scheme was performed. This included behaviors in both nonlinear and tangent linear contexts. Several different possible numerical integration schemes were investigated (such as split-explicit, N-cycle schemes) as well as both major and minor modifications of the Richardson number dependence of the eddy diffusion coefficients. This work was performed with the assistance and collaboration of Tom Rosmond (NRL), Kevin Raeder (NCAR), and Nancy Nichols (U. Reading, England).

For the re-analysis comparison, two 90-day seasons of daily data were examined. Statistics included means, maximum absolute differences, variances, vertical covariances, and horizontal power spectra. This work was performed with the collaboration of Steve Mullen (U. Ariz.). A manuscript is being prepared.

New perturbation software for generating NOGAPS ensembles was developed at NRL with the assistance of Carolyn Reynolds, Tom Rosmond, and Rolf Langland. It has been tested only to the point of ensuring that it is performing as designed. Once an example of the subsequent behavior of these perturbations in forecasts is examined, this technique will be described in a publication.

MAMS2 has been successfully ported to three new platforms. This includes the nonlinear, tangent linear, and adjoint models. It does not yet include the pre- and post-processors or the software for generating singular vectors.

RESULTS

In one winter cyclone case examined, precipitation sensitivity was generally uncorrelated with vorticity sensitivity. For a second winter cyclone, however, the two sensitivities were significantly positively correlated for forecasts longer than 12 hours.

None of the attempts at stabilizing the NOGAPS linearized PBL scheme have been suitable.

Minor modifications of the vertical diffusion coefficient are sufficient, but only if the linearization also departs from consistency with the NOGAPS semi-implicit time scheme. Importantly, it was noticed that that time scheme greatly reduces the effects of large diffusion coefficients, and it was determined how to a-priori reduce the coefficients but obtain similar results in the nonlinear model. Unfortunately, this has not helped stabilize the corresponding linearized model. This work is therefore continuing.

The differences between NCEP and ECMWF re-analyses are large. For example, the standard deviations of differences in the north-central Pacific are greater than 2 degrees. When averaged north of 20N, the standard deviation of the 50kPa height differences is 17m. Within the troposphere, vertical correlations of differences drop to approximately 0.5 in 10kPa. Power spectra of differences indicate a red noise, rather than white, spectrum.

The new perturbation technique behaves as designed. Although several adjustments are performed on the original spectrum, the properties designed into the original perturbations appear generally preserved well. In particular, altering the horizontal power spectrum from white to red does not seem to significantly disturb the locally defined variances or vertical correlations. Furthermore, the NOGAPS non-linear normal mode initialization scheme does not greatly affect the perturbation spectra except for those of the divergence field.

IMPACTS/APPLICATIONS

Since vorticity forecasts in the vicinity of developing cyclones are sensitive to initial moisture perturbations, the accurate analysis of moisture fields should receive more attention than it has.

Since forecasts of precipitation rate are very sensitive to initial temperature errors, the adjustment of temperature for fitting precipitation observations in 4DVAR systems should not be ignored.

That the sensitivities of precipitation and vorticity have different temporal behavior and spatial structures suggests that the mechanisms that generate vorticity or precipitation are basically different, and that two processes are effectively uncoupled although present in the same synoptic feature.

Development of an accurate PBL scheme having a useful and correct adjoint is still not on the horizon.

The problem is much more difficult than thought by almost everyone. While investigation of this problem continues, it is truly best done by the original developers of such schemes.

The differences between reanalysis are significantly large, even though the assimilating models and assimilation schemes are similar in many respects, and the available data for many observation types are identical. These statistics can provide lower bounds on analysis error statistics. In lieu of better information, they can also be used to tune artificial perturbation systems for ensemble forecasting or predictability studies.

The new perturbation technique now installed at NRL still requires some tuning, especially regarding its consistency with the statistics of reanalysis differences. The behavior of these as initial perturbations in forecasts also needs examination

TRANSITIONS

Initial perturbation software originally developed by myself and Tom Mayer at NCAR has been ported and re-designed for application to NOGAPS. Once tested and tuned, this software is intended to generate the next generation of operational ensemble forecasts at FNMOC.

RELATED PROJECTS

Determination of mesoscale predictability limits with respect to uncertainty in the larger-scale environment. A project funded by ONR with Joseph Tribbia and David Baumhefner (NCAR) as CO-PIs.

SUMMARY

Many things that researchers had thought unimportant actually are important; e.g., small errors in moisture analyses used as initial conditions for weather forecast models can create large errors at later times.

Although precipitation and winds are both aspects of winter storms, the mechanisms that affect both appear to be very different, so that what improves prediction of one aspect may not necessarily improve the other.

The development of linearized versions of weather forecast models for conducting sensitivity analysis is much more difficult than researchers have thought. Also, models behave very differently than their users and developers have thought, as new tools developed by this P.I. reveal.

When beginning a numerical forecast, we know less about the initial state of the atmosphere than most people are aware. In particular, we seem to know little for certain about small spatial scales. Random errors introduced in the initial conditions of a forecast model grow in time, if they have reasonable vertical and horizontal structures. Such random errors can be effectively used to mimic the general characteristics of real, but unknown analysis errors, and thus are appropriate for generating ensembles of possible predictions to estimate forecast uncertainty due to initial uncertainty.

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PUBLICATIONS

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