

Development and Application of Adjoint Models and Ensemble Techniques

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Grant Number: N00014-0310554

<http://www.gmao.gsfc.nasa.gov>

LONG-TERM GOALS

This proposal covers some broad topics that are of mutual interest to scientists at the Goddard Earth Science and Technology Center (GEST), the Global Modeling and Assimilation Office (GMAO) at NASA, the University of Innsbruck, Austria, and the Marine Meteorology Division of the Naval Research Laboratory. These concern problems related to numerical weather prediction, particularly the use and evaluation of initial data and the estimation of forecast and analysis uncertainty. Since specific analysis techniques are constantly being modified and eventually replaced, a goal of this study is to distinguish what is fundamental from what is transitory, so that the work has long-term applications. The support provided by ONR augments work being performed at GEST and allows continuation of extensive collaborations between the P.I. and staff at these other institutions, particularly NRL.

OBJECTIVES

Research objectives for the term of this proposal 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 GEST will be on fundamental aspects of the problems, including, but not limited to: parameterization of model Jacobians for efficient and effective tangent linear and adjoint calculations, evaluation of candidate ensemble forecasting systems, determination of the characteristics of proposed ensemble Kalman filter data assimilation techniques, and utilization of observation system simulation experiments (OSSEs) as a diagnostic tool for data assimilation.

APPROACH

Several tools are to be used to investigate diverse aspects of the problems to be investigated. One is NASA's Goddard Earth Observing System atmospheric general circulation model (GEOS-5) and its accompanying data assimilation system. This includes tangent linear and adjoint versions of both its dynamical core with rudimentary physics and its analysis solver. Also, a new quasi-geostrophic (QG) model has been developed by Martin Ehrendorfer (Univ. Innsbruck, Austria) and the PI. It is intended to allow reasonably efficient implementation of full and reduced rank Kalman filters. The different systems will be used as each may be particularly appropriate to a question examined and also to investigate the generality of results obtained.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2005	2. REPORT TYPE	3. DATES COVERED 00-00-2005 to 00-00-2005			
4. TITLE AND SUBTITLE Development and Application of Adjoint Models and Ensemble Techniques		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Global Modeling and Assimilation Office, Code 610.1, Goddard Space Flight Center, Greenbelt, MD, 20771		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES code 1 only					
14. ABSTRACT This proposal covers some broad topics that are of mutual interest to scientists at the Goddard Earth Science and Technology Center (GEST), the Global Modeling and Assimilation Office (GMAO) at NASA, the University of Innsbruck, Austria, and the Marine Meteorology Division of the Naval Research Laboratory. These concern problems related to numerical weather prediction, particularly the use and evaluation of initial data and the estimation of forecast and analysis uncertainty. Since specific analysis techniques are constantly being modified and eventually replaced, a goal of this study is to distinguish what is fundamental from what is transitory, so that the work has long-term applications. The support provided by ONR augments work being performed at GEST and allows continuation of extensive collaborations between the P.I. and staff at these other institutions, particularly NRL.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

For many applications concerning data assimilation, numerical weather prediction, and climate analysis, it is desirable to have a characterization of analysis error. For example, for the problem of creating sets of initial conditions for ensemble forecasting, before it is claimed that these are representative of analysis error, it would help to know some things about those errors, such as their spatial covariances. There is no straightforward way to estimate these characteristics.

One very useful and as yet unexploited technique is to examine results produced as a byproduct of well designed Observation System Simulation Experiments (OSSEs). With this intention, the PI has collaborated with Michiko Masutani and Jack Woollen at NOAA/NCEP who have developed a well-validated OSSE system. The nature run for this study is provided by a one-month T213L32 simulation provided by the European Centre for Medium Range Weather Forecasts (ECMWF).

WORK COMPLETED

The QG model has been tuned for a variety of resolutions, including T21L3, T45L6 and T106L9.

It is forced using a relaxation to climatology and a term to prevent drift. Damping includes horizontal diffusion and an effective linear surface drag. It replicates both stationary and transient components of atmospheric energy spectra surprisingly well.

Several OSSEs have been examined. These include T63 and T175 analyses using both conventional and satellite observations and T175 analyses using only the former. Our examinations consist of analysis and background error statistics in terms of means, variances, vertical correlations, and horizontal spectra. Kalman gains are also estimated along with local measures of anisotropic horizontal correlation lengths. As part of the OSSE validation procedure, statistics of the simulated analysis increments are compared with real those of a real analysis system.

RESULTS

The forcing and damping parameters for the new QG model have been tuned to yield a k^{-3} inertial range with a realistic partitioning between kinetic and available potential energies and stationary and transient components. Singular vectors (SVs) have also been computed at this resolution. Maximum squared singular values for a 24-hour optimization period are as large as 60, and only 10% percent of the singular vectors are growing ones. A manuscript documenting the model and its SV results is being prepared.

The OSSE results reveal several potentially important characteristics of analysis error. Error variances are as large over the central Pacific Ocean as they are in the southern hemisphere. The spectra of error kinetic energy are white for spherical harmonic wave numbers $n < 25$. Error variances are as large as for the analysis fields themselves at scales $n > 80$ for most fields at most levels. For the error kinetic energy of the divergent wind, this saturation occurs for $n > 40$. The Kalman gain is positive for most fields for $n < 100$. Two manuscripts are being prepared to describe all the results.

IMPACT/APPLICATIONS

The new T45L6 quasi-geostrophic model will be particularly useful for examining numerical weather prediction and data assimilation questions related to the basic non-modality of forecast errors. The size

of its state vector is sufficiently large to reflect atmospheric complexity but hopefully still small enough to allow computation of a full extended Kalman filter. This will then provide a benchmark for comparing various reduced rank data assimilation schemes using the same model, including ensemble techniques.

The characterization of analysis error provided by the OSSEs will be compared with equivalent statistics of ensembles of analyses error produced using various techniques. Of particular concern are dynamical techniques based on bred growing vectors (BGVs) that, for fundamental dynamical reasons, are expected to produce initial error ensemble statistics very dissimilar to the OSSE results. The OSSE characteristics will also be used to define a new analysis error simulator.

TRANSITIONS

If the analysis error simulator produces ensembles of forecast error that appear to behave as real forecast error, with error growth over 12-24 hours and only minor dynamical imbalances, it will be transitioned to NRL Monterey for consideration as a next-generation operational ensemble forecasting system for the U.S. Navy.

The first version of the adjoint modeling systems based on the NASA data assimilation and forecast systems will be made available to interested users within the next few months. A set of demonstration results is currently in production. We envision these systems being used for both forecast and assimilation diagnostic studies.

RELATED PROJECTS

The National Science Foundation is funding the P.I. on a project to examine the implications of non-modality on ensemble forecasting and data assimilation.

NASA is funding several projects related to adjoint model development, singular vector analysis and applications, data assimilation, and observation system simulation experiments. The P.I. is a Co-PI on all of these projects.