Accomplishments and Plans for NCAR Data Assimilation Initiative
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1.1 Introduction: Rationale for Initiative

Data assimilation is the term used in atmospheric and oceanic sciences for the process of merging observations with a model. Data assimilation can transform diverse and heterogeneous observations to regularly spaced estimates of uniform quantities that can be interpreted more easily. At the same time the assimilation process provides quantitative information on model error, forecast skill and observational errors. In more advanced applications of data assimilation, models can be improved by confronting them with data, through sequential estimation of model parameters for instance. Recent advances in assimilation algorithms and software engineering have provided unprecedented opportunities to make rapid advances in both the theory and application of data assimilation. A focused data assimilation research effort should be able to greatly increase the rate of development of improved data assimilation methodologies, in turn leading to improved data sets, improved models, better predictions, and a more efficient design of observational systems.

The NCAR Data Assimilation Initiative (DAI) is creating and leading a research community for data assimilation where individuals benefit from sharing ideas, methodologies, and software tools as well as access to a data assimilation testbed. NCAR has a large number of researchers for whom data assimilation is an essential part of their ongoing or planned research. New developments in theoretical data assimilation and in software engineering are making collaborations between data assimilation experts, modelers, observational specialists and statisticians easier and more productive than was possible in the past. The DAI is accelerating the progress of many other NCAR projects by providing a centralized data assimilation expertise which can be coordinated with existing observational and modeling expertise. With a carefully controlled continued expansion of DAI, it should be possible for NCAR to be recognized as a leader in research data assimilation within 3 years.

1.2. Overall Goals

DAI is making NCAR a recognized leader in data assimilation research while helping to coordinate and accelerate the efforts of a set of internal and external collaborations. By the end of three additional years, DAI will provide:

1. A data assimilation community within NCAR to produce leading-edge research and to provide focus to disparate efforts;
2. A software environment for supporting data assimilation research and evaluation; the Data Assimilation Research Testbed (DART);
3. A mechanism for data assimilation research collaboration with strategically selected partners from universities and government research labs;
4. Software tools for use in undergraduate and graduate education;
5. Basic research and implementation support for ‘operational’ partners, both within NCAR and outside;

6. A digital infrastructure for communicating advances in data assimilation research and applications to a broad community.

1.3 Accomplishments for FY03

During FY03, DAI underwent a transition to a fully operating initiative with a dedicated staff and budget. Once the budget was finalized late in calendar year 02, DAI began a search for several new scientists and continued ongoing activities. Kevin Raeder (start date December 02), Alain Caya (April 03), and Hui Liu (July 03) joined DAI during the year. In addition, Dale Barker (MMM) and Syed Rizvi (MMM) devoted a portion of their time, as did the PIs, to DAI activities. FY03 saw further development of the Data Assimilation Research Testbed (DART) and active efforts by DAI to establish meaningful collaborations both within NCAR and with external partners. A number of specific activities have been completed during the year consistent with the goals outlined in section 1.2:

1. A prototype of the Data Assimilation Research Testbed (DART) was completed including a variety of ensemble filter assimilation methods, a suite of low-order models, two realistic atmospheric prediction models, and a number of tools for designing and analyzing observing system simulation experiments.
2. DAI co-sponsored the ASP summer 2003 colloquium on data assimilation using DART software for exercises. This preliminary version of DART is available on the web and is being used by a number of external university collaborators.
3. A prototype ensemble filter assimilation system for synthetic observations with MMM's WRF model was constructed using the DART framework.
4. Fundamental research on ensemble filtering methods has resulted in increased understanding and improved filter performance. In particular, methods to automatically calibrate ensemble filters are under development.
5. Filters for the GFDL's FMS atmospheric model and NCEP's operational global model (GFS) have been completed and tested. A preliminary comparison of the NCEP filter to the operational variational assimilation was completed in the spring and has guided further development of filtering methods.
6. DAI hosted long-term visits from Luc Fillion (DRM), Jim Hansen (MIT), Ron Errico (NASA GMAO), and Shree Khare (Princeton) as well as a number of short-term visitors.
7. An ensemble filter system for the CCSM CAM is under development. Results are available from an initial version of this system using synthetic observations to perform observation system simulation experiments with CAM.
8. A project to import observational data into the DART framework is underway. Preliminary assimilations with CAM have revealed the challenges of confronting a climate model with observations.
9. DAI is co-sponsoring a postdoc (Tomoko Matsuo) in GSP to do data assimilation research; she is helping to develop links with HAO.
11. Adjoints for some of the DART low-order models have been produced.

Publications: FY03

1) Anderson, J. L., "A local least squares framework for ensemble filtering," *Monthly Weather*

Review, **131**, 634-642, 2003.

2) Tippett, M. K., J. L. Anderson, C. H. Bishop, T. M. Hamill, and J. S. Whitaker, "Ensemble square root filters," *Monthly Weather Review*, **131**, 1485-1490, 2003.

3) Zhang, S. and J. L. Anderson, "Impact of spatially and temporally varying estimates of error covariance on assimilation in a simple atmospheric model,", *Tellus*, **55A**, 126-147, 2003.

4)Snyder, C. and F. Zhang, "Assimilation of simulated Doppler radar observations with an ensemble Kalman filter," *Monthly Weather Review*, **131**, 1663--1677, 2003.

5) Bengtsson, T., C. Snyder and D. Nychka, "Toward a nonlinear ensemble filter for high dimensional systems," accepted in *J. Geophys. Res.*, 2003.

6) Zhang, F., C. Snyder and J. Sun, "Impacts of initial estimate and observations on convective-scale data assimilation with an ensemble Kalman filter," accepted in *Monthly Weather Review*, 2003.

7) Tribbia, J. J. and D.P. Baumhefner, "Scale Interactions and Atmospheric Predictability: an Updated Perspective," accepted in *Monthly Weather Review*, 2003.

1.4. Plans to Achieve Goals

A small core of dedicated DAI scientists and software engineers is working together to facilitate the achievement of DAI goals. In addition, other NCAR scientists with interest and expertise in data assimilation are affiliated with DAI by having a fraction of their remuneration paid through DAI funds. The three NCAR DAI principals (Nychka, Snyder and Tribbia) are already acting as affiliated scientists and this group has grown to include other scientists who are interested in playing a key role in data assimilation research. As DAI grows, a group of postdoctoral researchers, graduate students, and short/medium term visitors from the external research community will also be in residence at NCAR.

This DAI staff will be actively involved in fundamental data assimilation research. DAI will also maintain active collaborations with a number of NCAR research activities and with selected external research and development activities. DAI will focus its effort on a limited number of productive collaborations; this number will grow as DAI resources and experience dictate.

DAI core scientists will provide continuity of effort and expertise in specific areas, such as ensemble data assimilation, variational data assimilation, methods for quantifying uncertainty, and eventually applications of data assimilation for model improvement. Such expertise will also come, as opportunities allow, from shared appointments of NCAR scientists. For collaborations with NCAR projects, the DAI core experts and affiliated scientists provide a conduit for collaboration. NCAR scientists affiliated with a particular NCAR project will obtain technical expertise on data assimilation and software for evaluation of data assimilation methods from the DAI core staff. At the same time, the DAI core staff will gain an understanding of a new assimilation application.

Eventually, the models, observational data, and specialized assimilation applications developed for the project will become part of the DART. Each collaborative project will be overseen by a designated member of the DAI core or affiliated staff.

Prioritized plans for specific accomplishments and products from DAI follow:

A. FY04 accomplishments / products

1. Following a major redesign of software for dealing with real observations, DART will be beta-released for community evaluation. Several university collaborators have expressed interest in using DART for teaching purposes.
2. Work will continue on developing an ensemble filter system for CAM in collaboration with CGD. The capability to assimilate NCEP operational observation data will be added and CAM's capabilities as a forecast model will be evaluated.
3. Research on capabilities of ensemble filters will continue. In particular, robust methods to deal with problems of filter divergence and small ensemble size will be completed.
4. Improved ensemble filters for mesoscale applications in WRF will be developed in collaboration with MMM. A capability to assimilate real observations in the WRF filter will be developed and coordinated with existing WRF variational assimilation software.
5. Development of an ensemble filter for the operational NCEP global model will continue. Additional comparisons to the operational assimilation schemes will be completed.
6. A collaboration with COSMIC will begin to evaluate forward observation operators for GPS radio occultation observations; these methods will be incorporated in DART.
7. The possibility of extending the CAM filtering system to WACCM will be investigated in collaboration with CGD and ACD.
8. Initial efforts to coordinate WRF and CAM ensemble filtering systems will commence. The goal (FY05) is to enable the use of CAM assimilation fields as boundary conditions for WRF regional ensemble assimilations.
9. An exploration of the possibility of assimilating data from the TIMED satellite for the upper atmosphere will be initiated.
10. An informal DAI seminar series will be initiated.
11. DAI will continue supporting a postdoc with GSP.

If additional funds were to become available, the following activities would be undertaken:

12. Variational assimilation methods will be added to DART for one or more larger models. Comparison of the capabilities of variational and ensemble assimilation methods will be expanded ($180,000 MMM S).
13. DAI will initiate a sabbatical research program to host longer term visitors from operational centers and universities ($50,000).

B. FY05 accomplishments / products

1. DAI will hold a workshop on research and educational use of the DART in conjunction with a joint GSP/DAI/SAMSI workshop on ensemble data assimilation.
2. DAI will continue to support NCAR and external research.

3. A prototype coherent global/regional ensemble assimilation system will be developed, probably using WRF with CAM or the NCEP GFS.
4. The information content of GPS observations will be evaluated in filter assimilation systems.
5. Operational parallel tests of the NCEP GFS filter will be evaluated.
6. A new research thrust aimed at understanding systematic error, quality control of observations, and model improvement will commence. Of particular interest will be efforts to use data assimilation methodologies to tune and evaluate the performance of model parameterizations.
7. In coordination with the completion of NASA's ESMF project, DART will be updated to be consistent with ESMF interfaces.
8. Maintenance and development will continue for DART.
9. DAI will continue to support postdocs.
10. The DAI seminar series will continue and will include more external guest speakers.

Additional funds would be required for the following:

11. Research will continue on variational assimilation algorithms and possible ensemble/variational hybrid methods ($180,000 MMM S).
12. The DAI sabbatical program will continue ($50,000).
13. Measures of uncertainty and forecast skill appropriate for assimilation evaluation will be developed ($56,000, 1/3 Sci. 1 MMM).

C. FY06 accomplishments / products

1. Ongoing activities with DART will continue.
2. Assimilation techniques for tuning and evaluating model parameterizations will be tested in global and regional models.
3. One or more collaborative projects with operational prediction centers will be formalized.
4. Efforts to design a nearly automated, self-calibrating data assimilation system will be accelerated.
5. Research into adaptive observations and observing system design will be initiated with formal links to activities such as THORPEX.
6. Possible assimilation applications for the ocean will be explored.

Additional funds would be required for the following:

7. Research will continue on variational assimilation algorithms and possible ensemble/variational hybrid methods ($180,000 MMM S).
8. The DAI sabbatical program will continue ($50,000).
9. A mature DART would require significant additional support to be widely released for use by the university community ($400,000 for Software Engineer and PS).

1.5. NCAR Team

J. Anderson (CGD/MMM), D. Nychka (CGD/GSP), C. Snyder (MMM), J. Tribbia (CGD), T. Hoar (CGD), K. Raeder (CGD), H. Liu (CGD), A. Caya (MMM), S. Rizvi (MMM), D. Barker (MMM)

1.6. Internal and External Collaborators

W. Skamarock, J. Sun (MMM)
W. Kuo (COSMIC)
R. Saravanan (CGD)
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