COMET Cooperative Project Final Report

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Type of Project: Cooperative

Project Title: Development of a High Resolution Ensemble Kalman Filter for Operational Analysis and Short-term Forecasting at the National Weather Service

UCAR Award No.: Z10-81101

Date: 9/30/2011

Section 1: Summary of Project Objectives

The focus of this project was to compare two high-resolution surface analysis methods currently in place at the National Weather Service (NWS) to a new ensemble-based technique. The two operational NWS surface analysis methods are the match-observations-all (MOA) system, run locally at different weather forecast offices (WFOs), and the real time mesoscale analysis (RTMA), run at the Environmental Modeling Center (EMC) and distributed to the WFOs. Both systems produce gridded hourly surface analyses and are performed at 2.5-km resolution (RTMA was upgraded from 5-km to 2.5-km grid spacing during the coarse of this project). Both systems assimilate surface observations and combine them with a first-guess field produced by a numerical weather prediction model to produce an analysis. The MOA system uses a 12-km Weather Research and Forecasting (WRF) model real-time forecast run at the University of Washington as a first guess, and subsequently matches observations exactly at their locations in the first guess field. Information is then spread spatially in the analysis using weighting functions that reduce the influence of observations farther from their locations. The RTMA is a two-dimensional variational assimilation system that uses the Rapid Update Cycle 1-hr forecast as a first guess. Unlike the MOA, the RTMA takes observation and first-guess uncertainty into account, and uses climatological covariances to spread observational information spatially during assimilation.

The ensemble-based technique used in this work is the ensemble Kalman filter (EnKF). The EnKF spreads observational information spatially and into other variables using flow-dependent covariances derived from an ensemble of forecasts. In turn, the EnKF presents a variety of potential advantages over the MOA and RTMA: 1) analyses are produced with flow-dependent relationships among atmospheric variables that may be particularly important in the complex terrain of the Pacific Northwest, 2) flow-dependent analysis uncertainty is straightforward to create, and 3) the EnKF inherently produces fully three-dimensional analyses and forecasts, both of which don't exist within the MOA and RTMA. Thus, the primary objectives of this project were to:

- Determine whether a WRF-model EnKF can match or exceed the quality of analyses produced by the current NWS high-resolution operational surface analysis techniques MOA and RTMA
- Determine the usefulness of WRF-model EnKF analysis uncertainty in the NWS forecasting process
- Determine the quality and usefulness of probabilistic short-term forecasts produced by a WRF-model EnKF in an operational setting

Section 2: Project Accomplishments and Findings

In order to achieve the stated goals of this project, two different evaluation procedures were instituted – 1) an objective, historical evaluation of EnKF and RTMA wind and temperature surface analyses (MOA could not be run historically), and 2) a subjective evaluation of EnKF, RTMA, and MOA surface wind and temperature analyses by NWS forecasters at participating WFOs (Seattle, Pendleton, Spokane, Portland, Medford). The historical evaluation involved the assimilation of identical observations and observational uncertainties on a 6-hr cycle with RTMA and EnKF over a 2-month period (October/November of 2009). The first-guess field was also identical for both systems, and analyses were verified against an independent set of unassimilated observations. The EnKF used a WRF-model 80-member ensemble, and both systems were run at 12-km and 4-km grid spacing. The EMC Global Statistical Interpolation (GSI) two-dimensional system was used to produce RTMA analyses, mirroring the North American operational configuration over the Pacific Northwest. Bias was removed from the first-guess field prior to assimilation.

A variety of parameters were first tuned over a week of assimilation cycles within the EnKF and RTMA to produce optimal analyses. These parameters involve the extent observational information is spread in both systems (localization), the weight of the background error variance in RTMA, and the degree of ensemble inflation in the EnKF. The tuned parameters were then used over a 2-month period (roughly 200 assimilation cycles) to produce EnKF and RTMA surface analyses.

At both 12-km and 4-km grid spacing, EnKF wind analyses were superior to those of the RTMA (13% improvement in RMS analysis error at 12km, 11% at 4km). Interestingly, however, temperature analyses were degraded in the EnKF compared to the RTMA (11% improvement in RTMA at 12km, 8% at 4km). This improvement appeared to be independent of the bias removal scheme, as these results were unchanged among cases both with and without bias in the first-guess field.

The subjective evaluation of EnKF, RTMA, and MOA surface analyses involves real-time assessment by NWS forecasters and was designed to reveal the strengths and weaknesses of the different analysis techniques from a day-to-day operational perspective in different areas of the domain (i.e. coastlines, complex terrain). A 10-question web-based form was created using University of Washington web software for each participating WFO, and real-time, online assessment commenced in September 2011. Both 00 and 12 UTC analysis cycles are assessed on a voluntary basis by NWS personnel over a 2-month period, and this evaluation remains ongoing. Early results suggest equivalent performance among the RTMA and EnKF for the surface temperature field, but improved performance by EnKF regarding the surface wind field.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

Benefits from the operational perspective include enhanced collaboration and interaction with the research community, operational access to an additional high resolution analysis and a renewed focus on the operational use of real time, high resolution analyses at the local forecast office. WFO Seattle maintins a continued relationship with the University of Washington, Department of Atmospheric Science. The COMET Cooperative Project on the development and evaluation of the EnKF analysis and short term forecast system has been another strong link between the university and the NWS. This collaboration in implementing an evaluation plan, developing software and strategies for delivering data and products to local offices and the exploration and evaluation of the meteorology involved in the project has acted to strengthen the operational and research ties in the Pacific Northwest and perhaps on a larger scale as well. The operational access to the high-resolution EnKF analysis at the local offices has proven to be a powerful resource in itself, as well as brining a secondary benefit in terms of evaluation of other operationally used analysis in the local offices. In addition, the framework of the evaluation has facilitated a renewed interest in the operational use and interpretation of high resolution analysis at the local office level throughout the northwest, hopefully furthering the effort of implementing a nationally maintained Analysis of Record (AoR).

Lessons learned from the operational perspective include the reminder that significant differences in the data and software requirements between operational and research meteorology continue to exist and represent a continued challenge to future collaborative work. Many of the delays and problems encountered during the project dealt with identifying and addressing data and software differences, ultimately reducing the effectiveness and efficiency of this project. This is especially critical in a short-term effort such as this.

Section 4: Benefits and Lessons Learned: University Partner Perspective

A variety of benefits to the universities involved in this work have been realized during this project. The most important is the successful implementation of the RTMA analysis procedure on university computers. Run operationally at EMC, the RTMA has rarely been used in a university setting to conduct research in tune with the "research to operations" goals of the COMET program. By successfully implementing the RTMA at both Texas Tech University and the University of Washington, an operational system could be examined in a research environment, allowing the goals of this study to be satisfied. Furthermore, the RTMA and its parent system the GSI can now be used at both universities to build upon this work and to engage in new studies involving variational data assimilation. Another primary university benefit is the successful creation of a real time data transfer technique to allow easy transition of research products into the NWS AWIPS system for evaluation. Such a technique means future collaboration between universities and the NWS can be significantly smoother, and is already being leveraged in an active CSTAR project involving Texas Tech University and the Lubbock, TX WFO.

A number of lessons have also been learned during this project. Although eventually successful, the implementation of the operational RTMA technique on university computers was long and arduous. Porting the RTMA to a different computing system and configuring the RTMA on that system and its associated files was very difficult. This process began with Dr. Ancell's attendance at the GSI workshop at the WRF model Developmental Testbed Center (DTC) in Boulder, CO in June of 2010, and successful university RTMA runs were not performed until June 2011. These difficulties will be considered in future proposals involving this type of transition. As a result, since most of the work involved in this project relied on the successful execution of the RTMA system on university computers, it is anticipated that the full amount of expected research results will not be completed until after this project ends.

Section 5: Publications and Presentations

A publication involving the results from the objective evaluation of this project is planned for submission to the American Meteorological Society journal *Weather and Forecasting* in the coming months following the project deadline. A presentation involved with this project was also given:

“Comparison of RTMA and Ensemble Kalman Filter Surface Analyses”, Joint Session: 15th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Ocean, and Land Surface/24th Conference on Weather and Forecasting and 20th Conference on Numerical Weather Prediction, American Meteorological Society (AMS) Annual Meeting, Seattle, WA, January 23-27, 2011.

Section 6: Summary of University/Operational Partner Interactions and Roles

The following responsibilities were undertaken by the project participants during this project:

University Partner

- Attend GSI workshop and learn GSI/RTMA assimilation system
- Work closely with EMC staff (Manuel Pondeca, Michael Leuken) to properly configure GSI/RTMA system on university computers
- Fully Implement EMC operational GSI/RTMA system at Texas Tech University/University of Washington
- Execute EnKF and RTMA runs over 2-month period and evaluate subsequent surface analyses
- Conduct webinar involving participating NWS WFOs for training purposes on how to subjectively evaluate EnKF, RTMA, and MOA in real time
- Maintain regular meetings with Seattle WFO to update on work status and discuss future project plans
- Enable data transfer technique from University of Washington to the Seattle WFO of grids that can be used in NWS AWIPS system
- Execute real-time EnKF and RTMA analyses and supply them to the Seattle WFO for subjective analysis and distribution to other participating WFOs

Operational Partner

- Provide additional training resources for participating NWS WFOs
- Maintain regular meetings with the University of Washington as well as neighboring WFOs to update on work status and discuss future project plans

- Develop data transfer technique from WFO Seattle to surrounding WFOs of grids that can be used in NWS AWIPS system
- Develop and run a data assimilation system to ingest common set of observations used by the project analyses systems into the MatchObsAll analysis system.
- Develop and run a specialized version of the MatchObsAll analysis system to run over the project domain and disseminate this analysis to neighboring WFOs for the evaluation.
- Provide feedback during the evaluation on quality and usefulness of the analyses in local area of responsibility.
- Troubleshoot and support data feed to local WFOs during the evaluation as well as act as a conduit between the University and local forecast offices.