Convective-scale Warn-on-Forecast:
The Severe Weather Forecast Improvements Project

Report on Project Activities
March 2011 through February 2012

Progress during second project year (March 2011 – February 2012)

VORTEX2 . Radar observations from the Goodland, KS, and Pueblo, CO, WSR-88Ds have been manually quality controlled for the 11 June 2009 Colorado tornadic supercell case. Several groups are working together on high-resolution multi-platform analyses and simulations of the 18 May 2010 Dumas, TX and 13 June 2010 Booker, TX tornadic supercells observed by VORTEX2.

WRF, Unipost, and NCL were configured to provide 15-min output from the High-Resolution Rapid Refresh (HRRR) model, both for real-time and retrospective forecasts. Retrospective full-CONUS 0-6 h HRRR forecasts with 15-min output were produced for the following initial times: 1800 UTC 5 June, 2100 UTC 5 June, 2100 UTC 11 June, 0000 UTC 12 June, and 0300 UTC 12 June 2009. These are high-priority VORTEX2 cases for which NSSL is producing quality-controlled radar datasets. 15-min HRRR output in NetCDF, GRIB1, and GRIB2 formats was provided to Warn-on-Forecast partners.

Data Quality Control. Several automated radar QC techniques have been implemented in WDSS-II and tested. These include reflectivity QC methods (AP-Remove, QCNN, and CREM) as well as velocity QC methods (legacy WSR-88D dealiasing, 2D dealias). The code for a third velocity method, AR-VAD (Xu) was also obtained, but the implementation has been put on hold with the departure of key personnel. Some initial comparison statistics were generated for these methods compared to the manually quality controlled "truth" data sets, but a more comprehensive and careful examination is needed.

A method for detecting ground clutter based on the Clutter Residue Editing Map (CREM) technique was implemented in the Observation Processing and Wind Synthesis (OPAWS) and the DORADE Radar Editing Algorithms, Detection, Extraction, and Retrieval (DREADER, developed by Curtis Alexander) software packages. Clutter maps are based on the frequency of occurrence of Doppler velocity close to zero and reflectivity above a specified threshold. This method for detecting and removing ground clutter has proven particularly valuable for mobile radar datasets and for older WSR-88D datasets.

WDSSII Java code was developed to convert radar observations in WDSSII-netcdf to Foray-netcdf formats. One lingering issue to be addressed is that the Foray-netcdf produced by this program cannot be read into Solo due to incorrect netcdf headers; however, it apparently can be read by the model data ingest routines that require these data. A workaround has been created to fix the header issues.

Manual quality control of phased array radar observations (MPAR) from the 14 June 2011 Norman, Oklahoma, microburst event have been completed. In addition, manual quality control of MPAR observations and WSR-88D observations from the Twin Lakes and Fredrick, OK, sites for the Oklahoma tornadic supercells on 24 May 2011 are available.

Data Assimilation. A prototype system for assimilating reflectivity data on the HRRR 3-km grid was developed and tested for a retrospective period 11-19 August 2011.

Latent heating on the 3-km grid was applied during one hour of forward model integration, based on reflectivity data every 15 min, before a 15-h HRRR forecast was produced. Qualitative improvement was apparent in reflectivity forecasts for some cases (Fig. 1). For the full retrospective period, the 1-h and 2-h forecast critical success index (CSI) was increased by assimilating reflectivity data on the 3-km (HRRR) grid rather than on the 13-km (RAP) grid, but CSI was changed very little for forecasts of 3 h or more.

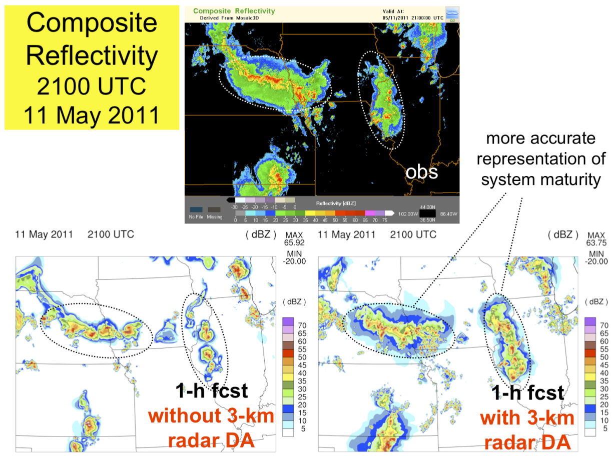

Figure 1. Observed (top), and HRRR 1-h forecast (bottom) composite reflectivity for multiple convective systems in the Plains and Upper Midwest on 11 May 2011. The forecast illustrated in the lower left was initialized from the Rapid Refresh model at 2000 UTC, with diabatic digital filter initialization (DDFI) applied on the 13-km grid. The forecast illustrated in the lower right was initialized from the Rapid Refresh analysis at 1900 UTC followed by reflectivity data assimilation on the HRRR grid at 15-min intervals from 1900 to 2000 UTC.

A four-dimensional asynchronous ensemble square root filter (4DEnSRF) algorithm has been developed for WRF and ARPS, and is now implemented in the parallel EnKF framework of CAPS and is being further refined. The 4DEnSRF system is being applied to a fast-moving tornadic supercell that occurred on 10 May 2010. Preliminary results show clear advantages of the 4DEnSRF algorithm. With 4DEnSRF, elevation scans are analyzed at the times they are taken; excellent flow structures are obtained for the tornadic supercell of 10 May 2010.

The CAPS parallel EnKF system has been enhanced to include all conventional observations used by ADAS and ARPS 3DVAR, and the correctness of their assimilation on parallel platforms has been verified. The efficiency of the system has been further improved by careful load balancing for data from large radar networks. This EnKF system has been applied to two VORTEX2 cases: the 10 May 2010 Oklahoma-Kansas tornado outbreak and 5 Jung 2009 Goshen County, Wyoming, tornadic supercell. The performance of the system for assimilating multi-scale observations over a mesoscale domain with a storm-scale nest is being investigated for the 10 May 2010 case. To include both the mesoscale and storm-scale features important on this day, storm-scale ensemble analyses at 4-km grid spacing are nested inside the regional EnKF analysis based on the WRF model for the Rapid Refresh domain with 40-km grid spacing.

Results show that the analyzed reflectivity exhibits a good fit with the observations. A line of strong, isolated storms in central Kansas and Oklahoma is reasonably well captured by the ensemble forecasts up to several hours. Further testing is underway. The effect of multi-physics on ensemble forecasts of the 5 June 2009 Goshen County tornadic supercell storm is presently being tested with a 1-km grid nested inside 3-km forecasts. This work is still in progress and will be part of the intercomparison project.

Progress has also been made with the ARPS 3DVAR system, including an assessment of the impact of including a diagnostic pressure equation constraint (DPEC) within the 3DVAR on the analysis and forecast of convective storms. The variational assimilation of radar reflectivity has been incorporated into the ARPS 3DVAR system, which paves the way for assimilating reflectivity in a hybrid system. Comparison of this method with several other approaches for assimilating reflectivity data, including those in WRF-VAR, COAMPS-VAR and ADAS, is being carried out. A Local Ensemble Transform Kalman Filter (LETKF) has been modified to assimilate radar observations and initial testing indicates that it is performing well, yielding results very similar to those from an EnKF. A parallel implementation is under development. An initial interface between the ARPS EnKF system with WRF model has been implemented and tested with OSSE data.

Over the past year, ensemble data assimilation systems have been used to test the Warn-on-Forecast concept on several tornadic supercell thunderstorm cases, a microburst case, a flash flood event and a mesoscale convective system event. Results indicate that the approach works well for isolated thunderstorms (Fig. 2), but is more challenging when applied to mesoscale convective systems where the cold pool strength plays a large role in the accuracy of the ensemble forecasts. For these mesoscale events, it is important to get the mesoscale structures represented correctly, which is difficult with present observational datasets. Thus, we also are investigating the benefits of assimilating satellite observations to improve representations of the mesoscale environment. Results from assimilating Atmospheric Infrared Sounder (AIRS) temperature and dewpoint profiles have been positive, and cloud cover information from geostationary satellites are now being explored.

A framework for the inter-comparison of different radar-data assimilation schemes is being developed. Initial testing is underway for the 27 April 2011 tornado outbreak in the southeastern US. Analyses and forecasts on WRF grids with a 3-km horizontal grid spacing are being compared for three sub-hourly radar-data assimilation methods: latent-heating specification based on reflectivity data, EnKF assimilation of reflectivity and Doppler velocity data, and 3DVar assimilation of reflectivity and Doppler velocity data. WSR-88D datasets were automatically quality controlled with OPAWS for 14 radars for this case. In preliminary experiments, Doppler velocity and reflectivity data from 4 radars were assimilated into a 45-member WRF ensemble. The following characteristics were noted in 0-1 h ensemble-based probabilistic forecasts of the tracks of rotating updrafts: maintenance of supercells that were already mature at the initialization time, broadening of probability swaths with time for these mature storms, development of new rotating updrafts during the forecast, and agreement between the directions of motion of simulated rotating updrafts and observed tornadoes.

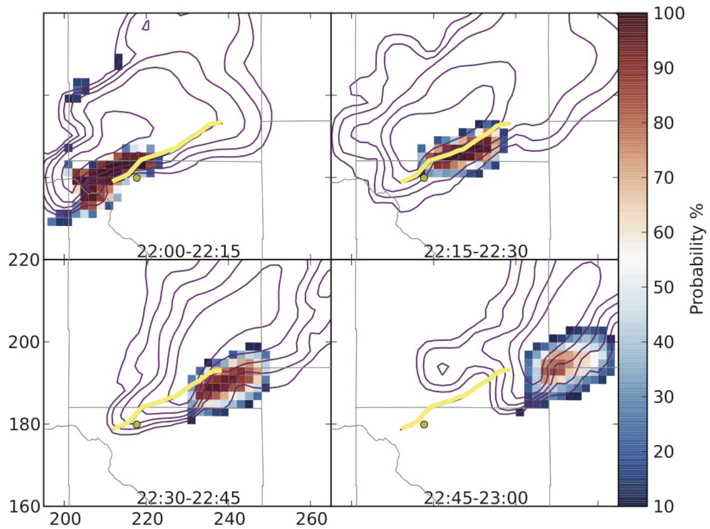

Figure 2. Ensemble probability of vorticity exceeding 0.00375 s^{-1} at ~ 1 km AGL for the 8 May 2003 forecast experiment for four 15-min time windows starting at 2200 UTC 8 May 2003. Simulated radar reflectivity regions greater than or equal to 30 dBZ and 50 dBZ are shaded in light and dark gray, respectively, for ensemble member 7 at the beginning of each time interval for each panel. Overlaid in each panel is the observed tornado damage track (black outline), the location of Moore, Oklahoma (yellow dot), and county borders (thin black lines). The time interval (UTC) of each 15-min period is indicated in each panel.

Hazardous Weather Testbed. A three-dimensional variational assimilation (3DVAR) real-time system was implemented for the spring Hazardous Weather Testbed Experimental Warning Program on a 1 km grid domain. The 3DVAR assimilates all nearby radar observations to create a fully three-dimensional storm analysis every 5 minutes with background environmental conditions provided by the North American Mesoscale model. Fields from the 3DVAR analyses were displayed in AWIPS for use by forecasters in the HWT/EWP. Data were processed (and subsequently archived) for four floating domains, typically from 17 UTC to 02 UTC each day, from April 17 to July 17, 2011. The actual forecaster-based evaluation occurred during four weeks between May 9 and June 10 2011, with data from all real-time events archived.

The OUN WRF hourly-updated forecasts became available in the Hazardous Weather Testbed in May 2011. During the 2011 Spring Experiment, forecasters evaluated several experimental products derived from the OUN WRF output. Results from the experiment show that forecaster situational awareness was enhanced by high frequency model output. However, forecasters found high-resolution output somewhat difficult to use during high-stress warning scenarios.

A convection initiation desk was added to the HWT Experimental Forecast Program in 2011 to examine forecasts of storm initiation as well as convective coverage. New methods for extracting information from ensemble forecasts were developed.

Social Science Research. The research project on how K-12 public school district officials anticipated and responded to 2011 NWS tornado warnings has been completed. The research included interviews with 11 participants from six school districts. Several conclusions have significance for the Warn-on-Forecast team. Many of the school district officials' actions, most notably communicating with staff, students, and parents, occur through several phases from when severe weather is approaching to when the tornado warning has passed. "Lead time" for K-12 school district decision makers began several hours before the tornado warning was issued, emphasizing the need to step away from the traditional mindset that a tornado warning lead time is only minutes before a tornado occurs.

Each decision maker made varying decisions according to the local circumstances. Several non-weather factors, such as time of day and location of students, played large roles in determining how they perceived the warning and how they carried out their severe weather plans. When a warning was issued, most participants immediately told their students and staff to "take shelter". These participants prefer more spatial information with clear indication of whether or not the storm is likely to impact their district directly. Overall, the participants indicated that extended tornado warning times would provide more time to go over plans and communicate with others. An annotated bibliography of social science research literature related to the relevant topic of 'Time and Hazards' was created and is available in pdf form on the SSWIM website (www.sswim.org).

A survey to test the efficacy of tornado warning statements was completed by over 1000 participants. Early results show that spotter reports are weightier than Doppler indicated; a sense of dread is most likely to induce shelter-seeking behavior; more information is needed, but not preferred during high stress events; emphasis in text (e.g., bold type or all caps) is preferred since it conveys urgency; a time range for the expected danger is preferred to a general expectation of danger until the warning expires; categorical risks are slightly preferred over percentages.

A study of societal response during the 24 May 2011 tornado outbreak is underway. Advanced notice of this tornado outbreak (very similar to what might be expected from an operational Warn-on-Forecast system) was provided by National Weather Service and television meteorologists. It is speculated that this, in conjunction with intense media coverage of recent tornadoes (notably, in Tuscaloosa and Joplin), led to a massive societal response. Undoubtedly, this saved lives in many instances. However, traffic jams and overcrowded shelters were common in central Oklahoma during the event, potentially putting lives in danger.

Capabilities. The WoF project also has a webpage that outlines the project goals and project plans and lists all the partner institutions (http://www.nssl.noaa.gov/projects/wof). Quality-controlled radar data and various ancillary data from selected case studies are available on the NSSL ftp site for download to project partners.

Summary

The progress made during the second year of the WoF project remains very good.

Thanks to all of the WoF partner institutions for working together and developing the needed collaborations to strengthen the project and build healthy relationships among all the various groups.

Status of Deliverables

NOAA/OAR/National Severe Storms Laboratory

Deliverable	**Completed/Underway**
Quality controlled and supplemental data sets for 11 June 2009 VORTEX2 case completed and available to project partners.	**Completed**
Successful completion of the 2011 HWT Experimental Warning Program with assessment of the performance of the 3DVAR analyses for assisting warning operations.	**Completed**
Assist Norman NWS FO in using 3DVAR in their hourly WRF model forecasts.	**Completed**
Archival of the 3DVAR assimilated fields and corresponding data sets (radars, etc.) from real-time operations.	**Completed**
Development of needed radar data converters.	**Completed**
Development and application of automated radar QC methods in sequential form and testing on available manual QC data sets.	**Completed, results being analyzed.**
Initial results from real data applications of ensemble Kalman filter to the assimilation of radar observations from a supercell thunderstorm case and a mesoscale convective system case.	**Completed**
Develop a website for sharing data for selected cases of interest.	**Completed**
Hold fall 2011 radar data assimilation meeting with NSSL, GSD and CAPS.	**Completed. Report on WoF webpage.**
Written plan to unify the social science research activities within the warn-on-forecast project.	**Underway. Delay due to loss of key personnel.**

NOAA/OAR/ESRL/Global Systems Division

Deliverables	Completed/Underway
HRRR gridded forecast output produced at 15-minute intervals during the 0-3 h forecast time frame and made available to project partners for 5 June and 11 June 2009 cases.	**Completed**
Continued testing of DFI within HRRR.	**Completed**
Initial results from a storm-scale ensemble sensitivity analysis.	**Underway**

NOAA/NWS/NCEP/Storm Prediction Center

Deliverables	Completed/Underway
Successful completion of the 2011 Hazardous Weather Testbed, Experimental Forecast Program with a convection initiation desk.	**Completed**
Assessment of new visualization approaches within the HWT.	**Completed**
Development of a social science research project in collaboration with SSWIM.	**Completed**

NOAA/NWS Norman Forecast Office

Deliverables	Completed/Underway
Successful delivery of hourly-updated WRF model forecasts to the HWT.	**Completed**
Survey questions completed to evaluate efficacy of call-to-action statements in tornado warnings.	**Completed**
Initial comparison of forecasts started using LAPS versus those started using 3DVAR.	**Underway. Delay due to loss of key personnel.**

University of Oklahoma/Center for Analysis and Prediction of Storms

Deliverables	Completed/Underway
Enhanced ARPS EnKF system for multi-scale observations (e.g., radar, surface and upper-air) completed and testing started.	**Completed**
A local ensemble transform Kalman filter (LETKF) system completed and implemented within the ARPS EnKF framework.	**Completed**
An interface for the ARPS EnKF data assimilation system with Advanced Research WRF (ARW) model completed and made available to project partners.	**Underway**

University of Oklahoma/Social Sciences Woven into Meteorology Program

Deliverables	Completed/Underway
Initial results from interviews of K12 school administrators.	**Completed**
Annotated bibliography of social science literature deemed relevant to the WoF project.	**Completed**