

COMET Cooperative Project Final Report

University: Purdue University

Name of University Researcher Preparing Report: Michael Baldwin

NWS Offices: NWSFO Indianapolis, IN, NWSFO North Webster, IN, NCEP/Storm Prediction Center

Names of NWS Researchers Preparing Report: John Kwiatkowski, Jeffrey Logsdon, Steven Weiss

Type of Project: Cooperative

Project Title: An Experimental, Real-Time Prediction System for High-Impact Convective Weather Events

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Section 1: Summary of Project Objectives

The objective of this project was to develop and prototype a real-time system to predict specific characteristics of high-impact convective weather events. This prediction system would be based on a system-oriented approach. Automated analysis procedures, based upon image processing algorithms, would be applied directly to high-resolution NWP model output in order to identify significant convective weather systems in the multivariate forecast data. The objective of applying such automated procedures was to speed up the process of model diagnosis and allow forecasters to focus on weather systems and areas in the forecast that were most likely to be associated with hazardous weather. The products would quickly highlight those regions, and are expected to be particularly useful in processing high-resolution ensemble information, helping to address situations where the forecaster is overwhelmed with a huge volume of information from numerous sources.

Section 2: Project Accomplishments and Findings

To meet these objectives, Purdue researchers implemented twice-daily, real-time runs of the WRF model at 4.25 km horizontal grid spacing over a large portion of the CONUS (Figure 1). These runs were initiated at 0000 and 1200 UTC and used the NCEP operational NAM model output to generate initial and boundary conditions. The WRF runs were produced locally at Purdue on a large Linux cluster that the PIs helped to purchase using departmental (startup) funds. The 0000 UTC run was considered the standard run and was integrated out to 36h. The 12 UTC run was considered an experimental parallel run and was integrated out to 24h. Having a separate parallel run

allowed for real-time testing of new diagnostic output and other modifications to the model configuration before implementation into the full standard daily run.

Application of object-oriented analysis procedures to identify, characterize, and classify precipitating weather systems was accomplished using image processing algorithms that were adapted for use with WRF model output obtained by the NCEP WRF Post Processing system (WPP). For example, Figure 1 demonstrates the results of application of the Baldwin et al. (2005) object identification routine using a 5 mm/hr precipitation threshold for the Super Tuesday (06 Feb) 2008 severe weather outbreak case. The algorithm can identify the larger-scale banded precipitation systems along the northern edge of the system, and discriminate those from the small-scale cellular systems that were predicted over Arkansas.

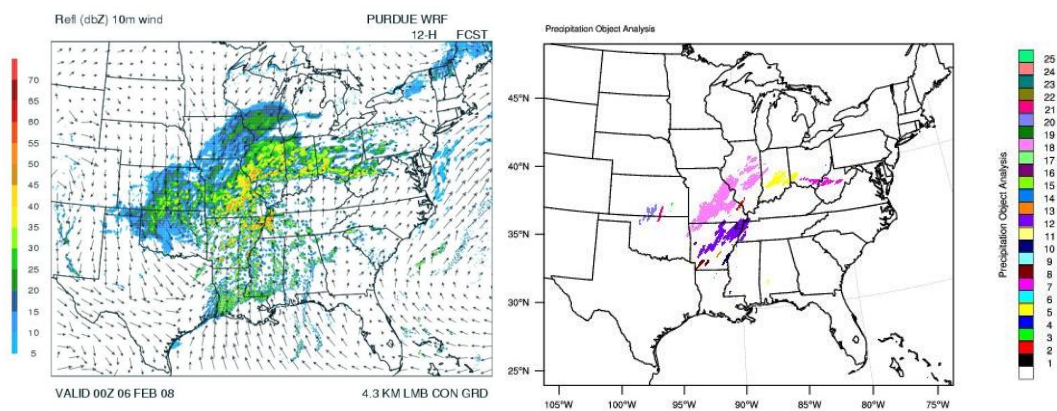


Figure 1. Left panel: simulated reflectivity 1km AGL (dBZ) and 10m wind vector 12h forecast valid 0000 UTC 06 Feb 2008. Right panel: results of precipitation object identification algorithm (different colors represent different precipitation “objects”)

Model output was made available at 30 minute frequency, which was determined to greatly improve the continuity of time-loops of forecast variables such as reflectivity. In addition, the convective-object identification algorithm was applied to the routine forecast output and also made available on the web at 30min intervals. In practice, two object identification algorithms were implemented, “standard” convective objects were identified as contiguous regions of simulated composite reflectivity greater than 40 dBZ. In addition, “potential supercells” were defined as those convective objects that also contained a maximum within-object value of updraft helicity (vertical velocity multiplied by vertical vorticity, integrated over a depth between 2-5km AGL) greater than $50 \text{ m}^2/\text{s}^2$. Forecast soundings at several locations across the state of Indiana and other standard forecast charts were also made available based upon input from NWSFO Indianapolis. These output fields from the Purdue WRF runs were made available to the NWS in real-time during each run on the web at:

<http://wxp.eas.purdue.edu/wrfdata/>

and

<http://wxp.eas.purdue.edu/wrfdata/wrfpara/>

Substantial efforts were made to evaluate the forecasts produced by this system. Forecasts from 2008 were retrieved from a tape archive and compared to radar observations as well as storm reports from the same period. Figure 2 displays a comparison of the frequency of occurrence of simulated composite reflectivity greater than 40 dBZ at each 4.25km grid point, comparing the 00Z runs with the 12Z runs over the 12-36h forecast period. The convective object identification algorithms were applied to the forecast and observed data, and a Euclidean distance-based verification approach was developed by the PIs and graduate students Jacob Carley and Nathan Hitchens.

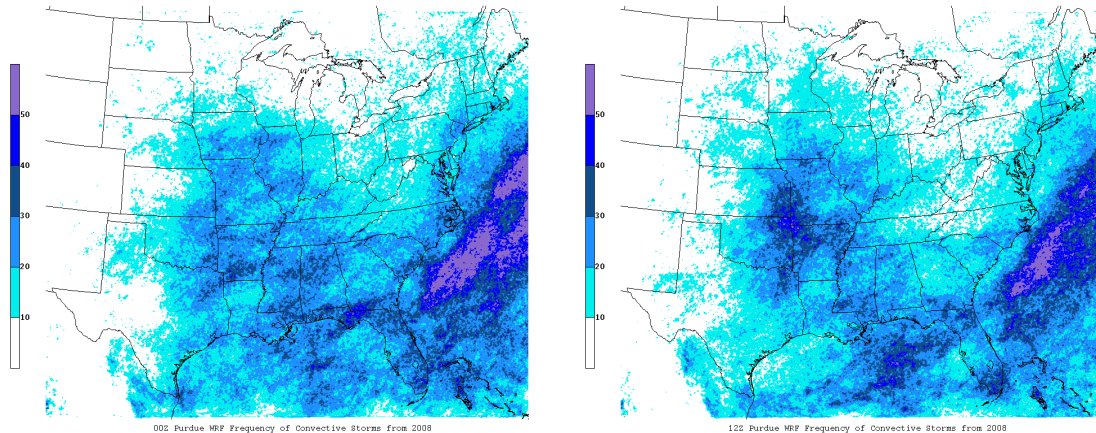


Figure 2. Left panel: simulated composite reflectivity greater than 40dBZ from all available 00Z WRF model runs during 2008, 12-36h forecast period. Right panel: same, except for available 12Z WRF model runs during 2008.

In late October of 2009, graduate student Jacob Carley upgraded the parallel WRF runs to WRF version 3.1.1 and added a 00Z cycle. Additionally, a data assimilation step was also implemented in the parallel runs using NCEP's community Gridpoint Statistical Interpolation 3DVAR system. This added data assimilation routine uses the previous 12hr forecast from the prior parallel run as the first guess and the corresponding current NAM analysis field as the observations. Using this system has allowed for increasing continuity between model runs and has helped mitigate the spin up time required to achieve kinetic energy spectra representative of the mesoscale, therefore making the early hour forecast data more useful. More testing is still required to bring these methods to a reliable level appropriate for the "operational" cycle.

Purdue researchers visited all three of the NWS offices in order to collaborate with NWS partners and discuss project plans with NWS researchers and other interested staff. PIs Baldwin and Trapp visited the Indianapolis office in May 2008, PI Baldwin visited the North Webster office in December 2007, and PI Baldwin visited the Storm Prediction Center in May 2008. PI Baldwin gave a seminar at the North Webster office on the topic of NWP and winter precipitation types in December 2007. PI Baldwin also presented project plans at the Indianapolis office in July 2008 during a regional MIC meeting, where MICs from Lincoln, Chicago, North Webster, Wilmington, Louisville, and

Paducah were in attendance. PI Baldwin gave a seminar at the Indianapolis office on the topic of NWP and convection in February 2009. In addition, PI Baldwin and graduate student Jacob Carley visited the Indianapolis office in February 2009 in order to present and discuss project results with NWS researchers and other interested staff.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

NWS forecasters have benefited from the interaction and collaboration with Purdue researchers during the course of this project. Purdue PIs visited each forecast office, and in the case of IND and IWX, presented training seminars on related topics of the representation of convection and winter precipitation processes in operational NWP. Regarding experimental convection-allowing NWP, SPC continues to play a major role in designing and running the annual NOAA Hazardous Weather Testbed Spring Experiment, which focuses on testing and conducting operationally-oriented evaluation of multiple convection-allowing WRF models including a preliminary storm-scale ensemble forecast (SSEF) system. The initial 4 km SSEF was run first in 2007, and an upgraded SSEF was run in 2008. In 2009, the SSEF expanded to 20 members from the 10 members in the first two years, with NMM and ARPS being added to existing WRF-ARW members. This has allowed SPC forecasters to become very familiar with WRF model output for convective forecasting purposes. The lessons learned during these previous Spring Experiments fed directly into the algorithm development in this project. Purdue researchers used a threshold for updraft helicity that was determined to highlight rotating convective updrafts in the WRF model forecasts and used this threshold in the algorithm that identifies “potential supercell” objects. This provides a foundational background that illustrates the benefit of automated object-oriented classification tools to assist forecasters in interpretation of convection-allowing model output by identifying different convective modes and their associated weather threats. Numerous analysis and diagnostic products for high resolution WRF model runs were developed collaboratively over the course of the project. Purdue researchers were provided valuable feedback regarding new applications of high resolution models, steering their efforts to provide better model guidance for the coming generations of operational models.

The main source of problems that have been encountered during this project have involved the long run time and less than 100% reliability of the Purdue WRF runs. For example, the 00Z run typically does not complete until ~12Z the next morning and is not available in time to be used in the formulation of early-morning forecast products. Updates of the WRF code version also led to less reliable production of these real-time runs. These issues were factors that precluded forecasters from regularly incorporating these experimental products into their operational forecast process. Since these problems resulted from issues with computing resources at Purdue, these issues are discussed in more detail in the upcoming section by the University partner.

Section 4: Benefits and Lessons Learned: University Partner Perspective

Purdue University students benefited by the availability of the twice-daily WRF model runs that were executed at Purdue. Students utilized this output in their own weather

analysis and forecasting (forecast contests and class weather briefings) and benefited by gaining exposure to real-time high-resolution NWP model output. The archive of numerous WRF forecasts was also beneficial in the development of the Euclidean-distance based forecast verification approach, and is expected to continue to have value in future development of new verification techniques and value-added forecasting products. PI Baldwin also supervised an undergraduate research project by Eric Robinson who added new forecast products to the Purdue WRF webpage and performed a case study of the performance of the object-oriented precipitation identification algorithm on the Super Tuesday 2008 severe weather outbreak (Figure 1). This work was presented at the Purdue Undergraduate Research and Poster Symposium in March 2008. PI Baldwin supervised an undergraduate research project by Adam Simkowski who performed a case study of the performance of the convective object identification algorithm on the April 3-4 1974 superoutbreak. This work was presented at the Purdue Undergraduate Research and Poster Symposium in 2009 and won the College of Science Dean's Choice award. PI Baldwin supervised an undergraduate research project by Dave Zelinsky who performed experiments with boundary layer parameterizations in the WRF model for the May 4, 2007 Greensburg, KS tornado case. This work was presented at the Purdue Undergraduate Research and Poster Symposium in 2009. The results from each of these undergraduate research projects led to various improvements in the real-time WRF products for this project, as well as valuable research experiences for these students.

The main source of problems that were encountered during this project involved issues with computing resources. The twice-daily WRF runs were executed on a Linux cluster at Purdue that was acquired in 2007. While the job queues on the cluster were designed to allow large jobs into the system with minimal delay, in practice delays in the job queues were frequently a major problem. To attempt to resolve this problem, the PIs worked with other cluster users to take advantage of other resources. However, the overall success rate for the twice-daily, real-time WRF runs at Purdue ended up at less than 50% over the course of the two year project period. A major amount of effort was spent in configuring and re-configuring scripts to run the model and post-processing routines in order to make them as fast and reliable as possible. The effort would often be unsuccessful due to overflowing job queues and unresolved IT issues. Storage issues were another secondary issue and the PIs worked with hardware specialists at Purdue to work around those problems. The time required to complete a full run was also an issue. For example, the 00Z run typically would not complete until ~12Z the next morning. The lack of timely and reliable model output impacted the data availability for the NWS forecasters and limited the usefulness of these products in the operational forecast workflow. Purdue acquired a newer (and much larger) cluster late in the summer of 2009 which improved reliability and timeliness somewhat, but not as significantly as initially expected. Efforts are continuing to improve the IT processing and the reliability and timeliness of the model runs.

The release of WRF version 3.0 during the first year of the project also caused major problems. The twice-daily Purdue WRF runs were upgraded to WRF 3.0 in July 2008, and immediately the PIs noticed that the character and quality of the forecasts changed significantly for the worse. Version 3.0 used the identical physics configuration as

version 2.2, but produced widespread light precipitation across the domain, along with much cooler near surface temperatures in the vicinity of this light rainfall. For example, Figure 3 shows the results of testing by the PIs of these two versions of the WRF code. WRF 3.0 is producing the widespread light precipitation, which actually gets worse and worse as the model executes. These test runs were generated using global reanalysis data, but the daily real-time Purdue WRF runs demonstrated similar characteristics. This problem was resolved by switching back to version 2.2 for the twice-daily runs. The release of updated WRF code (version 3.0.1.1) resolved this problem, and this version was implemented into the routine daily runs in late August 2008 and was used throughout 2009.

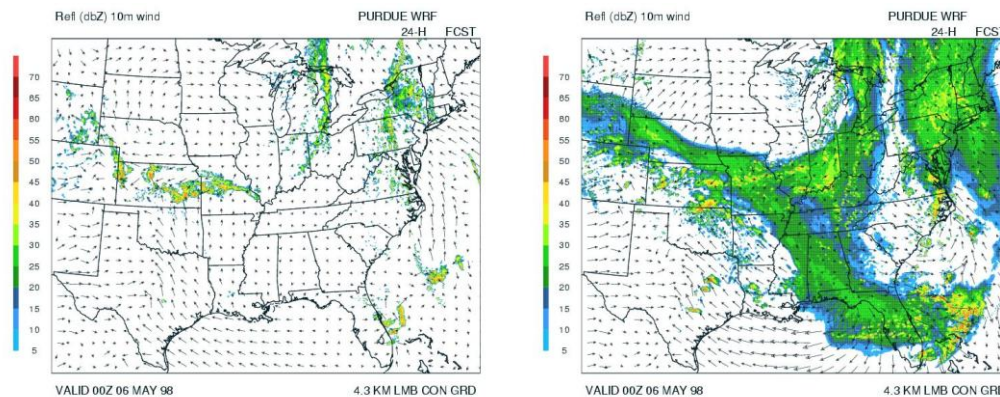


Figure 3. 24h forecast of 1km AGL equivalent reflectivity (dBZ) and 10m wind valid 0000 UTC 06 May 1998. Results from tests of WRF 2.2 (left) and WRF 3.0 (right) for the same configuration as the twice-daily Purdue WRF runs. Runs were executed on the supercomputer at NCAR using standard executables that are maintained by the NCAR wrfhelp staff. NCEP/NCAR global Reanalysis data were used as initial and boundary conditions.

Section 5: Publications and Presentations

Baldwin, M.E., 2008: Multivariate cluster analysis for automated identification of precipitating weather systems. 19th conference on Probability and Statistics, AMS Annual Meeting, New Orleans, LA, January 21-24, 2008.

Robinson, E. D., M. E. Baldwin, and R. J. Trapp, 2008: Object-Oriented Forecast Analysis of the 2008 Super Tuesday Tornado Outbreak, Purdue Undergraduate Research and Poster Symposium, Purdue University, March 31, 2008.

Baldwin, M. E., and J. Carley, 2009: Tracking precipitating weather systems in forecast and observed data. Presentation for 7th Conference on Artificial Intelligence and its Application to the Environmental Sciences, AMS Annual Meeting, Phoenix, AZ, January 11-15, 2009, J7.3.

Carley, J., M. E. Baldwin, J. Trapp, J. Kwiatkowski, J. Logsdon, and S. J. Weiss, 2009: Ongoing development of an experimental, real-time prediction system for high-impact convective weather events. Presentation for 23rd Conference on Weather Analysis and Forecasting/19th Conference on Numerical Weather Prediction, AMS, Omaha, NE, June 1-5, 2009, 3B.4

Carley, J., M. E. Baldwin, J. Trapp, J. Kwiatkowski, J. Logsdon, and S. J. Weiss, 2009: Operational High-Performance Numerical Weather Prediction for Severe Weather Events using Purdue's Pete Cluster. Presentation for Purdue Student Chapter of the Society for Industrial and Applied Mathematics Student Conference, West Lafayette, IN, Mar 30, 2009.

Baldwin, M. E., 2009: Evaluation of numerical forecasts of convective precipitation system containing realistic detail. Presentation for Purdue EAS Departmental Seminar, 3 Sep 2009.

Baldwin, M. E., 2009: Verification of the time evolution of precipitation systems in numerical weather forecasts. In: *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation*. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, Anderssen, R.S., R.D. Braddock and L.T.H. Newham (eds), July 2009, 4177-4183. ISBN: 978-0-9758400-7-8.
(<http://www.mssanz.org.au/modsim09/J1/baldwin.pdf>)

Carley, J. R., N. M. Hitchens, M.E. Baldwin, R. J. Trapp, J. Kwiatkowski, J. Logsdon, S. J. Weiss, 2010: Object-oriented Euclidean Distance Measures for Verification of Numerical Weather Prediction Models, *Wea. Forecasting, in prep*

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

Purdue researchers visited all three of the NWS offices in order to collaborate with NWS partners and discuss project plans with NWS researchers and other interested staff. PIs Baldwin and Trapp visited the Indianapolis office in May 2008, PI Baldwin visited the North Webster office in December 2007, and PI Baldwin visited the Storm Prediction Center in May 2008. PI Baldwin gave a seminar at the North Webster office on the topic of NWP and winter precipitation types in December 2007. PI Baldwin also presented project plans at the Indianapolis office in July 2008 during a regional MIC meeting, where MICs from Lincoln, Chicago, North Webster, Wilmington, Louisville, and Paducah were in attendance. PI Baldwin gave a seminar at the Indianapolis office on the topic of NWP and convection in February 2009. In addition, PI Baldwin and graduate student Jacob Carley visited the Indianapolis office in February 2009 in order to present and discuss project results with NWS researchers and other interested staff.

Project Roles:

Michael Baldwin (Purdue University) – PI: project manager, algorithm development, forecast system evaluation, real-time WRF model system implementation and maintenance

Jeff Trapp (Purdue University) – PI: algorithm development, forecast system evaluation

Jacob Carley (Purdue University) – graduate student researcher: algorithm development, real-time WRF model system implementation and maintenance, web product development

Steven Weiss (NWS/NCEP/SPC) : forecast system evaluation

John Kwiatkowski (NWS/IND) : forecast system evaluation

Jeffrey Logsdon (NWS/IWX) : forecast system evaluation