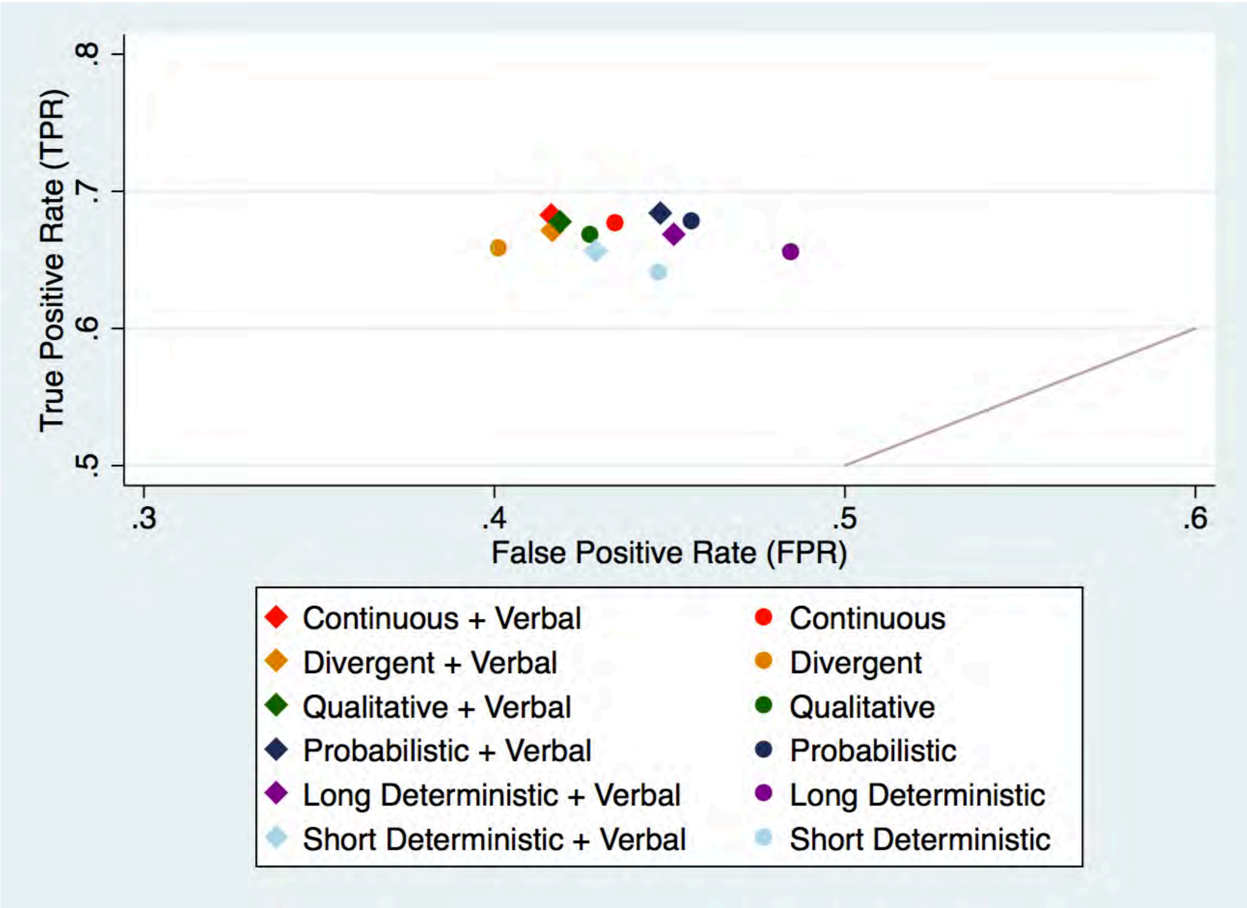

Cooperative Institute for Mesoscale Meteorological Studies

Annual Report

Prepared for the
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research

Cooperative Agreement NA11OAR4320072

Fiscal Year – 2013

Cover figure – *Receiver Operating Characteristic diagram showing the proportion of times that lab participants protected out of all times a tornado occurred (true positive rate) and protected out of all times a tornado did not occur (false positive rate). A perfectly discriminating person would be represented in the upper left corner. In this study, for all types of graphics provided to the participants, the true positive rate was relatively constant across all graphics. The short deterministic graphic group recorded the lowest true positive rate. What varied most among the different graphic types provided was the false positive rate. People receiving deterministic information, and specifically the long deterministic graphic, had the highest false positive rate. Notably, people receiving the probabilistic graphic that did not contain color clustered with those who received the deterministic graphics; they also had higher false positive rates than those provided with color-emphasized probabilistic information. Generally, being provided verbal information (the diamonds in the graphic) helped people to reduce their false positive rate. More on this project, "The Impact of Uncertainty Information on Tornado Warning Response: Developing Recommendations for Warning Best Practices" by Kim Klockow, Renee McPherson, and Rick Thomas, can be found on p. 262.*

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COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES
THE UNIVERSITY OF OKLAHOMA

Annual Report of Research Progress Under
Cooperative Agreement NA11OAR4320072
During the 2013 Fiscal Year

Peter J. Lamb, Director
Randy A. Peppler, Associate Director
Tracy L. Reinke, Executive Director of Finance and Operations

INTRODUCTION

General Description of CIMMS and its Core Activities

The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) was established in 1978 as a cooperative program between the National Oceanic and Atmospheric Administration (NOAA) and The University of Oklahoma (OU). CIMMS provides a mechanism to link the scientific and technical resources of OU and NOAA to create a center of research excellence in weather radar, stormscale meteorological phenomena, regional climate variations, and related subject areas – all with the goal of helping to produce better forecasts and warnings that save lives and protect property.

CIMMS promotes cooperation and collaboration on problems of mutual interest among university researchers and the NOAA Office of Oceanic and Atmospheric Research (OAR) National Severe Storms Laboratory (NSSL), National Weather Service (NWS) Radar Operations Center (ROC) for the WSR-88D (NEXRAD) Program, NWS NCEP (National Centers for Environmental Prediction) Storm Prediction Center (SPC), NWS Warning Decision Training Branch (WDTB), NWS Norman Forecast Office (OUN), and NWS Training Center (NWSTC) in Kansas City, Missouri.

CIMMS research contributes to the NOAA mission through improvement of the observation, analysis, understanding, and prediction of weather elements and systems and climate anomalies ranging in size from cloud nuclei to multi-state areas. Advances in observational and analytical techniques lead to improved understanding of the evolution and structure of these phenomena. Understanding provides the foundation for more accurate prediction of hazardous weather and anomalous regional climate. Better prediction contributes to improved social and economic welfare. Because small-, meso-, and regional-scale phenomena are also important causes and manifestations of climate, CIMMS research is contributing to improved understanding of the global climate system and regional climate variability and change. CIMMS promotes research collaboration between scientists at OU and NOAA by providing a center where government and academic scientists may work together to learn about and apply their knowledge of stormscale weather and regional-scale climate processes.

CIMMS is part of the National Weather Center, a unique confederation of federal, state, and OU organizations that work together in partnership to improve understanding of the Earth's atmosphere. Recognized for its collective expertise in severe weather, many of the research and development activities of the Center have served society by improving weather observing and forecasting, and thus have contributed to reductions in loss of life and property.

In addition to CIMMS, National Weather Center organizations include:

- NOAA OAR National Severe Storms Laboratory (NSSL)
- NOAA NWS Warning Decision Training Branch (WDTB)
- NOAA NWS NCEP Storm Prediction Center (SPC)
- NOAA NWS Radar Operations Center (ROC)
- NOAA NWS Norman Forecast Office (OUN)
- Oklahoma Climatological Survey (OCS)
- OU Center for Analysis and Prediction of Storms (CAPS)
- OU Atmospheric Radar Research Center (ARRC)
- OU College of Atmospheric and Geographic Sciences
- OU School of Meteorology
- OU Department of Geography and Environmental Sustainability

CIMMS, under the new cooperative agreement, concentrates its research and outreach efforts and resources on the following principal themes: (1) weather radar research and development, (2) stormscale and mesoscale modeling research and development, (3) forecast and warning improvements research and development, (4) impacts of climate change related to extreme weather events, and (5) societal and socioeconomic impacts of high impact weather systems.

This report describes NOAA-funded research and outreach progress made by CIMMS scientists at OU and those assigned to our collaborating NOAA units under cooperative agreement NA11OAR4320072 during 1 July 2012 through 30 June 2013. NOAA-funded projects are explicitly identified in project titles. Publications written, awards received, and employee and funding statistics are presented in Appendices.

Management of CIMMS, including Mission and Vision Statements, and Organizational Structure

CIMMS was competed in 2010-11 and OU was awarded a new cooperative agreement beginning in October 2011, retaining the name CIMMS. A new Memorandum of Understanding is pending. An Executive Board and an Assembly of Fellows govern CIMMS under the new cooperative agreement.

The CIMMS Executive Board is to meet quarterly to provide advice and recommendations to the Director of CIMMS regarding appointments, procedures, and policies; to review and adopt bylaws; and to periodically review the accomplishments and progress of the technical and scientific programs and projects of the CIMMS.

The Assembly of Fellows meets as needed and is composed of a cross-section of local and national scientists who have expertise relevant to the research themes of CIMMS and are actively involved in the programs and projects of CIMMS. Appointment as a Fellow, by the CIMMS Executive Board, is normally for a two-year term, and reappointment is possible. Appointments may be made for a shorter period of time or on a part-time basis with the concurrence of the appointee and the CIMMS Executive Board. Fellows will review and suggest modifications of bylaws, participate in reviews of CIMMS activities, and elect two of their number to serve on the Executive Board. The Executive Board appoints Fellows.

The Mission and Vision Statements of CIMMS are as follows:

Mission *– To promote collaborative research between NOAA and OU scientists on problems of mutual interest to improve basic understanding of mesoscale meteorological phenomena, weather radar, and regional climate to help produce better forecasts and warnings that save lives and property*

Vision *– A center of research leadership and excellence in mesoscale meteorology, weather radar, regional climate, and forecast and warning improvement, fostering strong government/university collaborations*

The organizational structure of CIMMS includes its Director (Peter Lamb), Associate Director and Assistant Director of NOAA Relations (Randy Peppler), Finance and Operations Director (Tracy Reinke), Administrative Assistant (Luwanda Byrd), and Account and Budget Staff (Melanie Norris). Scientists, students, and post-docs are housed on the OU campus in its National Weather Center (NWC). Some CIMMS undergraduate students have duty stations off-campus at ROC in Norman.

Executive Summary Listing of Activities during FY2013 Under the New Cooperative Agreement

Weather Radar Research and Development

At the very center of NOAA's mission are the objectives of achieving a "reduced loss of life, property, and disruption from high-impact weather events", "improved transportation efficiency and safety", and "improved freshwater resource management" (*NOAA' s Next Generation Strategic Plan,* Long-Term Goal: Weather Ready Nation, pp. 10-14, December 2010). The weather systems involved include severe thunderstorms, tornadoes, tropical storms and hurricanes, and winter cyclones. Those systems produce the high intensity precipitation, strong winds, flooding, lightning strikes, freezing rain, and large snow accumulations that damage property, cost lives, disrupt transportation, and cause other economic dislocation. Reduction of these adverse impacts can result from the availability and use of accurate forecasts of the above weather systems and their associated phenomena, for future periods ranging from several days down to a few

minutes. One of the essential starting points for developing those forecasts is the detailed observation of the present state of the atmosphere.

For almost 60 years, remote sensing via weather radar has been a vital source of the necessary observations. The present national weather radar system (WSR-88D) uses reflectivity and Doppler velocity measurements to document the location and movement of the above weather systems, and indicate the time evolution of their precipitation intensity and wind strength. However, this radar system soon will be as old (30 years) as the chronologically and technologically ancient system (WSR-57) that it replaced in 1988. This situation has two crucial implications for NOAA's continued pursuit of its above objectives to achieve a "reduced loss of life, property, and disruption from high impact weather events", "improved transportation efficiency and safety", and "improved freshwater management". First, NOAA and its partners must complete the recently initiated development of the new Multi-Function Phased Array Radar (MPAR) system that will replace the WSR-88D and is incorporating all relevant technological advances during the last 20+ years. Second, since completion of this development activity will require another 7-12 years at its current rate of progression, the ongoing current WSR-88D upgrades (especially Dual-Polarization) must be brought to fruition as soon as possible.

During the past year, research was conducted at NSSL on:

NSSL Project 1 – Advancements in Weather Radar

- WSR-88D Improvements
  - *Range Oversampling Techniques*
  - *Range-and-Velocity Ambiguity Mitigation*
  - *Ground Clutter Mitigation*
  - *Noise Power Estimation*
  - *Coherency-Based Thresholding*
  - *Improving Data Quality of Polarimetric WSR-8D Radars*
  - *High-Resolution Nationwide Mosaics of Radar Data*
  - *Enhancements to the Warning Decision Support System (WDSS-II)*
- Dual-Polarization
  - *Quality Control of Radar Reflectivity Data Using Polarimetric Variables*
  - *Which Polarimetric Variables are Important for Quality Control?*
  - *Dual-Polarization Signal-Processing Improvements*
  - *Improved Estimation of Correlation Coefficient*
  - *KOUN Hardware and Software Development*
  - *Validation of the New Polarimetric QPE Algorithm Based on Specific Attenuation*
  - *Quantification of Snow and Mixed-Phase Precipitation Using Polarimetric Radars and Disdrometers*
  - *Investigation of Polarimetric Signatures of Melting Hail and Their Practical Implications*
  - *Development of a New Surface-Based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network*

- *Polarimetric Radar Analysis of Winter Storms*
    - *Testing of a Background Classification Algorithm for Use with Dual-Polarization Radars in Determining Precipitation Type at the Surface*
    - *Developing a New Version of the Melting Layer Detection Algorithm (MLDA) Using Dual-Polarization Radar, NWP Model Data, and Object Identification Techniques*
    - *Investigating Microphysical Processes in Clouds and Precipitation with Explicit Modeling and Polarimetric Radar Data*
- Phased Array Radar
    - *NWRT PAR Software Upgrades (MPARSUP)*
    - *NWRT PAR Operations*
    - *PAR Dual-Polarization Issues*
    - *MPAR Program*
    - *Cylindrical Polarimetric Phased-Array Radar (CPPAR)*
    - *PAR Clutter Characterization and Mitigation*
    - *Radar Data Management*
    - *PAR and WSR-88D Comparisons for a VORTEX2 Case*
    - *2013 Phased Array Radar Innovative Sensing Experiment*
    - *Rapid Sampling of Radar Precursor Signatures Associated with Downbursts in Central Oklahoma*

NSSL Project 2 – Hydrometeorology Research

- Evaluating Dual Pol Precipitation Estimates Using the Q3 Verification System
- WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities
- Reflectivity Quality Control for the Canadian Radar Networks
- A Three-Dimensional Aviation In-Flight Weather Hazard Product Based on the Hydrometeor Classification Algorithm (HCA)
- QPE Scheme for Merging Observations of Radars Operating at Different Wavelengths
- Ground Radar-Based QPE Improvement Using Satellite Radar Data
- Crowd-Sourcing Reports of Hydrometeor Type and Location using mPING
- Evaluating Dual-Polarization Precipitation Estimates vs. the Legacy Precipitation Processing System
- Winter Surface Hydrometeor Classification Algorithm
- Probabilistic Identification of Enhanced Rain Rates From Warm Rain Processes using Analysis of the Near-Storm Environment

CIMMS Task III Projects

- Next Generation Weather Radar Technology Research at OU
    - *MPAR Resource Management and Adaptive Weather Sensing*
    - *Multi-Mission Observations of the Clear-Air Environment*
    - *Ground/Space-Based Radar Precipitation Measurements*
    - *MPAR System and Cost Models*
    - *Biases in Precipitation Estimates using Polarimetric Cylindrical Arrays*
    - *Bayesian Approaches to Detect and Mitigate Ground Clutter in Weather*

    - *Pulse Compression Waveforms for High-Sensitivity Weather Observations*
- Support for the MPAR Wind Shear Study
- Digital Backend Design and Demonstration for Next-Generation Weather Radar Systems

Stormscale and Mesoscale Modeling Research and Development

Research and development for stormscale and mesoscale modeling are essential for NOAA's aforementioned objectives. Use of stormscale and mesoscale models is a major ingredient of the forecasting and nowcasting procedures for high impact weather events, and is expected to grow in the future. The initialization of those prediction models is depending increasingly on wind and other observations from the current weather radar systems. This dependence also is anticipated to expand and therefore is a principal motivation for the weather radar research and development proposed above -- to improve the initialization and hence performance of the prediction models. At the center of this radar-modeling interface is the manner in which radar data are ingested into the models, especially in combination with measurements from other platforms (e.g., satellite, rawinsonde, surface) via "assimilation" procedures. In addition to their predictive roles, stormscale and mesoscale models also are used extensively in a research mode to understand better the behavior of weather systems on those scales. The atmospheric processes that receive particular attention in these simulations include mesoscale dynamics, convective initiation, cloud dynamics and microphysics, and the precipitation process. Also investigated is the sensitivity of the simulation results to the data assimilation procedures. The ultimate goal of such stormscale and mesoscale simulation research is to improve the performance of the operational forecasting models.

During the past year, research was conducted on:

NSSL Project 3 – Numerical Modeling and Data Assimilation

- Influence of Mesonet Observations on the Accuracy of Surface Analyses Generated by an Ensemble Kalman Filter
- Testing of Radar Data Assimilation for a Case Study of Lake-Effect Snow
- Assessing High-Resolution Ensemble Forecasts of Low-Level Supercell Rotation Within an Observing System Simulation Experiment (OSSE) Framework
- Objective Detection and Characterization of Tornadoes and Mesocyclones in High-Resolution Model Wind Fields
- Removing Acoustic-Mode Pressure Oscillations from Storm-Scale Ensemble Kalman Filter Analyses
- Exploring the Impact of Assimilating Phased Array Radar Data on Storm-Scale Ensemble Prediction
- Development of a Community Variational Dual-Doppler Wind Retrieval Code
- Investigating Implications of a Vortex Gas Model and Self-Similarity for Tornadogenesis and Maintenance
- Storm-Scale Data Assimilation and Ensemble Forecasting for Warn-on-Forecast

- Ensemble Kalman Filter Analyses and Forecasts of a Severe Mesoscale Convective System Observed During BAMEX
- Storm-Scale Cloud Water Path Assimilation
- Mesoscale GOES-ABI Radiance Assimilation OSSE Experiments
- The Impact of Mesoscale Environmental Uncertainty on the Prediction of a Tornadic Supercell Storm using Ensemble Data Assimilation Approach
- The Analyses and Prediction of a Supercell Storm from Assimilating Radar and Satellite Observations using Ensemble Kalman Filter Data Assimilation Technique
- Support NSSL Users on the Jet and Boomer HPC Environments
- Support of OUN WRF Experiment 2013
- Support the Development and Testing of Forecast Verification/Diagnostics for Warn-on-Forecast and Hazardous Weather Testbed Applications
- Support Ensemble Verification using Object Based Approaches for Defining Storms and Storm Characteristics as Proxies for Severe Weather
- Evaluation of Total Lightning Data Assimilation Algorithm Within the WRF Framework

NSSL Project 4 – Hydrologic Modeling Research

- Flooded Locations and Simulated Hydrographs (FLASH) Demonstration
- Evaluation of FLASH Outputs
- Creating Display Web Tools for the FLASH Project to Predict and Monitor Flooding
- Evaluation of CI-FLOW Outputs

NSSL Project 7 – Synoptic, Mesoscale and Stormscale Processes Associated with Hazardous Weather

- Explicit Forecast of Lightning Threats Within the WRF Framework
- Effects of the Choice of Microphysical Parameterization on the Presence of Supercooled Liquid Water in Winter Storms
- Radar Quality Control for Storm-Scale and Mesoscale Data Assimilation and Modeling
- Influence of Mesonet Observations on the Accuracy of Surface Analyses Generated by an Ensemble Kalman Filter
- Hazardous Weather Testbed Support
- Storms, Forms, and Complexity of the Urban Canopy: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather

Forecast and Warning Improvements Research and Development

It is under this theme that the results of the research and development from the two preceding themes are integrated and converted into improved weather forecasts and warnings disseminated to the U.S. public. The ultimate outcome is to provide NWS forecasters routinely with enhanced information on which to base their forecasts. Two areas of highly innovative activity, anchored within the Hazardous Weather Testbed

(HWT), dominate this effort – the Experimental Forecasting Program and the Experimental Warning Program. Activity within this theme also is dominated by the training activities of CIMMS scientists at the Warning Decision Training Branch.

During the past year, research and training was conducted on:

NSSL Project 5 – Hazardous Weather Testbed

- Experimental Forecast Program
- Experimental Warning Program
- Implemented Model with Radar Cycling in an Operational Warning Environment
- Coordination for the 2013 HWT Spring Experiment

NSSL Project 6 – Development of Technologies and Techniques in Support of Warnings

- The Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS)
- Warn-on-Forecast Real-Time Data Assimilation Experiment
- Multi-Radar/Multi-Sensor (MR/MS) Severe Weather Algorithm Development
- The Severe Hazards Analysis and Verification Experiment (SHAVE)
- Prototype Development for Time-Ensemble Products

ROC Project 10 – Analysis of Dual Polarized Weather Radar Observations of Severe Convective Storms to Understand Severe Storm Processes and Improve Warning Decision Support

- Applications Branch
- Engineering Branch

SPC Project 11 – Advancing Science to Improve Knowledge of Mesoscale Hazardous Weather

- GOES-R Proving Ground
- Hazardous Weather Testbed
- Collaboration with the EWP
- Ensemble Verification of Proxy Severe Storm Reports
- A Four-Year Climatology of Simulated Convective Storms from NSSL WRF
- Special Projects in Effective Communication

WDTB Project 12 – Warning Decision-Making Research and Training

- The Advanced Warning Operations Course (AWOC) – Core and Severe Tracks
- The Advanced Warning Operations Course (AWOC) – Flash Flood Track
- Advanced Weather Interactive Processing System (AWIPS) - II Training
- Distance Learning Operations Course (DLOC)
- Dual-Polarization WSR-88D Operations Training
- Experimental Warning Program/NOAA Hazardous Weather Testbed Support
- Weather Event Simulator (WES) – I
- Weather Event Simulator (WES) – II
- WSR-88D Build Improvement Training

OST Project 13 – Research on Integration and Use of Multi-Sensor Information for Severe Weather Warning Operations

- Operations Coordination for the Experimental Warning Program's 2013 spring experiment
- Severe Weather Warning R&D
- Lightning Jump Algorithm evaluation
- Development of Innovative Methods to Quantitatively Evaluate Severe Weather Warnings
- AWIPS-II
- Central Weather Service (Taiwan) Activities

NWSTC Project 14 – Forecast Systems Optimization and Decision Support Services Research Simulation and Training

- Using Graphical Forecast Editor (GFE) in the Forecast Process
- Introduction to GFE
- GFE Focal Point Training
- Using NWSChat
- Community Hydrologic Prediction System (CHPS)
- CHPS Display Configuration Training
- CHPS Advanced Configuration Training
- CHPS User Training
- NWS Observational Programs Overview
- AWIPS-II Collaboration Tool
- Safety and Environmental Focal Point Training
- Social Media Outreach
- Training Within the NWSTC
- Decision Support Service Deployment Boot Camp
- Emergency Response Specialist Professional Development Series
- Weather and Climate Analysis for FEMA Watchstanders
- Social Science Integration – Assessing Effectiveness of Hazard and Impact Messaging in the Context of NWS Products and Services
- NWS Winter Hazards Simplification Demonstration
- Operations Proving Ground Operational Readiness Evaluations (OREs)
- South Dakota Fire Weather Partner Meeting

CIMMS Task III Projects

- Development of Short-Range Realtime Analysis and Forecasting System based on the ARPS for Taiwan Region – Year 3
- Ensemble Simulation of GOES-R Proxy Radiance Data from CONUS Storm-Scale Ensemble Forecasts, Product Demonstration and Assessment at the Hazardous Weather Testbed GOES-R Proving Ground
- Contribution to Model Development and Enhancement Research Team by the Center for Analysis and Prediction of Storms
- Advanced Data Assimilation and Prediction Research for Convective-Scale "Warn-on-Forecast"

- National Sea Grant Weather & Climate Extension Specialist
- Storm Tracking and Lightning Cell Clustering using Geostationary Lightning Mapping Data for Assimilation and Forecast Applications
- Prototyping and Evaluating Key Network-of-Networks Technologies

Impacts of Climate Change Related to Extreme Weather Events

Here, we are concerned with the regional and global climate system context of mesoscale and stormscale weather variability, and especially the functioning of what now is termed the weather-climate interface. The genesis and trends of extreme events are of particular interest, given society's current concerns about climate maintenance and change. The optimum path forward will require an appropriate combination of observational (using fine resolution data) and modeling (emphasizing convection) research. This theme also addresses the NOAA objective of achieving "improved scientific understanding of the changing climate system and its impacts" and "assessments of current and future states of the climate system that identify potential impacts and inform science, services, and stewardship decisions" (*NOAA's Next Generation Strategic Plan*, Long-Term Goal: Climate Adaptation and Mitigation, pp. 5-10, December 2010).

During the past year, research and outreach was conducted on:

CIMMS Task I Project

- Building Resilience to Face Recurring Environmental Crisis in the African Sahel

CIMMS Task III Project

- Program Support for the Assimilation, Analysis, and Dissemination of Pacific Rain Gauge Data: PACRAIN

Societal and Socioeconomic Impacts of High Impact Weather Systems

This theme contributes to several of NOAA's objectives - - providing "mitigation and adaptation choices supported by sustained, reliable, and timely climate services"; achieving "a climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions"; and furnishing "services meeting the evolving demands of regional stakeholders" (*NOAA's Next-Generation Strategic Plan,* Long-Term Goal: Climate Adaptation and Mitigation, pp. 5-10, December 2010). Much of the effort here is motivated and fed by results obtained under the Forecast and Warning Improvements and Extreme Weather-Climate Change Impacts themes that, in turn, are built around the core of the more basic Weather Radar and Stormscale/Mesoscale Modeling Research and Development. The goal here is to facilitate the mitigation (enhancement) of the adverse (beneficial) social and socioeconomic impacts of high-impact weather systems and regional/seasonal-scale climate variations. Thus, our contributions to this theme are part of NOAA's crucial ultimate interface with society, and therefore will reflect the continuing and increasing involvement of OU social scientists.

During the past year, research and outreach was conducted on:

NSSL Project 8 – Warning Process Evolution and Effective Communication to the Public

- Use of the NSSL Mesoscale Ensemble Within the Hazardous Weather Testbed
- Special Projects in Effective Communication
- HWT-EFP-EWP Collaboration
- Use and Impact of Convection-Allowing Models in Operational Forecasting
- Assessment of Forecast Reasoning
- Damage Surveys for May 2013 Tornadoes
- Prototype Interface for Probabilistic Hazard Information

NSSL Project 9 – Evaluating the Impact of New Technologies, Data, and Information in the Operational Forecasting Environment

- Phased-Array Radar Innovative Sensing Experiment (PARISE)

CIMMS Task III Projects

- Southern Climate Impacts Planning Program (SCIPP)
- Local Assessment of Drought Impacts and Climate Change Adaptation

Public Affairs and Outreach

CIMMS education and outreach activities help NOAA achieve its objectives of providing "an engaged and educated public with an improved capacity to make scientifically informed environmental decisions" and making "full and effective use of international partnerships and policy leadership to achieve NOAA's mission objectives" (*NOAA's Next Generation Strategic Plan*, Engagement Enterprise Objective, pp. 30-32, December 2010). CIMMS location and role within the OU-NOAA National Weather Center (NWC) has embedded it within a wide-ranging and ongoing set of education and outreach activities that will draw continuously on the knowledge developed within the five above research themes. Those activities (a) involve local and national outreach to the general public, (b) extend across all levels of formal education, and (c) provide post-doctoral and professional development opportunities for individuals in careers related to the atmospheric sciences.

During the past year, public affairs and outreach activities included:

- NOAA NSSL Public Affairs and Outreach
- NOAA Weather Partners Educational Outreach
- Outreach Conducted by CIMMS Staff at WDTB

Awards

The following awards or other notable achievements occurred in the past fiscal year:

- Travis Smith (CIMMS at NSSL), Kiel Ortega (CIMMS at NSSL), Valliappa Lakshmanan (CIMMS at NSSL), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), Kevin Manross (former CIMMS at NSSL, now at Unidata), and Karen Cooper (INDUS), David Jorgensen (NSSL), Madison Miller (OU School of Meteorology at CAPS), and John Cintineo (former OU School of Meteorology at CIMMS, now at CIMSS/University of Wisconsin), received the 2013 NOAA Technology Transfer Award for "leading the development of an on-demand, near real-time, web-based tool for tracking severe weather and hail swaths across the continental US." (http://www.nssl.noaa.gov/briefings/2013/09/nsslcimms-team-receives-2013-noaa-technology-transfer-award/)

- Charles Doswell III (CIMMS at OU) was bestowed the 2013 Nikolai Dotzek Award, presented at each European Conference on Severe Storms, for *an outstanding contribution to the science of severe storms*. Dr. Doswell was honored in June 2013 for an accumulation of important accomplishments during his distinguished scientific career.

- The Youcun Qi (CIMMS at NSSL) et al. paper titled "Correction of radar QPE errors for non-uniform VPRs in mesoscale convective systems using TRMM observations" that is in press in *Journal of Hydrometeorology* was referred to NOAA/OAR Headquarters as a "Significant" contribution.

- The Nusrat Yussouf (CIMMS at NSSL) et al. paper "The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes" was referred to NOAA/OAR Headquarters as a "Significant" contribution.

- The Adam Clark (CIMMS at NSSL) et al. paper "Tornado Pathlength Forecasts from 2010 – 2011 Using Ensemble Updraft Helicity" was referred to NOAA/OAR Headquarters as a "Significant" contribution. Subsequently, this paper was featured on the NOAA/OAR Research website.

- Adam Clark (CIMMS at NSSL) was awarded the Mark and Kandi McCasland Award for Outstanding Undergraduate Research for his role as mentor to three undergraduate students that completed their Capstone course at OU.

- Alexandre Fierro (CIMMS at NSSL) was awarded 2012 Editors' Citation for Excellence in Refereeing for *Geophysical Research Letters.*

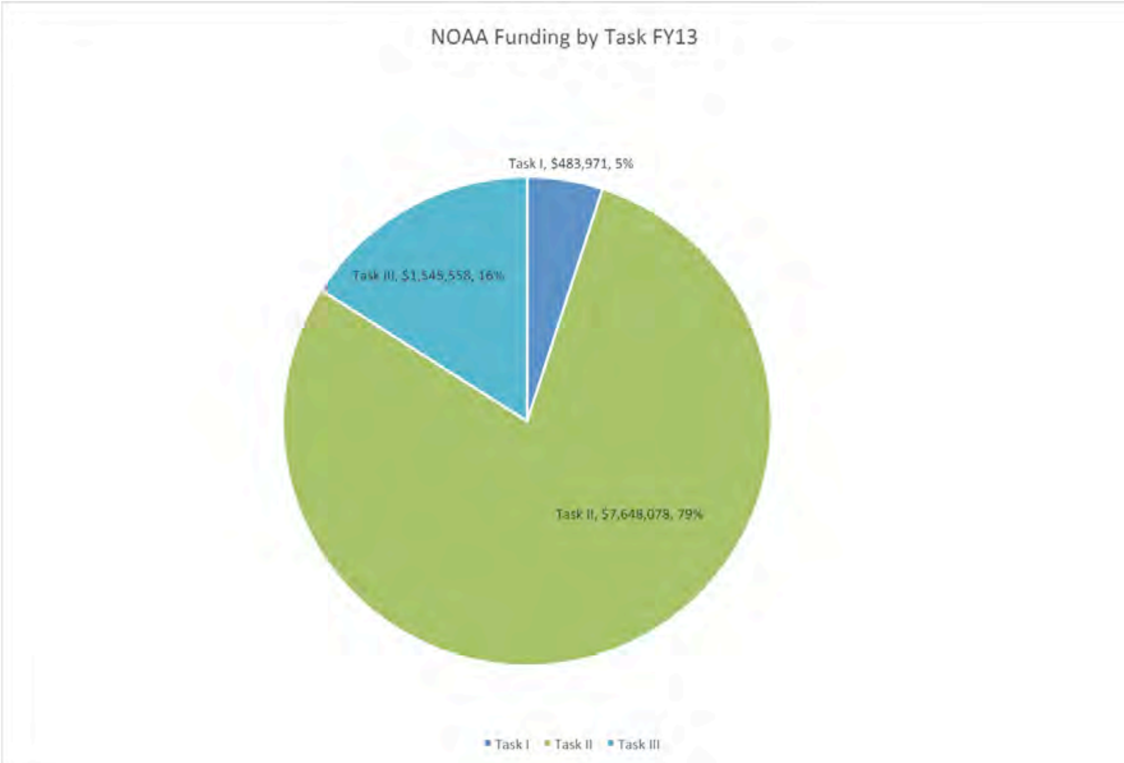
- The WDTB was awarded the National Weather Association's Operational Achievement Group Award "For delivering an innovative and highly effective

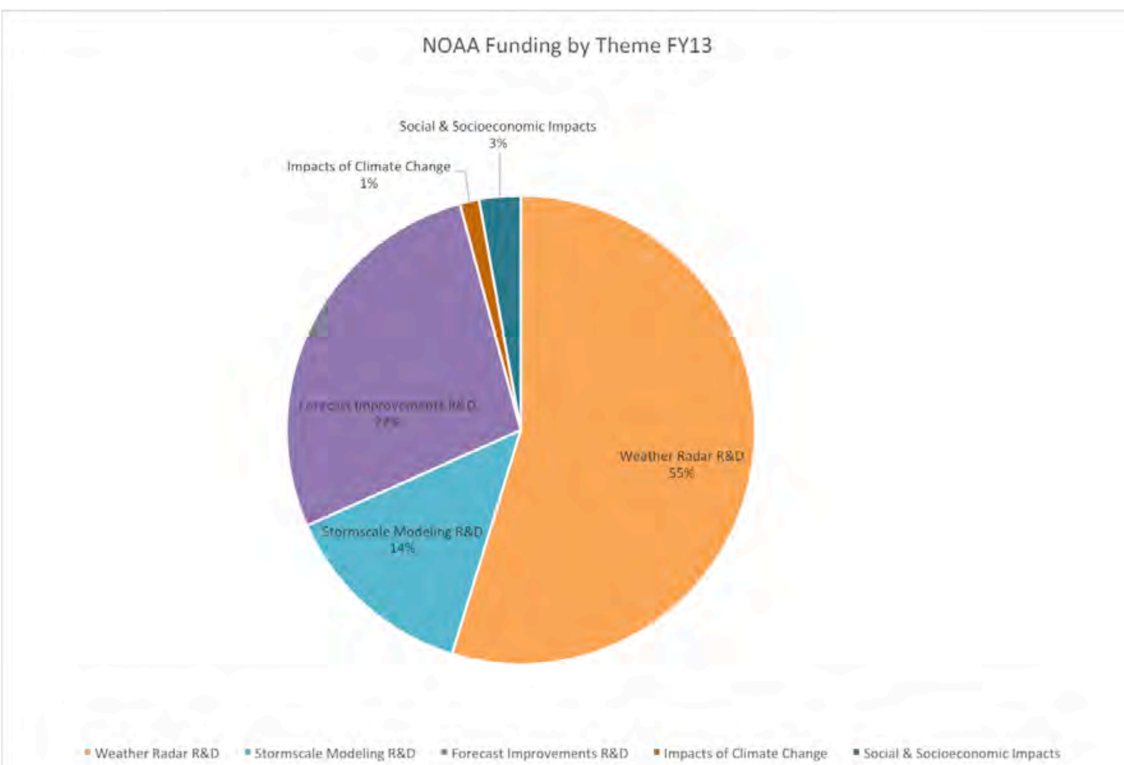
training course, ahead of schedule, for NWS forecasters and partners as a critical element of the nation's dual polarization weather radar upgrade."

- James Kurdzo (OU School of Meteorology at ARRC), Boon Leng Cheong (OU ARRC), Robert Palmer (OU ARRC), and Guifu Zhang (OU School of Meteorology and ARRC) filed a *Provisional Patent* in 2012 titled "Optimized pulse compression waveforms for high-sensitivity radar observations."

- James Kurdzo (OU School of Meteorology at ARRC) was awarded a McNair's Choice Award and Second Place Overall (Science Category) at the OU Student Research and Performance Day in spring 2013.

Distribution of NOAA Funding by CIMMS Task and Research Theme





CIMMS Executive Board and Assembly of Fellows Meeting Dates and Membership

Under the new cooperative agreement, the Executive Board convened on 24 October 2012 and 3 May 2013. No Assembly of Fellows meetings took place.

Executive Board membership for 2013 is as follows:

- Dr. Peter Lamb (Chair), George Lynn Cross Research Professor of Meteorology, OU, and Director, CIMMS
- Dr. Kirsten de Beurs, Assistant Professor, Department of Geography and Environmental Sustainability, OU (Provost designated)
- Dr. Robert Palmer, Associate Vice President for Research, OU, and Professor and Tommy C. Craighead Chair, School of Meteorology, OU (Provost designated)
- Dr. Carol Silva, Associate Professor of Political Science, and Associate Director, CASR, OU (Provost designated)
- Mr. Kevin Kelleher, Deputy Director, NSSL (OAR designated)
- Dr. David Stensrud, Research Meteorologist, NSSL, and Affiliate Professor of Meteorology, OU (OAR designated)
- Mr. Richard Murnan, Radar Operations Center Applications Branch (NWS designated)
- Dr. Steven Weiss, Chief, Science Support Branch, SPC (NWS designated)
- Dr. Boonleng Cheong, Research Scientist, ARRC (Elected from CIMMS Assembly of Fellows)
- Dr. David Turner, Research Meteorologist, NSSL (Elected from CIMMS Assembly of Fellows)
- Mr. David Andra, Meteorologist-in-Charge, Norman NWS WFO (*ex-officio* member)
- Dr. Steven Koch, Director, NSSL (*ex-officio* member)
- Mr. Ed Mahoney, Director, WDTB (*ex-officio* member)
- Dr. Russell Schneider, Director, SPC (*ex-officio* member)
- Mr. Richard Vogt, Director, ROC (*ex-officio* member)
- Dr. David Parsons, Director, OU School of Meteorology, Associate Director, CAPS, and Mark and Kandi McCasland Professor of Meteorology (ex-officio member)
- Dr. Berrien Moore III, Dean, OU College of Atmospheric and Geographic Sciences, OU Vice President for Weather and Climate Programs, Director of National Weather Center, and Chesapeake Energy Professor of Meteorology (ex-officio member)

Assembly of Fellows membership for 2012-2014 is as follows:

- Dr. Jeffrey B. Basara, Director of Research, OCS, and Associate Professor of Meteorology, OU
- Dr. William H. Beasley, Professor of Meteorology, OU
- Dr. Michael I. Biggerstaff, Associate Professor of Meteorology, OU
- Dr. Howard B. Bluestein, George Lynn Cross Research Professor of Meteorology, OU
- Dr. Keith Brewster, Senior Scientist and Associate Director, CAPS, OU
- Dr. Harold E. Brooks, Research Meteorologist and Team Leader, Mesoscale Applications Group, NSSL, and Adjunct Professor of Meteorology, OU
- Dr. Jerry Brotzge, Research Scientist, CAPS, OU
- Dr. Frederick H. Carr, Professor of Meteorology OU
- Dr. Steven Cavallo, Assistant Professor of Meteorology, OU
- Dr. Boonleng Cheong, Research Scientist, ARRC, OU
- Dr. Phillip Chilson, Professor of Meteorology, OU
- Dr. Michael Coniglio, Research Scientist, NSSL
- Dr. Gerald E. Crain, Professor Emeritus of Electrical and Computer Engineering, OU
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- Dr. Claude E. Duchon, Emeritus Professor of Meteorology, OU
- Dr. Imke Durre, Scientist, NCDC

- Dr. David R. Easterling, Scientist, NCDC
- Dr. Evegeni Fedorovich, Professor of Meteorology, OU
- Dr. Chris Fiebrich, Associate Director, CAPS
- Dr. Caleb Fulton, Assistant Professor of Electrical and Computer Engineering, OU
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- Dr. Nathan Goodman, Associate Professor of Electrical and Computer Engineering, OU
- Dr. J.J. Gourley, Research Scientist, NSSL
- Dr. Pamela Heinselman, Research Scientist, NSSL
- Mr. Kurt Hondl, Research Meteorologist, NSSL
- Dr. Yang Hong, Associate Professor of Civil Engineering and Environmental Sciences, OU
- Mr. Ken Howard, Research Meteorologist, NSSL
- Mr. Michael Jain, Acting Chief, Radar Research & Development Division, NSSL
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- Dr. Youngsun Jung, Research Scientist, CAPS, OU
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- Dr. Steven Koch, Director, NSSL
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- Dr. Mark L. Morrissey, Professor of Meteorology, OU
- Dr. Robert D. Palmer, Tommy Craighead Chair and Professor of Meteorology, and Associate Vice President for Research, OU
- Dr. David Parsons, Director, School of Meteorology, Mark and Kandi McCasland Professor of Meteorology, OU
- Dr. Ramkumar Parthasarathy, Associate Professor of Aerospace and Mechanical Engineering, OU
- Dr. Thomas C. Peterson, Research Scientist, NCDC
- Dr. Robert Puls, Director, Oklahoma Water Survey, OU
- Dr. Robert Rabin, Research Scientist, NSSL
- Mr. John R. Reed, Chief, Radar Engineering Branch, ROC
- Dr. Diandong Ren, Associate Professor, Curtin University
- Dr. Michael B. Richman, E. K. Gaylord Presidential Professor of Meteorology, OU
- Mr. Lans Rothfusz, Deputy Chief, Warning Research and Development Division, NSSL
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- Dr. Russell Schneider, Director, SPC
- Dr. Mark Shafer, Assistant Professor of Geography and Environmental Sustainability, OU
- Dr. Alan M. Shapiro, American Airlines Professor and President’s Associates Presidential Professor of Meteorology, OU
- Dr. Hjalti Sigmarsson, Assistant Professor of Electrical and Computer Engineering, OU

- Dr. Carol Silva, Associate Professor of Political Science, and Associate Director, CASR, OU
- Dr. James Sluss, Morris R. Pitman Professor and Director, School of Electrical and Computer Engineering, OU
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- Dr. Paul Spicer, Professor of Anthropology, OU
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- Dr. Jerry M. Straka, Professor of Meteorology, OU
- Dr. Aondover A. Tarhule, Chair and Associate Professor, Department of Geography and Environmental Sustainability, OU
- Dr. David Turner, Research Scientist, NSSL
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- Mr. Richard Vogt, Director, ROC
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- Dr. Mark Yeary, Associate Professor of Electrical and Computer Engineering, OU
- Dr. Tian-You Yu, Acting Director, ARRC, and Associate Professor of Electrical and Computer Engineering, OU
- Dr. May Yuan, Brandt Professor and Edith Kinney Gaylord Presidential Professor of Geoinformatics, and Director, Center for Spatial Analysis, OU
- Mr. Allen Zahrai, Team Leader, Radar Engineering and Development, NSSL
- Dr. Guifu Zhang, Associate Professor of Meteorology, OU
- Dr. Jian Zhang, Research Hydrometeorologist, NSSL
- Dr. Yan Zhang, Assistant Professor of Electrical and Computer Engineering, OU
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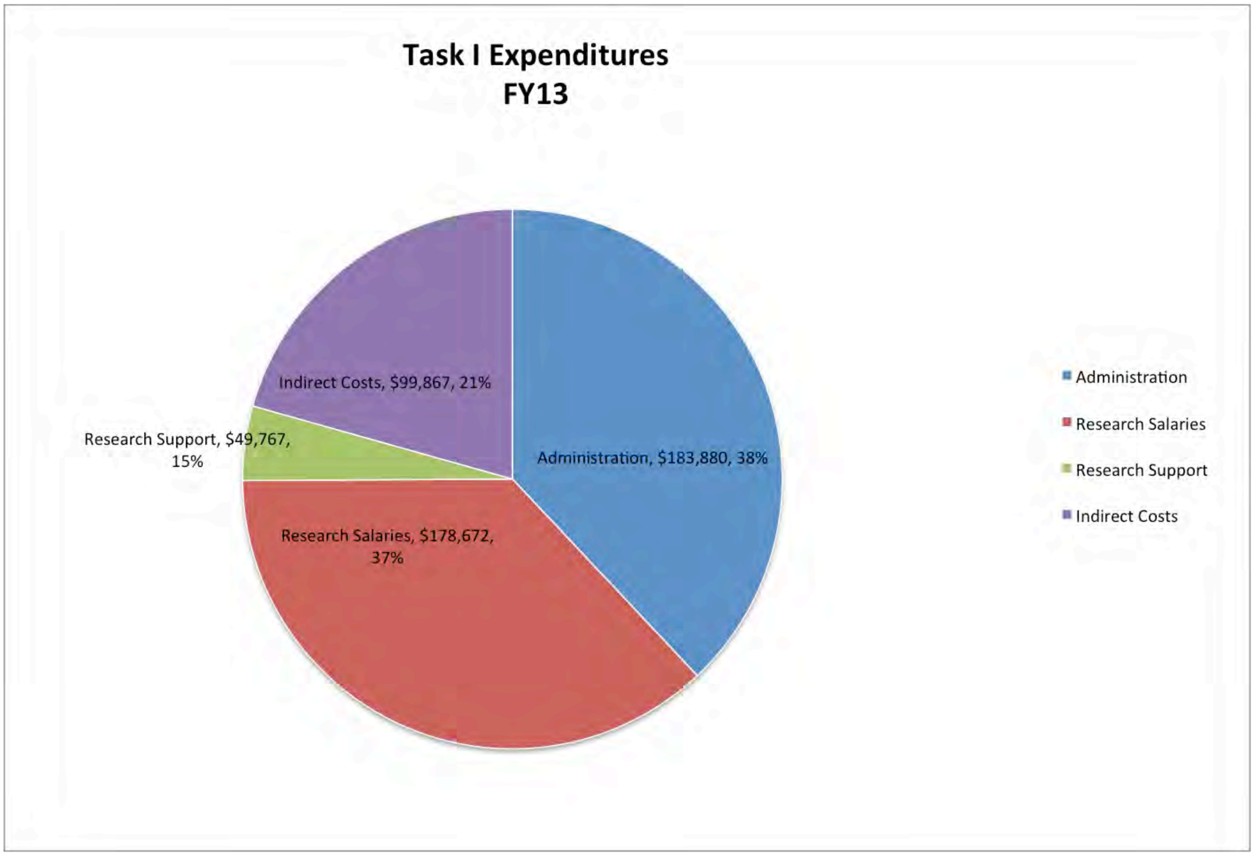
- Dr. Dusan S. Zrnic, Senior Engineer and Group Leader, Doppler Radar and Remote Sensing Research Group, NSSL, and Affiliate Professor of Meteorology and of Electrical and Computer Engineering, OU

General Description of Task I Expenditures



RESEARCH PERFORMANCE

Theme 1 – Weather Radar Research and Development

NSSL Project 1 – Advancements in Weather Radar

NOAA Technical Leads: Michael Jain, Kurt Hondl, Dusan Zrnić, Pamela Heinselman, and Allen Zahrai (all NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

1. WSR-88D Improvements

Overall Objectives
Conduct research and development to provide improvements to the NWS operational radar (WSR-88D). This research explores ways to improve the detection of hazardous weather and improve the weather radar data quality, and provides solutions for the issues identified during deployment of WSR-88D radars with polarimetric capability.

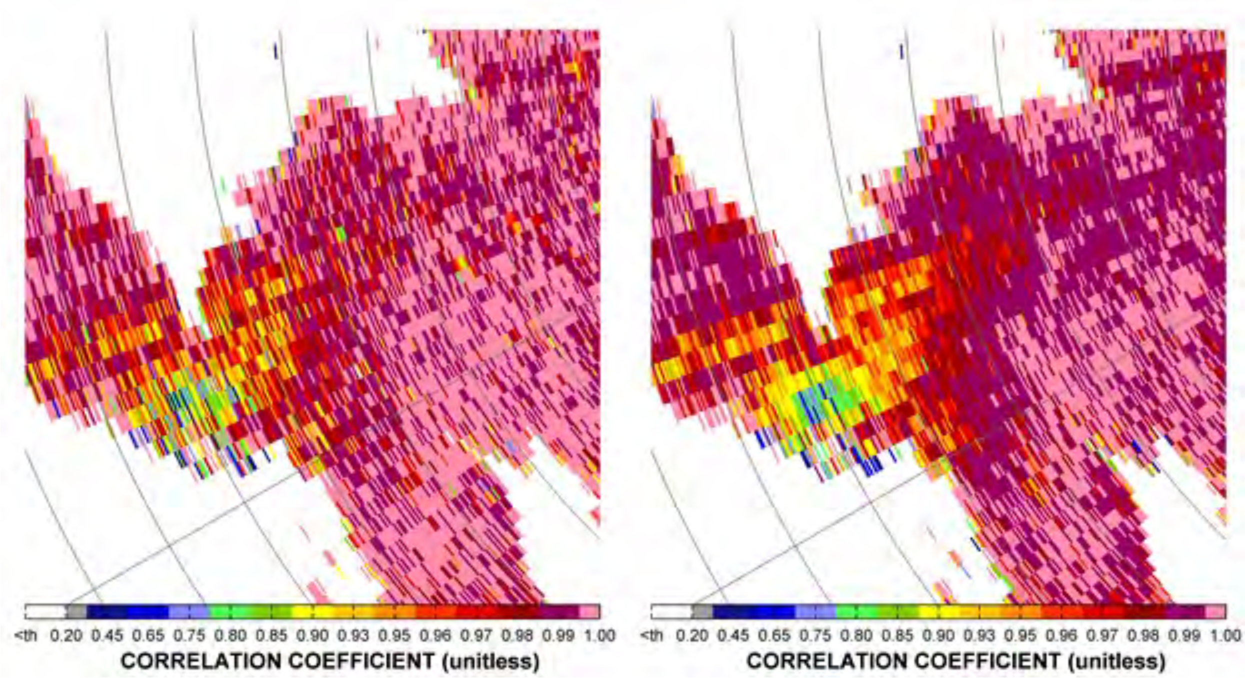
Accomplishments

a. Range Oversampling Techniques

Chris Curtis and Sebastian Torres (both CIMMS at NSSL)

Obtaining radar data at rates faster than current radar systems can provide an important capability for the observation of fast evolving weather phenomena. The conventional trade-off when increasing data rates involves sacrificing either spatial coverage or data precision. However, with range oversampling it is possible to add a new dimension to this trade-off: signal processing. That is, with range oversampling it is possible to obtain low-variance data without sacrificing update time or spatial coverage. This is particularly important for the polarimetric variables, which are needed with higher precision than is possible using legacy, single-polarization dwell times. During FY13, we continued our research on the practical effects of range oversampling techniques. This includes a new method for measuring the normalized range correlation matrix from data in real-time. Range-correlation measurement is an important aspect of range oversampling processing because an accurate measurement ensures optimal variance reduction and minimizes reflectivity biases. We also researched and implemented a new adaptive pseudowhitening algorithm for dual polarization data. Adaptive pseudowhitening can improve the estimates of dual-polarimetric variables while keeping the same scan times.

This project is ongoing.



Comparison of correlation coefficient estimates with conventional matched-filter processing (left) and adaptive pseudowhitening (right). Note that the adaptive pseudowhitening has fewer pink values (> 1) and a smoother, less noisy data field.

b. Range-and-Velocity Ambiguity Mitigation

David Warde and Sebastian Torres (both CIMMS at NSSL)

In pulsed Doppler weather radars, the range-and-Doppler-velocity ambiguity problems are coupled such that trying to alleviate one of them worsens the other. Special techniques are necessary to resolve both ambiguities to the levels required for the effective observation of severe weather. Efforts in this area are expected to culminate in significantly improved data quality when implemented on the NEXRAD network. The increased data quality will result in an improved ability for the WSR-88D to detect severe weather, flash floods, winter storms, and provide aviation forecasts. Over the last decade, two techniques have emerged as viable candidates to address the mitigation of range and velocity ambiguities thus reducing the amount of purple haze obscuration currently encountered during the observation of severe phenomena. These are: systematic phase coding (namely SZ-2) and staggered pulse repetition time (SPRT). The two techniques are complementary since they offer advantages at specific elevation angles; hence, they can be simultaneously incorporated into the same scanning strategy. The first stage of upgrades is now complete and has been operational with great success for a number of years. The second stage of upgrades dealing with range and velocity ambiguities involves the operational implementation of SPRT. We developed a novel spectral processing SPRT algorithm that incorporates the mature Clutter Environment Analysis using Adaptive Processing (CLEAN-AP) filter, range-overlaid recovery, dual polarization and a generalized PRT ratio. In previous

years, we had delivered the improved SPRT algorithmic description to the NWS Radar Operations Center for inclusion into the NEXRAD software update cycle. In FY13, we held several technical interchange meetings and provided continual scientific support to ease operational implementation of SPRT. With the recommended changes, we have provided a robust SPRT solution with enhanced ground clutter mitigation technology capable of meeting NEXRAD operational needs in the dual-polarization era.

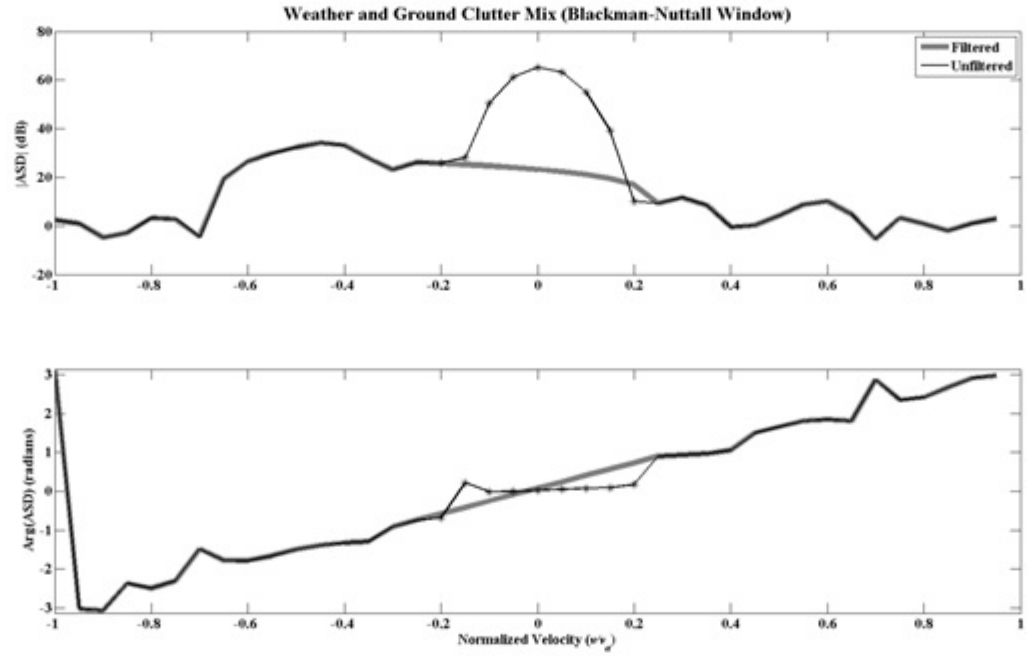
This project is ongoing.

c. Ground Clutter Mitigation

David Warde and Sebastian Torres (both CIMMS at NSSL)

A common dilemma in obtaining good-quality meteorological-variable estimates using Doppler weather radar is the application (or misapplication) of ground clutter filters (GCF) to mitigate contamination from ground returns. Typically, weather radars use static clutter maps (i.e., pre-identified clutter contaminated regions) to control the application of the GCF. Ideally, the GCF should only be applied if the ground clutter contamination obscures the weather estimate. However, the problem of applying the GCF becomes very complex considering the dynamic atmospheric effects on radar beam propagation. The goal of this project is to develop efficient techniques that provide both automated detection and application of ground clutter filtering. The CLEAN-AP filter developed by CIMMS staff and is a spectral technique for automatic detection and mitigation of ground clutter contamination. We had previously shown the clutter detection and mitigation performance of the CLEAN-AP filter using time-series data from the WSR-88D national network, the dual-polarized KOUN and OUPrime radars, and the National Weather Radar Testbed (NWRT). In 2011, the NEXRAD Technical Advisory committee recommended the CLEAN-AP filter be transitioned into the WSR-88D system for further engineering evaluation and operational use. In FY12, we had delivered the CLEAN-AP filter algorithmic description as part of the improved Staggered PRT algorithm to the NWS Radar Operations Center for inclusion into the NEXRAD software update cycle. In FY13, we enhanced the CLEAN-AP filter notch width determination for better clutter rejection in dual-polarimetric radars. Compared to current technologies used for ground clutter suppression, the CLEAN-AP filter provides a real-time, integrated clutter mitigation solution with: (a) improved ground clutter suppression, (b) effective ground clutter detection, and (c) dynamic ground clutter suppression characteristics optimally matched to the existing atmospheric environment. All of this is achieved with modest computational complexity and increased quality of meteorological estimates.

This project is ongoing.



An example of automated ground clutter mitigation is shown by applying the CLEAN-AP filter for weather and ground clutter mix on data collected with the KOUN radar in Norman, OK. Shown are the magnitude (top) and phase (bottom) of unfiltered (thin black line) and filtered (thick gray line) autocorrelation spectral density (ASD). In this example, the CLEAN-AP filter automatically identified nine coefficients (denoted with asterisks) and reconstructed the spectrum providing 28 dB of clutter suppression.

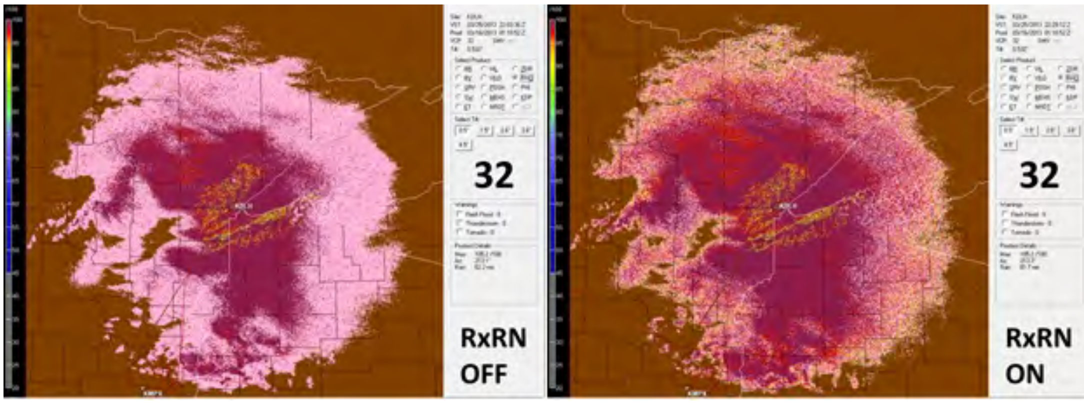
d. Noise Power Estimation

Igor Ivić, Chris Curtis, and Sebastian Torres (all CIMMS at NSSL)

The Radial-by-Radial Noise (RBRN) estimator developed by CIMMS staff produces noise-power measurements at each antenna position in real time. Given sufficient accuracy of noise estimates, the application of the technique will produce improved radar products. This especially reflects on the quality of dual-polarization variables because the differential-reflectivity and the correlation-coefficient estimates are sensitive to errors in noise powers. Implementation on real data has shown visible improvement in the number of valid correlation coefficient and spectrum-width estimates. Assessment of biases in the differential-reflectivity estimates has also shown improvement when the radial-by-radial noise measurement is used compared to the legacy calibration noise. An additional benefit of the RBRN technique is the increased coverage in cases when the legacy calibration noise power is overestimated. The technique has been endorsed by the NEXRAD Technical Advisory Committee and has been accepted for operational implementation. During FY13, the algorithm was completed and transferred to the ROC for operational implementation on the NEXRAD network. Also, the RBRN technique was thoroughly validated to ensure that the implementation was correct and complete.

During this process CIMMS staff provided documentation and extensive support to the ROC team.

This project is completed.



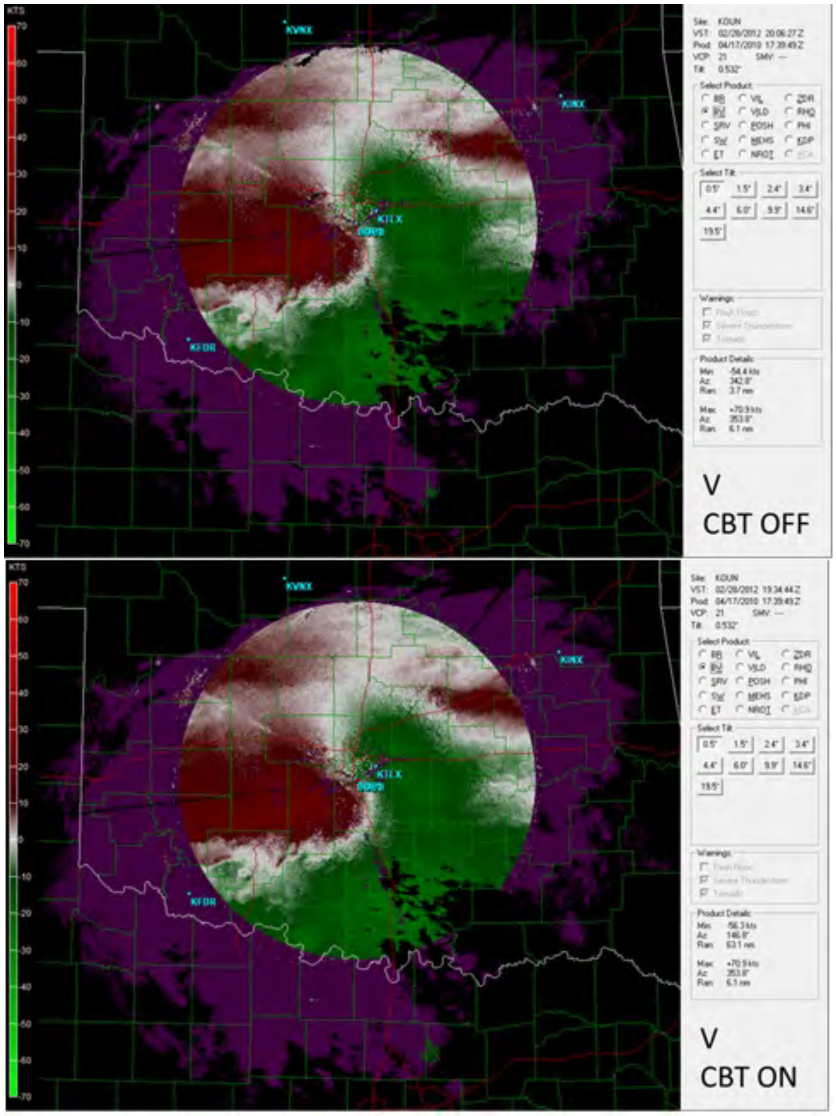
Plan-position-indicator (PPI) displays of the correlation coefficient generated using legacy calibration noise (left), and the radial-by-radial noise measurement technique (right). Gain both in the coverage and in the number of valid estimates (fewer estimates > 1) is evident.

e. Coherency-Based Thresholding

Igor Ivić and Sebastian Torres (both CIMMS at NSSL)

Coherency-based thresholding (CBT) developed by CIMMS scientists is a method that can be used to mitigate the 3 dB loss in sensitivity per channel inherent to the simultaneous transmission and reception of horizontally and vertically polarized waves in the WSR-88D polarimetric radar. Currently, the WSR-88D uses Signal-to-Noise Ratio (SNR) estimates for thresholding non-significant data. Thus, only data for which the corresponding SNR estimate is larger than the predetermined threshold are not censored and available to users and automatic algorithms. The network upgrade to dual polarization resulted in a 3-dB SNR reduction because the transmitter output was equally split between the horizontal and vertical channels. As a result, radar sensitivity has diminished. To mitigate the effects of an SNR decrease, CBT was proposed and accepted for operational implementation on the NEXRAD network. CBT improves radar data censoring by utilizing the weather signal coherency in sample-time and across channels, which has the potential to recover most of the signals that would be lost with the legacy thresholding approach. The technique had been originally implemented in the dual-polarimetric WSR-88D software and was subjected to testing and debugging at the ROC. CIMMS staff supported this effort by providing extensive consultation to the ROC team conducting the testing. In addition, research was conducted to compare CBT against two other techniques that also aimed at enhancing radar coverage.

This project is ongoing.



Plan-position-indicator (PPI) displays of Doppler velocity fields generated using legacy thresholds (top) and the CBT technique (bottom).

f. Improving Data Quality of Polarimetric WSR-8D Radars

Valery Melnikov (CIMMS at NSSL)

A method to control initial system differential phase has been proposed and currently being tested by the ROC. A white paper has been submitted to the NWS headquarters. Engineering measurements on the KOUN and KTLX WSR-88D radars have been made and the recommendations on the optimization of the procedure for differential reflectivity calibration have been summarized in a white paper sent to the NWS headquarters.

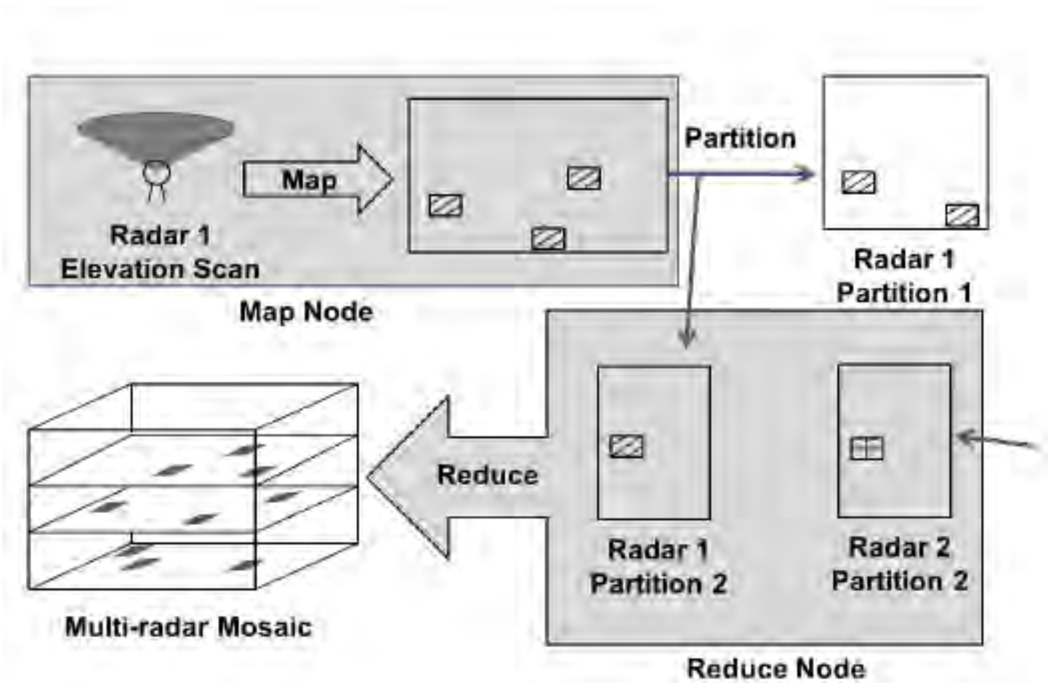
This project is completed.

g. High-Resolution Nationwide Mosaics of Radar Data

Valliappa Lakshmanan and Jeff Brogden (both CIMMS at NSSL)

Because of the high temporal and spatial resolution of data available from the United States' network of weather radars, creating radar mosaics in real-time has been possible only through compromises on the quality, timeliness or resolution of the mosaics. MapReduce is a programming model that can be employed for processing and generating large data sets by distributing embarrassingly parallel computations and data storage across a distributed cluster of machines. We developed a MapReduce approach to computing radar mosaics on a distributed cluster of compute nodes. The approach is massively scalable, and is able to create high-resolution 3D radar mosaics over the Continental United States in real-time. We can now create 0.5-km resolution mosaics every 30 seconds, which was a need of the Federal Aviation Administration (FAA).

This project is ongoing.



A recent method of creating multi-radar mosaics is massively scalable and capable of creating 0.5-km resolution mosaics over the continental U.S. every 30 seconds.

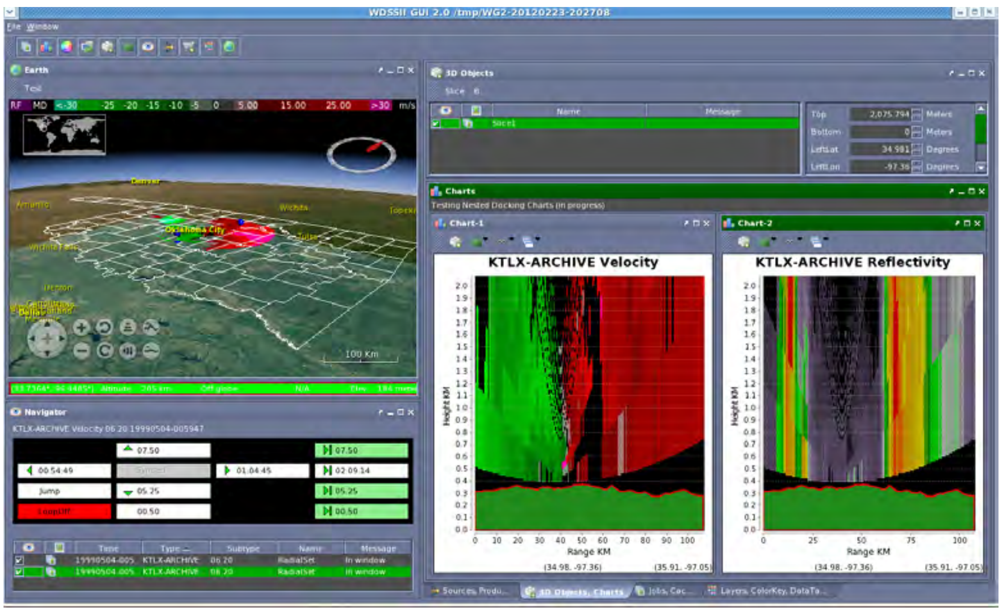
h. Enhancements to the Warning Decision Support System (WDSS-II)

Jeff Brogden and Robert Toomey (both CIMMS at NSSL)

New types of radar data as well as research datasets were successfully incorporated into the Warning Decision Support System (WDSS-II) in order to carry out visualization

and analysis tasks on the data. These datasets include mobile radar, Canadian and Chinese radar datasets and Terminal Doppler Weather Radar. In addition, a weather GUI was designed for viewing and interacting with real-time data from radar and/or algorithm sources. The main purpose is to allow us to view new experimental data at resolutions, speeds and formats not available in other software. It handles fast interaction of time-based data where optionally that data can be grouped into radar volume coverage patterns.

This project is ongoing.



Two data moments sharing a 3D vertical slice, as shown in the new weather GUI that has been recently developed at CIMMS.

WSR-88D Improvements Publications

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2. Dual-Polarization

Overall Objectives

Use dual-polarization radars for quantitative precipitation estimation, hydrometeor classification, and investigation of microphysical processes in clouds and precipitation.

Accomplishments

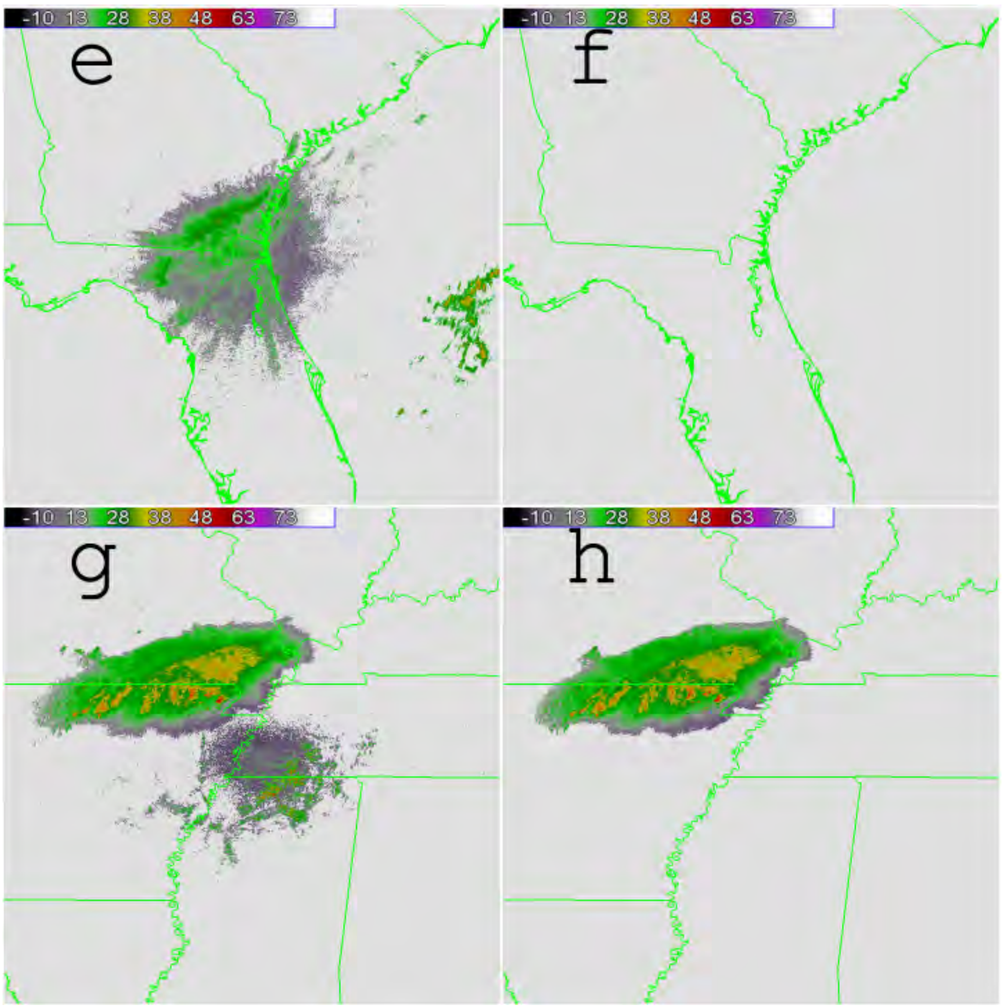
a. Quality Control of Radar Reflectivity Data Using Polarimetric Variables

Valliappa Lakshmanan, Chris Karstens, John Krause, and Lin Tang (all CIMMS at NSSL)

A quality control method to QC non-Doppler radar data using polarimetric variables was recently developed. At each range gate, a pattern vector consisting of the values of the polarimetric and Doppler moments, local variance of some of these features as well as 3D features computed in a virtual volume sense is computed. If the pattern cannot be preclassified based on RhoHV and Z, they are presented to a neural network that was trained on historical data. The neural network and preclassifier produce a pixelwise probability of precipitation at that range gate. The range gates are then clustered into contiguous regions of reflectivity, with bimodal clustering carried out close to the radar

and clustering based purely on spatial connectedness further away from the radar. The pixelwise probabilities are averaged within each cluster and the cluster either retained or censored depending on whether this average probability is greater than or less than 0.5. The QC algorithm was evaluated on a set of independent cases and found to perform well, with a Heidke Skill Score (HSS) of about 0.8. A simple gate-by-gate classifier, consisting of three simple rules, also is introduced in this paper and can be used if the full QC method is not able to be applied. The simple classifier has a HSS of about 0.6 on the independent dataset.

This project is ongoing.



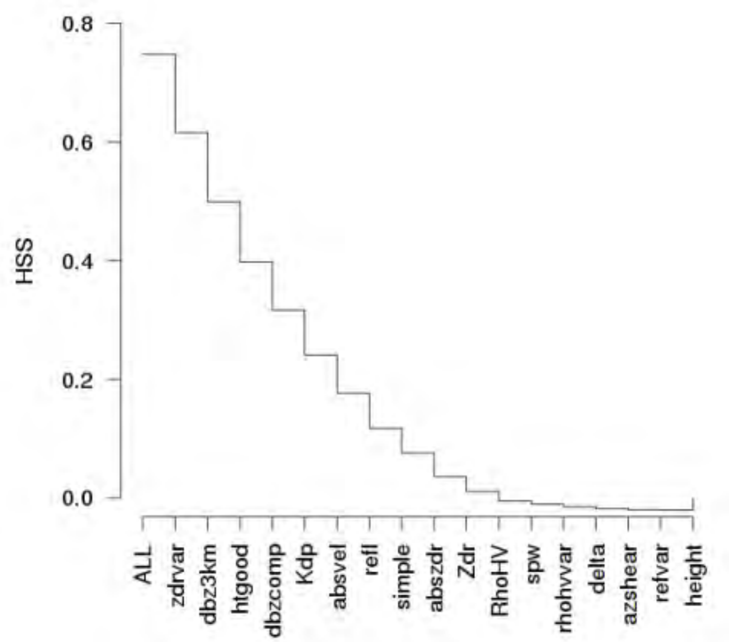
Examples of quality control using the newly developed polarimetric QC algorithm. On the left is the raw reflectivity field and on the right, the field with biological targets and anomalous propagation artifacts removed.

b. Which Polarimetric Variables are Important for Quality Control?

Valliappa Lakshmanan, Chris Karstens, and John Krause (all CIMMS at NSSL)

The importance of the different variables in the context of discriminating between weather and no-weather echoes was examined. The same statistical framework can be used to study the impact of calibration errors in variables such as Zdr. Among the variables studied for their impact on the quality control of radar data, the most important were the variance of Zdr, features relating to the 3D structure of the reflectivity and the radial derivative of PhiDP. The effect of Zdr calibration error on weather/no-weather discrimination was found to be negligible.

This project is ongoing.



The successive loss in Heidke Skill Score (HSS) as each variable is removed is shown. Variables are removed in order of importance so that earlier removals result in greater loss in skill.

c. Dual-Polarization Signal-Processing Improvements

David Warde, Igor Ivić, Sebastian Torres, and Chris Curtis (all CIMMS at NSSL)

The NWS has just completed a multi-year dual-polarization hardware upgrade to the NEXRAD network. The dual-polarization enhancement provides enhanced characterization of precipitation type (i.e., rain, snow, hail, etc.) and also of non-meteorological returns (i.e., tornado debris, ground clutter, birds, insects, etc.), improving precipitation estimates for hydrologists, and providing clarity to weather

forecasters. With the hardware upgrade complete, several improvements to dual-polarization signal processing can be readily transferred to operations. In FY13, we extended our signal-processing tools to include dual polarization processing. A new signal processor was created to process source data from single- or dual-polarimetric radar systems (e.g., WSR-88D, OUPrime, NWRT PAR, or mobile C-, X-, S-band radars). Included in the signal processor are enhancements that take advantage of dual-polarization, including improved velocity estimates by combining auto covariance estimates from horizontal and vertical channels, improved estimates of polarimetric variables by combining covariance estimates from multiple PRTs, clutter rejection by combining horizontal- and vertical-channel notch width selection, noise estimates using radial-by-radial noise, and reduced meteorological estimate variances using an automated range-correlation measurement technique and adaptive pseudowhitening. Additionally, the new signal processor uses the innovative spectral analysis technique developed by CIMMS staff based on the autocorrelation spectral density, which leads to unbiased auto- and cross- covariance estimates.

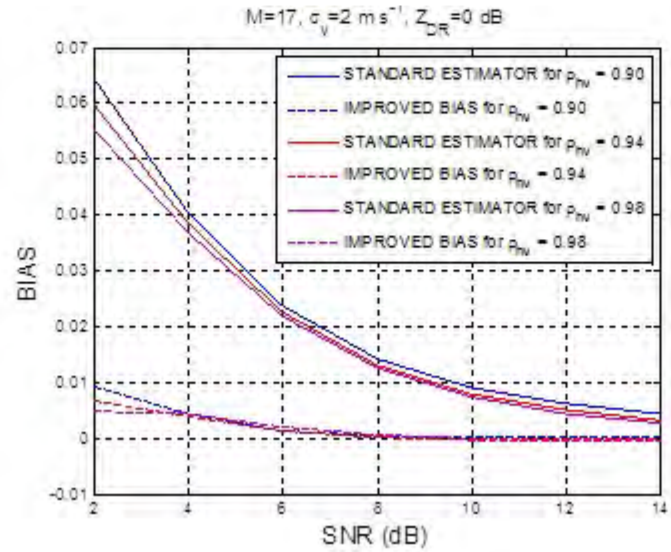
This project is ongoing.

d. Improved Estimation of Correlation Coefficient

Igor Ivić and Valery Melnikov (both CIMMS at NSSL)

The co-polar correlation coefficient (CC) is one of the three polarimetric variables being produced by the WSR-88D. CC aids in the recognition of types of radar echoes and in separation of returns from rain and snow. The latter requires precise measurements of CC in areas with low and moderate signal-to-noise ratios. Unfortunately, correlation coefficient estimates are unusable when they become larger than one, which is common when the number of samples per dwell is small and in areas with signal-to-noise ratio less than ~15 dB. In addition, the current CC estimator is positively biased, especially when the number of samples per dwell is small. To mitigate these issues, a novel correlation coefficient estimator is being developed that has a potential of being less biased for small number of samples. Mitigating the CC bias will improve polarimetric recognition of echoes. The improved CC estimator will provide improved accuracy while remaining computationally simple for easier operational implementation on the WSR-88D.

This project is ongoing.



Comparison between biases inherent to the standard and improved correlation-coefficient estimator as a function of the signal-to-noise ratio (SNR).

e. KOUN Hardware and Software Development

Matt McCord, Eddie Forren, and John Thompson (all CIMMS at NSSL)

RVP900 Signal Processor Upgrade: Vaisala has announced that the RVP-8 and RCP-8 processors are being designated as End-of-Life (EOL) and will no longer be supported as of 2015. Currently, the entire NEXRAD network is being controlled and processed by the RCP-8 and RVP-8; hence, the ROC has begun preparations to upgrade to the new Vaisala processor: the RVP-900. In support of this upgrade, NSSL and CIMMS staff have installed an RVP-900 in passive mode on the KOUN radar to begin data quality comparisons and to determine what components will need to be modified to support the new processor. In addition to the new processor, staff at NSSL and CIMMS has installed two COTS Linux-based servers and a 10GbE network for developing an open digital signal processor that can work alongside the RVP-900.

Sector Scans: General utilities were written to enable sector scanning with KOUN. This has enabled polarimetric studies with faster updates of small storm regions than using traditional scanning strategies.

NSSL DSP Port to KOUN: We have begun the process of porting the DSP system written for the NWRT to KOUN. The first step was to write a new ingest service that translates from Vaisala's proprietary format into the data format expected by the DSP software. This allows us to run the same product algorithms on KOUN as we are using on the NWRT. Additionally, the NSSL DSP software is fully owned by the government, reducing our dependency on Vaisala and allowing us to use COTS components for processing. Additionally, a playback tool was developed to ingest Vaisala's time-series data into our radar-independent DSP. Support for split, batch, and uniform modes of data collection for legacy or super-resolution was implemented, and the tool is designed

with internal mechanisms to easily add support other advanced waveforms in the future. Support for both the dual-polarimetric channels was also implemented along with a shared API that can be used by the real-time ingest software being developed.

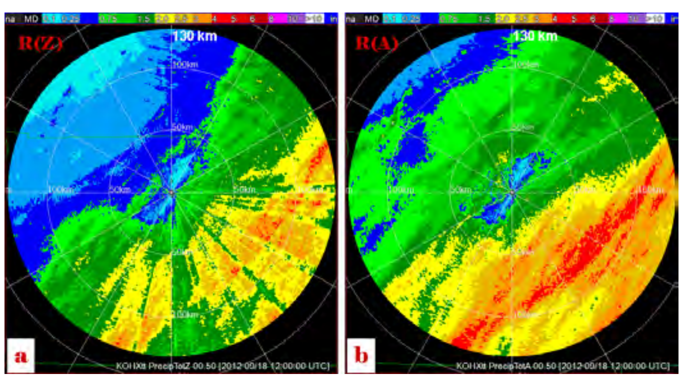
These projects are ongoing.

f. Validation of the New Polarimetric QPE Algorithm Based on Specific Attenuation

Alexander Ryzhkov, Pengfei Zhang, John Krause, and Yadong Wang (all CIMMS at NSSL)

A new polarimetric QPE algorithm based on the use of specific attenuation A has been recently introduced. The specific attenuation A can be reliably estimated from the measurements of radar reflectivity Z and total differential phase along a radial. The advantages of the R(A) estimator of rain rate R include its low sensitivity to drop size distribution variability and immunity to partial beam blockage, radar miscalibration, and impact of wet radome. The R(A) methodology also provides a solution for efficient compositing / mosaicking rainfall accumulation products because it eliminates the errors caused by reflectivity mismatch between neighboring radars which is still quite common on an operational radar network.

The method has been extensively tested using the comparison the R(A) rainfall estimates with gauge accumulations at S-, C-, and X-bands in different parts of the world in partnership with researchers in the US, Germany, and Taiwan. The performance of the R(A) technique at S band was validated using measurements by a number of polarimetric WSR-88D radars. Validation tests demonstrate that the R(A) algorithm generally outperforms the ones based on Z, differential reflectivity Z_{DR}, and specific differential phase K_{DP}. The benefits of the new QPE method are particularly visible in the areas affected by partial blockage of the radar beam. This project is ongoing.



24-hour rainfall totals estimated using a) convective R(Z) and b) R(A) based on measurements by KOHX WSR-88D radar from 12:00 UTC on 17 September to 12:00 UTC on 18 September 2013. Gaps caused by radar beam blockage in the rainfall accumulation field retrieved using R(Z) are completely restored in the R(A) rain total map.

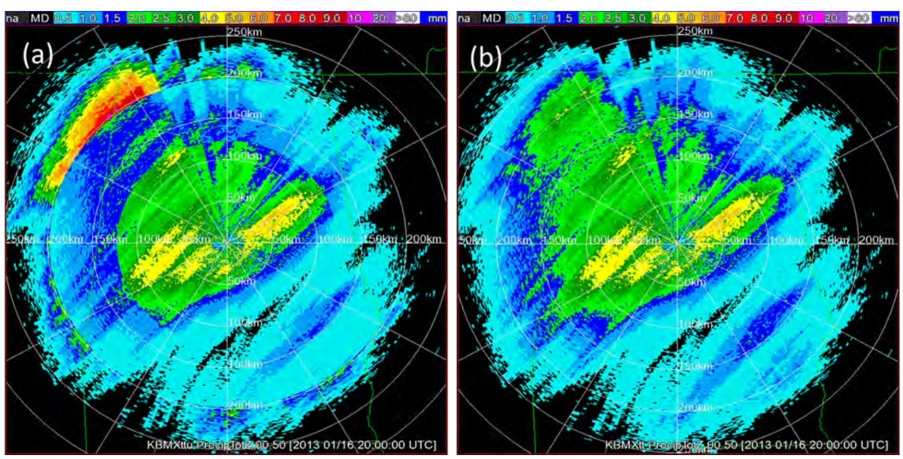
g. Quantification of Snow and Mixed-Phase Precipitation Using Polarimetric Radars and Disdrometers

Alexander Ryzhkov, Pengfei Zhang, and Petar Bukovcic (all CIMMS at NSSL)

Accurate quantification of snow and mixed-phase precipitation remains a challenge. Possible utilization of dual-polarization radars to address this issue has been explored for the first time. The major concept is that the traditional S – Z relations (S is snow rate water equivalent) should be parameterized by temperature and differential reflectivity Z_{DR}. Systematic disdrometer measurements of snow have been performed to substantiate this concept. The OU 2D video disdrometer was deployed near Grand Junction, CO. The disdrometer measurements were carried out as part of the 2012-2013 winter experiment funded by The Colorado Water Conservation Board. A possible improvement in snow water equivalent estimation comes from newly found dependence of coefficient *a* (in $S=aZ^b$ relation) on Z_{DR} (differential reflectivity). This dependence partially mitigates the effects of variability in Z-S relations and improves the snow estimation.

A principally new approach has been suggested to quantify rainfall at the surface at longer distances where the radar samples dry or melting snow aloft. This methodology helps to mitigate the problem of discontinuity in the maps of rain totals at the boundaries between pure rain, wet snow (melting layer), and dry snow which is inherent to the HCA-based QPE algorithm currently implemented on polarimetric WSR-88D radars.

This project is ongoing.



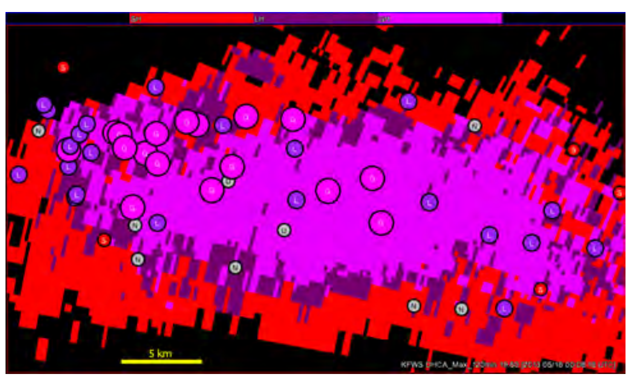
6-hour rainfall totals for the storm on 01/16/2013 observed with the KMBX WSR-88D radar in Birmingham, AL. (a) Output of the existing QPE algorithm; (b) output of the modified QPE algorithm. The new algorithm does not utilize discrete "fudge" factors in the R(Z) relations depending of the hydrometeor class which cause apparent discontinuities in the rain total field in the left panel. A much smoother and realistically looking map of rain total is produced with the new QPE algorithm.

h. Investigation of Polarimetric Signatures of Melting Hail and Their Practical Implications

Alexander Ryzhkov, Matthew Kumjian, Scott Ganson, Pengfei Zhang, Kiel Ortega, and Djordje Mirkovic (all CIMMS at NSSL)

Spectral (bin) microphysical models have been used to simulate polarimetric radar variables in melting hail. Most computations are performed in a framework of a steady state, one-dimensional column model. Vertical profiles of radar variables are modeled at S-, C-, and X-bands for a variety of size distributions of ice particles aloft. The results of theoretical modeling are utilized to develop practical recommendations for developing the algorithms for hail detection and determination of its size as well as attenuation correction and rainfall estimation in the presence of hail. Hailstones are commonly modeled as spheroids in existing scattering models. A more complex model of hailstone, which takes into account surface roughness, is used for simulation of key radar variables via employing a numerically rigorous full-wave computational electromagnetics approach.

Validation of the key assumptions in the Hail Size Discrimination Algorithm (HSDA) and its performance was accomplished through the Severe Hazards Analysis and Verification Experiment (SHAVE) and NOAA's Hazardous Weather Testbed Experimental Warning Program, which was conducted throughout the warm seasons in the years 2012 and 2013. The data collected by a number of polarimetric WSR-88D radars have been used for comparison with in situ reports during SHAVE. A unique dataset containing 39 hail cases yielding 1806 SHAVE reports has been built as a result of this effort. Among hail reports, 665 were identified as small hail, 459 as large hail, and 95 reports indicate giant hail. The results of in situ observations will be used for optimization of the membership functions in HSDA. This project is ongoing.



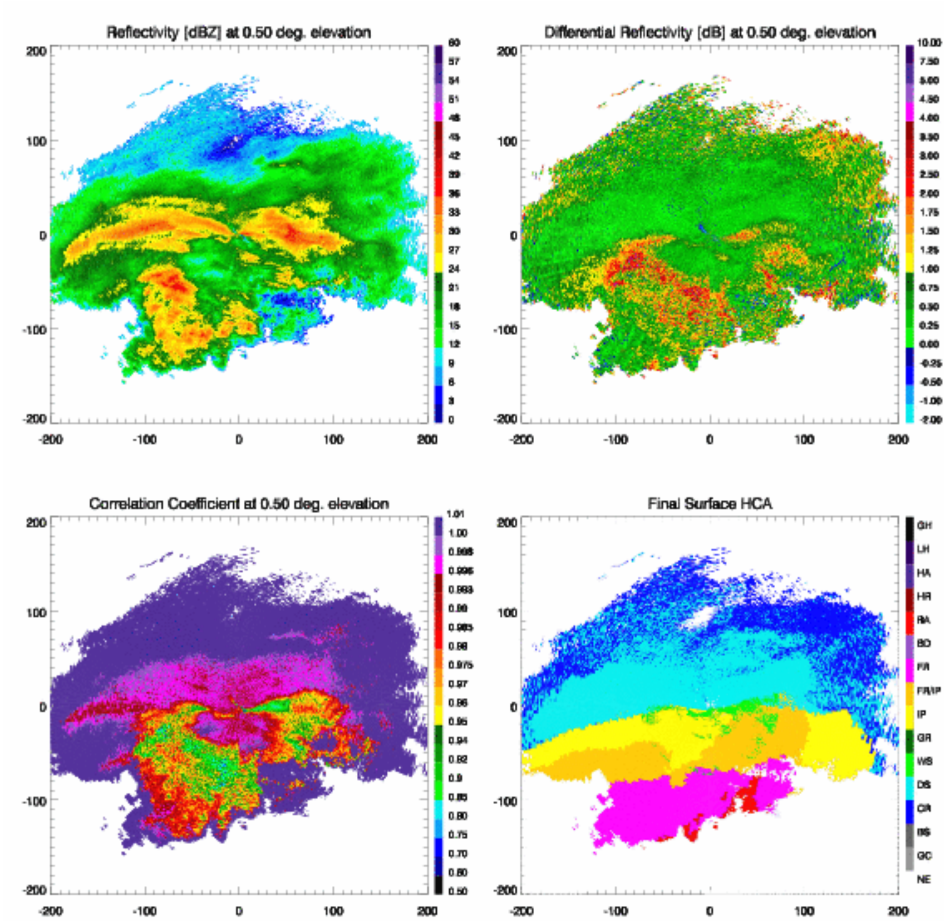
Spatial distribution of the HSDA output integrated over a period of 2 hours during hailstorm on 15 – 16 May 2013 observed by the KFWS WSR-88D radar. The color of the pixel in the map indicates the maximal hail size estimated by HSDA within a 2-hour period in this particular location. The overlaid circles of different size and color show locations of the SHAVE ground reports within the same time period. Small, large, and giant hail reports are designated as 'S' in red circles, 'L' in purple circles, and 'G' in magenta circles respectively. The reports with unknown hail size or "no hail reported" are marked with 'U' and 'N' correspondingly.

i. Development of a New Surface-Based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network

Terry Schuur, Alexander Ryzhkov, Heather Reeves, John Krause, Kim Elmore, and Kiel Ortega (all CIMMS at NSSL)

A new surface-based winter polarimetric Hydrometeor Classification Algorithm that uses thermodynamic output from the High Resolution Rapid Refresh (HRRR) model has been developed and tested. The classification of cold-season precipitation type at the surface is complicated by the broad range of precipitation types that might result from processes that occur below the height of the radar's lowest elevation sweep. For example, a shallow layer of subfreezing air near the surface might lead to either a complete refreezing of drops (ice pellets) or refreezing upon contact with the surface (freezing rain). Both of these precipitation types are difficult to determine using radar data alone, and may not be observed at all at distances > 50 km from the radar. The new algorithm allows fuzzy-logic-based classifications from the lowest elevation sweep to be projected to the surface as snow or ice crystals for cold season events where the entire atmospheric column above a location has T < -5ºC and as rain, big drops, or hail for warm season events where the surface temperature at a location that has a T > 5ºC. However, for intermediate conditions typical of transitional winter weather events, the algorithm uses vertical profiles of wet bulb temperature profiles derived from the HRRR to provide a background precipitation classification type. Polarimetric radar observations, when available, are then used to either confirm or reject the background classification. The introduction of thermodynamic output from the HRRR therefore provides an opportunity to not only enhance classification in regions where radar data are available, but also to extend classification capabilities to more distant ranges where low-level radar data are not available.

This project is ongoing.



Radar reflectivity (Z_H), differential reflectivity (Z_{DR}), correlation coefficient (r_{hv}) at 0.5° elevation and the final surface-based classification product from the new Hydrometeor Classification Algorithm using radar data from the Pittsburgh, PA (KPBZ) WSR-88D radar at 080332 UTC on 21 January 2012 and thermodynamic output from the High Resolution Rapid Refresh (HRRR) model at 08 UTC on 21 January 2012. Precipitation type categories are no echo (NE), ice crystals (CR), dry snow (DS), wet snow (WS), graupel (GR), ice pellets (IP), freezing rain/ice pellets (FR/IP), freezing rain (FR), big drops (BD), rain (RA), heavy rain (HR), hail (HA), large hail (LH), and giant hail (GH).

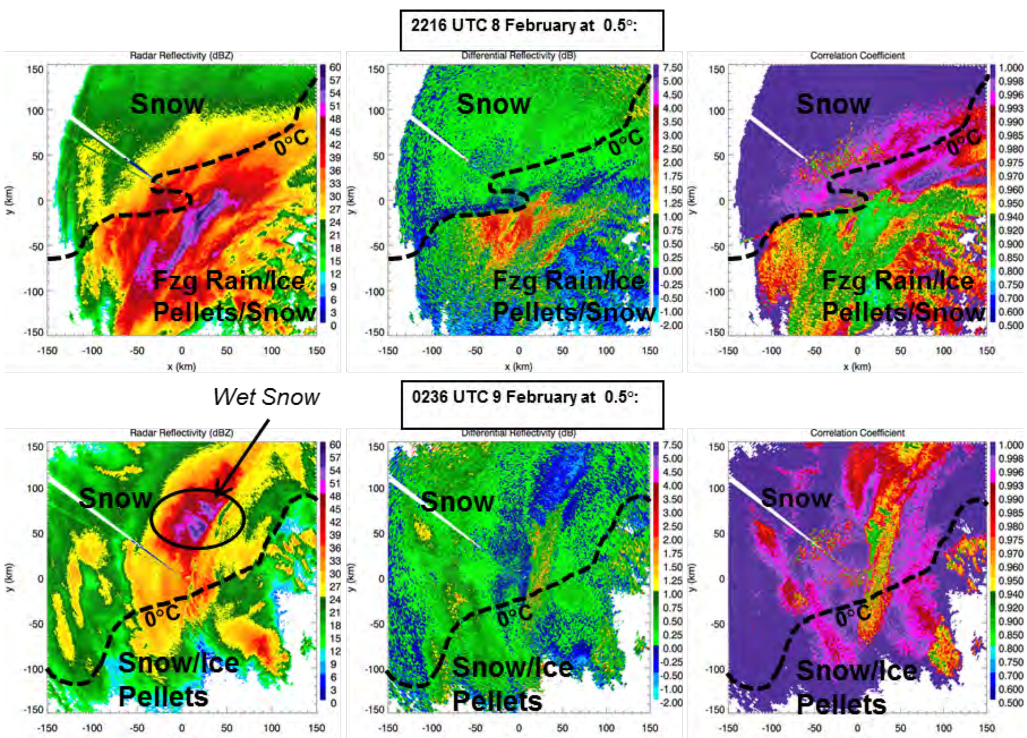
j. Polarimetric Radar Analysis of Winter Storms

Erica Griffin (OU School of Meteorology at CIMMS), and Terry Schuur and Alexander Ryzhkov (both CIMMS at NSSL)

The microphysical properties of winter storms have largely remained unexplored, as polarimetric investigations have been focused on warm-season and severe convective storms. With the recent polarimetric upgrade to the WSR-88D network, however, ample polarimetric data are now available for locations throughout much of the U.S., thereby providing an abundant data set for the study of the microphysical properties of winter precipitation. An investigation of these polarimetric/microphysical signatures is now underway, with an initial focus on the high impact blizzard that hit the northeastern U.S.

on 8-9 February 2013. A preliminary investigation of polarimetric observations from the Upton, NY, KOKX during this event reveals several intriguing features, including a distinct localized downward excursion of the melting layer bright-band to the surface (characterized by reduced ρ_{hv} and locally maximized Z_H and Z_{DR}), an abundance of radial streaks of enhanced positive and negative Z_{DR} due to depolarization of the transmitted radar signal, a "flare echo" or three-body scatter signature suggesting the presence of hailstones, and Z_H as high as 60 dBZ in a region of thundersnow over Connecticut. Additionally, there were numerous signatures of enhanced Z_{DR} located above the environmental freezing layer, which were associated with enhancements in K_{DP} and slightly reduced ρ_{hv}. These enhanced Z_{DR} values signified the presence of large, horizontally oriented ice crystals in the subfreezing temperatures aloft, primarily due to lack of aggregation. The results of this work will further understanding of the fundamental microphysical processes within winter storms, as well as aid in improvement of the representation of winter precipitation in numerical modeling.

This project is ongoing.



Radar reflectivity (Z_H), differential reflectivity (Z_{DR}), and correlation coefficient (r_{hv}) at 0.5° elevation from the New York, NY (KOKX) WSR-88D radar at 2216 UTC on 8 February 2013 (top row) and 0236 UTC on 9 February 2013 (bottom row). Dashed line on each plot delineates the location of T_W=0°C at the surface from the Rapid Refresh model at 22 UTC on 8 February 2013 and 02 UTC on 9 February 2013, respectively. Radar data at 0236 UTC shows a large region of heavy, wet snow over Connecticut, well to the north of the model indicated T_W=0°C line.

k. Testing of a Background Classification Algorithm for Use with Dual-Polarization Radars in Determining Precipitation Type at the Surface

Heather Reeves, Kim Elmore, Terry Schuur, John Krause, and Kiel Ortega (all CIMMS at NSSL)

A "background" classification of precipitation types at the surface is the first step in the Winter Hydrometeor Classification Algorithm. Five different methods based on vertical profiles of wet bulb temperature retrieved from the HRRR model have been examined and tested. Various contributors to the uncertainties in the precipitation type designations have been identified. These include the uncertainty introduced by the choice of algorithm, the horizontal variability of the precipitation type, and the analysis / forecast uncertainty. It is shown that the categories of pure snow and pure rain can be well detected, whereas considerable ambiguity still persists regarding freezing rain and ice pellets/sleet.

This project is ongoing.

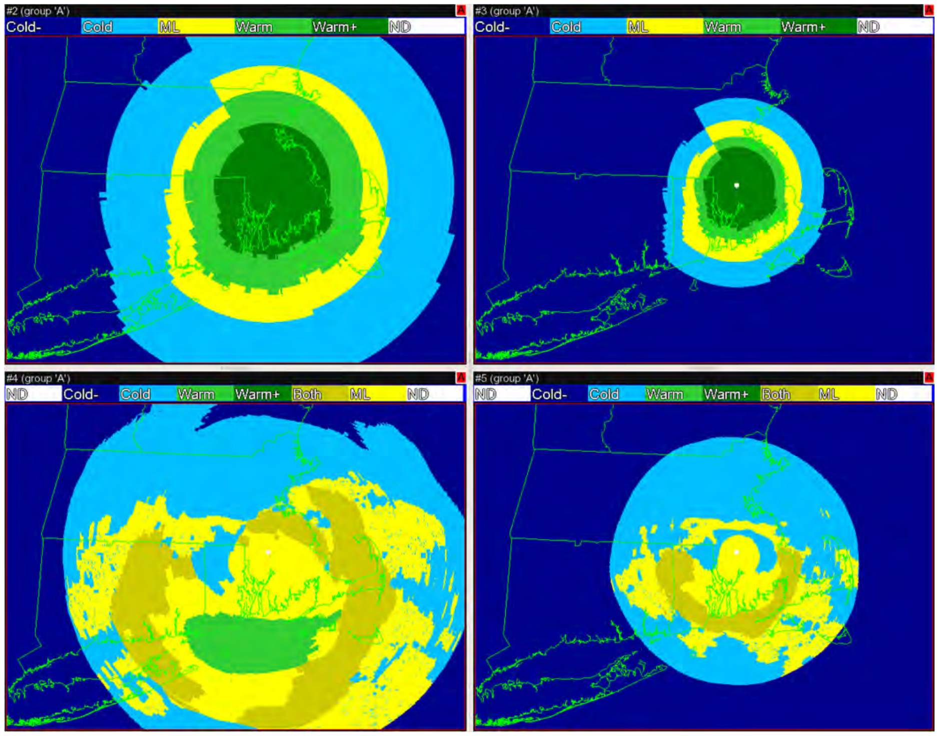
l. Developing a New Version of the Melting Layer Detection Algorithm Using Dual-Polarization Radar, NWP Model Data, and Object Identification Techniques

John Krause, Alexander Ryzhkov, and Valliappa Lakshmanan (all CIMMS at NSSL)

An advanced version of the Melting Layer Detection Algorithm (MLDA) has been developed that can identify the areas affected by the impact of the melting layer at any given PPI. This new algorithm combines polarimetric radar data and NWP model information to properly designate the melting layer (or wet snow) and contamination from the melting layer in the storms with complex temperature profiles. The MLDA module is a key element of the Hydrometeor Classification Algorithm (HCA) and Quantitative Precipitation Estimation (QPE) algorithm employed on the polarimetrically upgraded network of the WSR-88D radars.

The existing version of the MLDA uses radar information at relatively high antenna elevations (between 4 and 10°) and the ML designation is projected onto lower elevations assuming that the precipitation field is relatively uniform in the horizontal direction. The assumption of the horizontal uniformity does not hold in the presence of frontal boundaries. The modified version of MLDA provides ML designation at all antenna elevations without the need to assume horizontal uniformity. The wet bulb temperature information retrieved from the NWP models is utilized to constrain radar-based designation and to delineate the areas of "true" ML (or wet snow) as opposed to the regions of the "ML contamination" identified from the radar data.

The new algorithm exhibits robust performance in the most challenging winter storms in the northeastern U.S. associated with extratropical cyclones with particularly complex spatial structure. This project is ongoing.



Comparisons of the old and new MLDA products obtained from the KBOX WSR-88D radar near Boston on 12 January 2012. Upper left and right panels show old MLDA products at elevations 0.5° and 1.45° respectively, whereas new MLDA products are shown at bottom panels. The areas of the melting layer contamination retrieved from the radar are shown in yellow, the regions with wet bulb temperature between 0 and 3°C retrieved from the HRRR model are painted in orange. The frontal boundary between the northern and southern sectors is more objectively reproduced using the modified version of MLDA.

m. Investigating Microphysical Processes in Clouds and Precipitation with Explicit Modeling and Polarimetric Radar Data

Alexander Ryzhkov and Matthew Kumjian (both CIMMS at NSSL), and Jacob Carlin (OU School of Meteorology at CIMMS)

Spectral (bin) microphysical models of different complexity combined with the forward polarimetric radar operator developed at CIMMS/NSSL have been used to clarify different microphysical processes in clouds and precipitation.

The anatomy and physics of Z_{DR} columns have been examined using the Hebrew University Cloud Model (HUCM). It is shown that the Z_{DR} columns pinpoint localization of convective updrafts and their height above the freezing level is proportional to the updraft strength. The signature has important prediction value because tall Z_{DR} columns usually precede fallout of large hail or heavy rain by 15 – 30 min. The origins of the refreezing signature marked by enhanced Z_{DR} in cold air beneath warm elevated layer in cold-season storms have been examined. The signature shows up when freezing

drizzle is converted to ice pellets, hence it can be utilized for discrimination between freezing rain and ice pellets / sleet.

A 1D model of melting hail was utilized to derive radar relations for estimating mixing ratios of rain and hail (q_r and q_h) if rain is mixed with hail. Utilization of specific differential phase K_{DP} and results of polarimetric classification of melting hail of different sizes in addition to the radar reflectivity factor Z provides much better estimates of q_r and q_h for assimilation of radar data into storm-scale NWP models.

This project is ongoing.

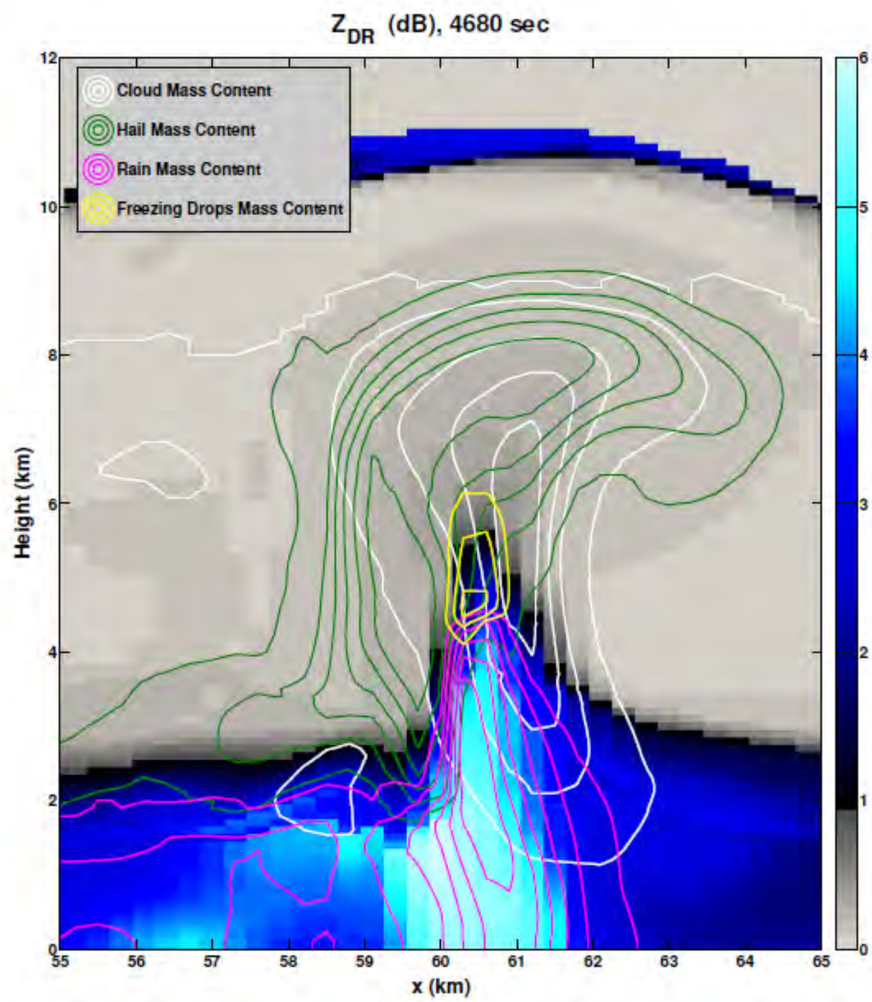


Illustration of the simulated Z_{DR} column associated with convective updraft using the HUCM model. Color shading is used for Z_{DR}. Overlaid are contours of hydrometeor mass content: cloud droplets (grey), rain (cyan), hail (red), and freezing drops (orange). Contour intervals are the same for each species, starting at 0.5 g m^{-3} with increments of 0.5 g m^{-3}.

Dual-Polarization Publications

Andrić, J, M. R. Kumjian, D. S. Zrnić, J. M. Straka, and V. M. Melnikov, 2013: Polarimetric signatures above the melting layer in winter storms: An observational and modeling study. *Journal of Applied Meteorology and Climatology*, **52**, 682-700.

Bodine, D., M. Kumjian, R. Palmer, P. Heinselman, and A. Ryzhkov, 2013: Tornado damage estimation using polarimetric radar. *Weather and Forecasting,* **2**, 139-158.

Kaltenboeck, R., and A. Ryzhkov, 2013: Comparison of polarimetric signatures of hail at S and C bands for different hail sizes. *Atmospheric Research,* **123**, 323-336.

Kumjian, M., S. Ganson, and A. Ryzhkov**,** 2012: Freezing of raindrops in deep convective storms: A microphysical and polarimetric model. *Journal of the Atmospheric Sciences*, **69**, 3471-3490.

Kumjian, M., A. Ryzhkov, H. Reeves, and T. Schuur, 2013: Dual-polarization radar observations of hydrometeor refreezing in winter storms. *Journal of Applied Meteorology and Climatology*, accepted.

Kumjian, M., 2013a: Principles and applications of dual-polarization weather radar. Part I: Description of the polarimetric radar variables. *Journal of Operational Meteorology*, accepted.

Kumjian, M., 2013b: Principles and applications of dual-polarization weather radar. Part II: Warm and cold season applications. *Journal of Operational Meteorology*, accepted.

Kumjian, M., 2013c: Principles and applications of dual-polarization weather radar. Part III: Artifacts. *Journal of Operational Meteorology*, accepted.

Lakshmanan, V., M. Miller, and T. Smith, 2013: Quality control of accumulated fields by applying spatial and temporal constraints. *Journal of Atmospheric and Oceanic Technology*, **30**, 745-757.

Ryzhkov, A., M. Kumjian, S. Ganson, and A. Khain, 2013: Polarimetric radar characteristics of melting hail. Part I: Theoretical simulations using spectral microphysical modeling. *Journal of Applied Meteorology and Climatology*, submitted.

Ryzhkov, A., M. Kumjian, S. Ganson, and P. Zhang, 2013: Polarimetric radar characteristics of melting hail. Part II: Practical implications. *Journal of Applied Meteorology and Climatology*, submitted.

Troemel, S., M. Kumjian, A. Ryzhkov, and C. Simmer, 2013: Backscatter differential phase – estimation and variability. *Journal of Applied Meteorology and Climatology,* accepted.

Wang, Y., J. Zhang, A. Ryzhkov, and L. Tang, 2013: C-band polarimetric radar QPE based on specific differential propagation phase for extreme typhoon rainfall. *Journal of Atmospheric and Oceanic Technology,* **30**, 1354-1370.

Zhang, P., D. Zrnic, and A. Ryzhkov, 2013: Partial beam blockage correction using polarimetric radar measurements. *Journal of Atmospheric and Oceanic Technology,* **30**, 861-872.

Awards

Alexander Ryzhkov (CIMMS at NSSL) was chosen to present three invited lecture courses on weather radar polarimetry abroad: 1) Korea Meteorological Agency (Seoul, Korea, October 2012); 2) Kyungpook National University (Daegu, Korea, October 2012); and 3) International Summer School on Remote Sensing of Clouds and Precipitation, University of Bonn, Germany, July 2013. Each lecture course includes 6 - 8 hours of lecturing. Ryzhkov also gave an invited lecture at the Hebrew University of Jerusalem, Israel, in April 2013.

3. Phased Array Radar

Overall Objectives

Continue engineering research and development in collaboration with NSSL and various other agencies to determine the usefulness of the military phased array radar system for meteorological observations. Phased array radars have been used for many years in military applications for detection and tracking of aircraft and missiles. To determine the feasibility of using this radar for meteorological observations, it must be

tuned. The NWRT phased array radar (PAR) testbed in Norman, Oklahoma, is the first of its kind to study meteorological applications of this technology. In addition, most phased array systems have only one polarization, so studies are being conducted to determine the feasibility of dual polarized phased array antenna systems along with the applications of using the radar for multi-purposes (i.e. aircraft tracking and wind profiling). Areas of research and development include, improved algorithm development for fast scan radars, new display techniques, data analysis to study structure and dynamics of convective phenomena, new fast scanning techniques, and digital signal processing techniques. Other objectives include: 1) determine the usefulness of PAR observations for forecasts and warnings and develop PAR parameter thresholds for severe weather and compare them to WSR-88D thresholds; 2) investigate the impact of higher-temporal resolution PAR data on the warning decision process of NWS forecasters during severe weather; and 3) obtain sufficient PAR background knowledge of convectively driven high-wind events to measure and analyze them.

Accomplishments

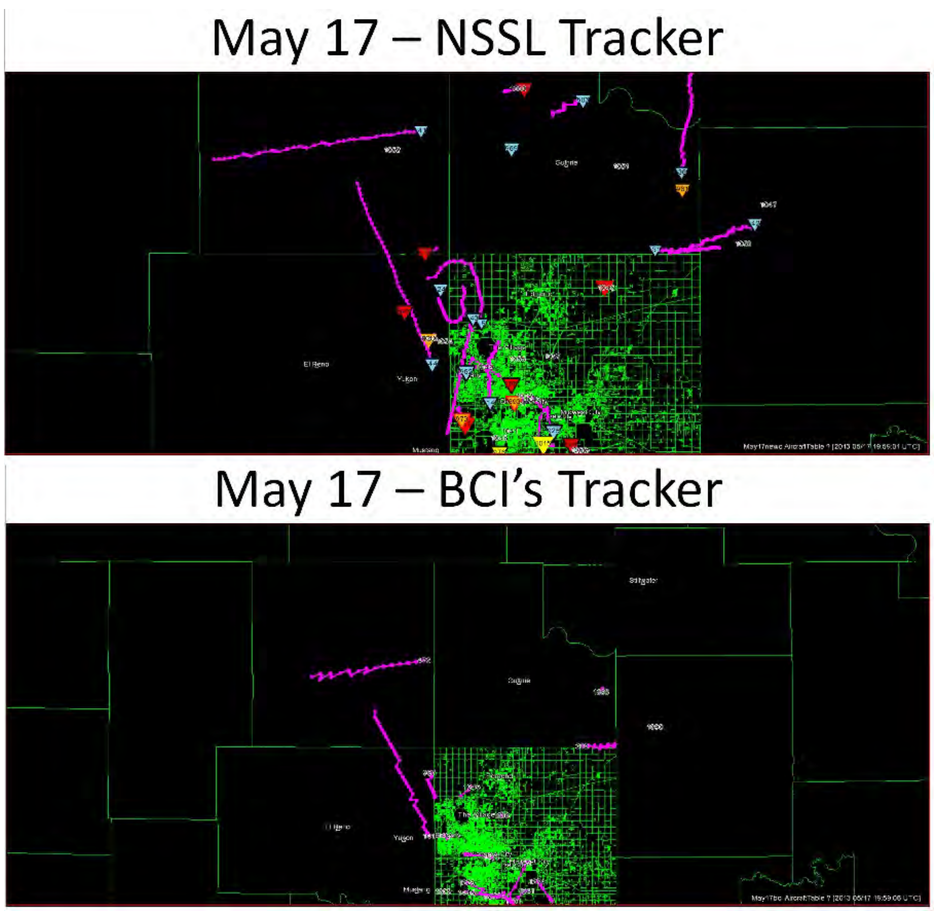
a. NWRT PAR Software Upgrades (MPARSUP)

Sebastian Torres, Richard Adams, Chris Curtis, Eddie Forren, Doug Forsyth, Igor Ivić, David Priegnitz, John Thompson, and David Warde (all CIMMS at NSSL), and Pam Heinselman and Michael Jain (both NSSL)

The goal of this project is to use the NWRT PAR to demonstrate the potential of PAR technology to simultaneously perform aircraft tracking and weather surveillance as a multi-function phased-array radar (MPAR) while highlighting many of its unique advantages for weather observations. During FY13, work continued to improve the quality of meteorological data produced by the NWRT PAR, to demonstrate adaptive scanning capabilities for weather observations, and to demonstrate multi-functionality. Developing new and modifying existing algorithms to demonstrate the benefits of PAR technology has been an ongoing goal of the MPARSUP project. Major accomplishments are reported next.

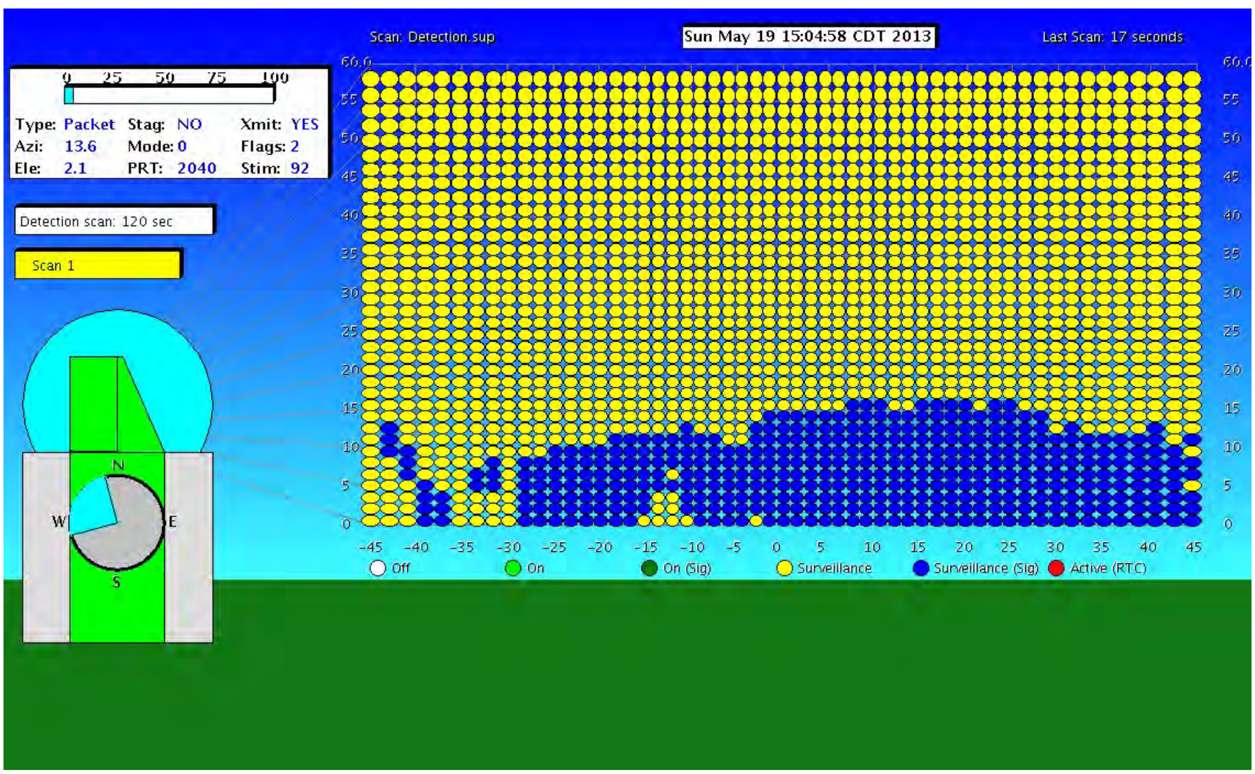
Aircraft Tracking (Forsyth, Ivić, Priegnitz, and Forren): An aircraft tracking system is being implemented on the NWRT in real-time in order to show the multi-functional capabilities of a PAR system. The first steps were to get the Aircraft Tracking Processor (ATP), delivered several years ago by Basic Commerce Industries (BCI), running again and data being displayed on the WDSS-II display system. This system is a stand-alone system and is limited on the type of scanning strategies that can be used. Thus, in order to provide flexibility in scanning strategies and not having to deal with proprietary software, we decided to implement our own aircraft tracking system and integrate it into the current real-time system running on the NWRT. Most of the NWRT code was first implemented in MATLAB and then converted to C for real-time operations. An aircraft tracker was implemented in MATLAB and its output was displayed in WDSS-II. The code is now being converted to real-time C and will be tested beginning this fall. To

support demonstrating the multifunction capability, a new aircraft scan strategy was designed, which provides complete areal coverage within a 90-degree azimuthal and 20-degree elevation sector. To achieve very fast update times, the aircraft scan was patterned after the ADAPTS detection scan, which uses only 4 pulses at each beam position. However, in this case, a short pulse repetition time of 800 μs at each beam position was chosen in order to maximally reduce the scan time. Thus, a complete aircraft scan can be completed in ~2.4 seconds. One of the requirements for aircraft scanning at the NWRT PAR is to run it concurrently with weather/detection scans, repeating regularly at intervals much shorter than a typical weather scan. For our demonstration, we are targeting an aircraft-tracking update time of ~4.8 seconds. Since the aircraft scan completes in ~2.4 seconds, we can use a 50-50 share between scan types. At the radar Real-Time Controller, a timer has been set up to interrupt active weather/detection scans when the aircraft-tracking update time is reached. To provide more flexibility, the update frequency can be modified by an operator at the Radar Control Interface (RCI).



Example of NSSL's aircraft tracker (top) and BCI's ATP (bottom) output from the same case on 17 May 2013. Triangles represent aircraft targets with the magenta showing the past tracks and the color of the triangle showing the current status of the target.

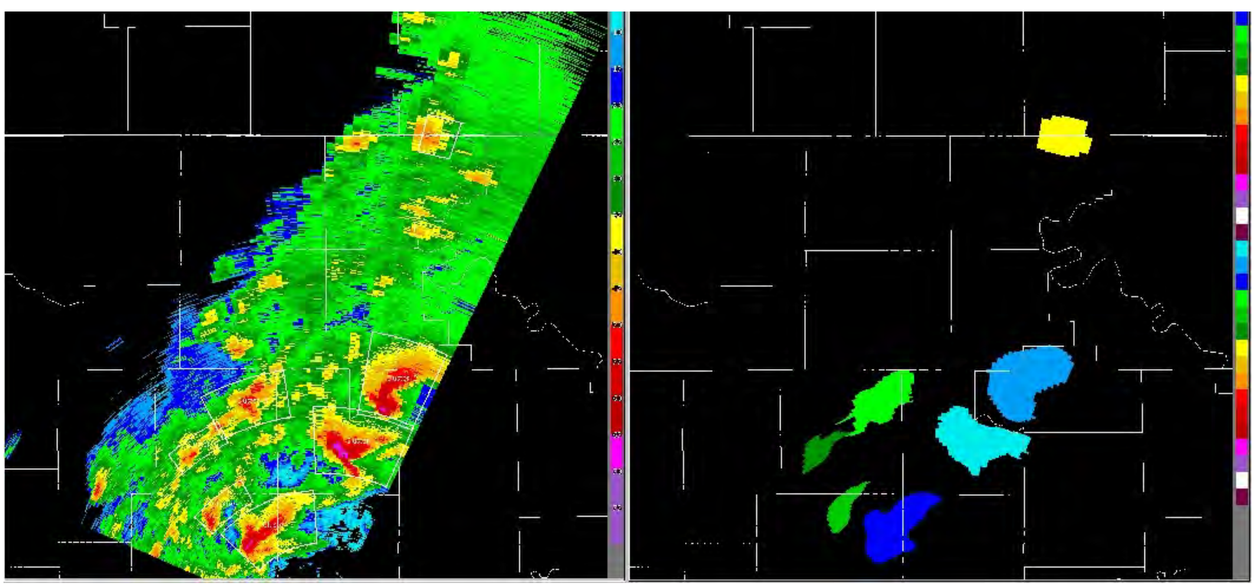
ADAPTS (Thompson, Priegnitz, Ivić, Warde, and Forren): The Adaptive Digital Signal Processing Algorithm for PAR Timely Scans (ADAPTS) went through several evolutions during the fall of 2012 and spring of 2013. In the fall of 2012, an option was added to the surveillance feature of the algorithm not to oversample azimuthally in areas determined not to contain significant weather (typical weather scanning strategies used by the NWRT PAR oversample azimuthally by one half beamwidth). Because the goal is to reduce scan times in the regions of non-significant weather, for surveillance purposes, it is not necessary to oversample in order to detect new echoes. In the spring of 2013, an option was added to ADAPTS which utilizes a dedicated detection scan for locating regions of significant weather. The detection scan is designed to cover the entire space inside a sector of 90 degrees in azimuth and 60 degrees in elevation. Each beam is separated by one beamwidth (on the NWRT PAR the transmitted beam width increases from ~1.5 degrees at bore site to ~2.1 degrees at +/- 45 degrees off boresight). Each beam consists of 4 pulses and a PRT corresponding to the unambiguous range that intersects a height of 18 km. The total detection scan time is ~7.8 s. Using detection information, weather scans no longer requires surveillance pulses in non-significant regions. The detection scan is independent of the weather scan(s); multiple weather scanning strategies can use the same detection beam map. An operator using an RCI client can control the frequency of execution for the detection scan, which determines how soon new developments are detected in inactive regions. In support of PARISE 2013, the detection scan frequency was set to 2 minutes.



Sample RCI client detection beam map for ADAPTS. Yellow dots represent beams that did not return significant echoes. Blue dots represent beams that did return significant echoes.

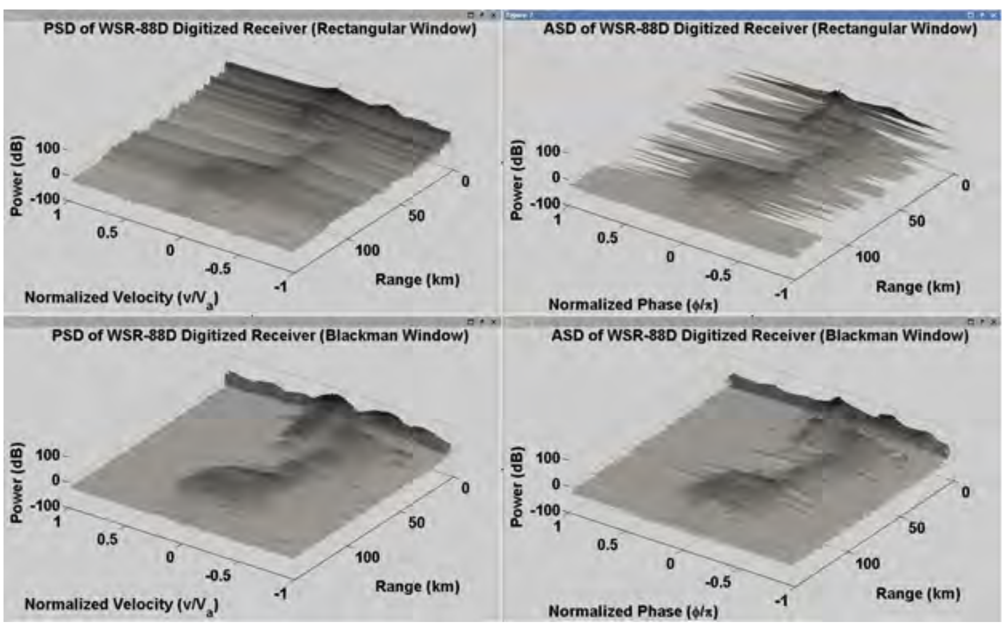
Auto PRT (Priegnitz): A new algorithm was developed that determines the optimal Doppler Pulse Repetition Time (PRT) for split/batch cuts that minimizes obscuration from multiple trip echoes inside a selected azimuthal sector. The algorithm uses reflectivity data from the lowest elevation. When used in combination with the cluster identification and weather tracking algorithms, obscuration inside a selected storm sector is minimized. A maximum PRT or minimum Nyquist velocity can be defined by the operator at an RCI client.

Cluster Identification and Weather Tracking Algorithms (Priegnitz): A new algorithm was developed that identifies weather features in reflectivity data. This algorithm, the Cluster Identification Algorithm (CIA), uses a technique developed by CIMMS staff to organize a two-dimensional reflectivity data set at the lowest elevation angle into a set of watersheds and then combines them into larger "clusters". One can think of a watershed being a cell and a cluster containing one or more related/adjoining cells. An example of a typical cluster analysis and display is shown in the figure below. One should note how well the most intense regions are identified and that the less intense/stratiform regions are removed. This is important in the process of identifying sector boundaries for the most intense storms. When used in combination with the weather-tracking algorithm (WXTRACK), clusters can be selected by an operator at the RCI client and automatically tracked. Additionally, the operator can schedule more frequent updates of a sector of interest for a specified amount of time. Sector scans on the storm cluster of interest are repeated until the time has expired. If ADAPTS processing is enabled, sector scan times can be further reduced by not executing beams in inactive parts of the sector.



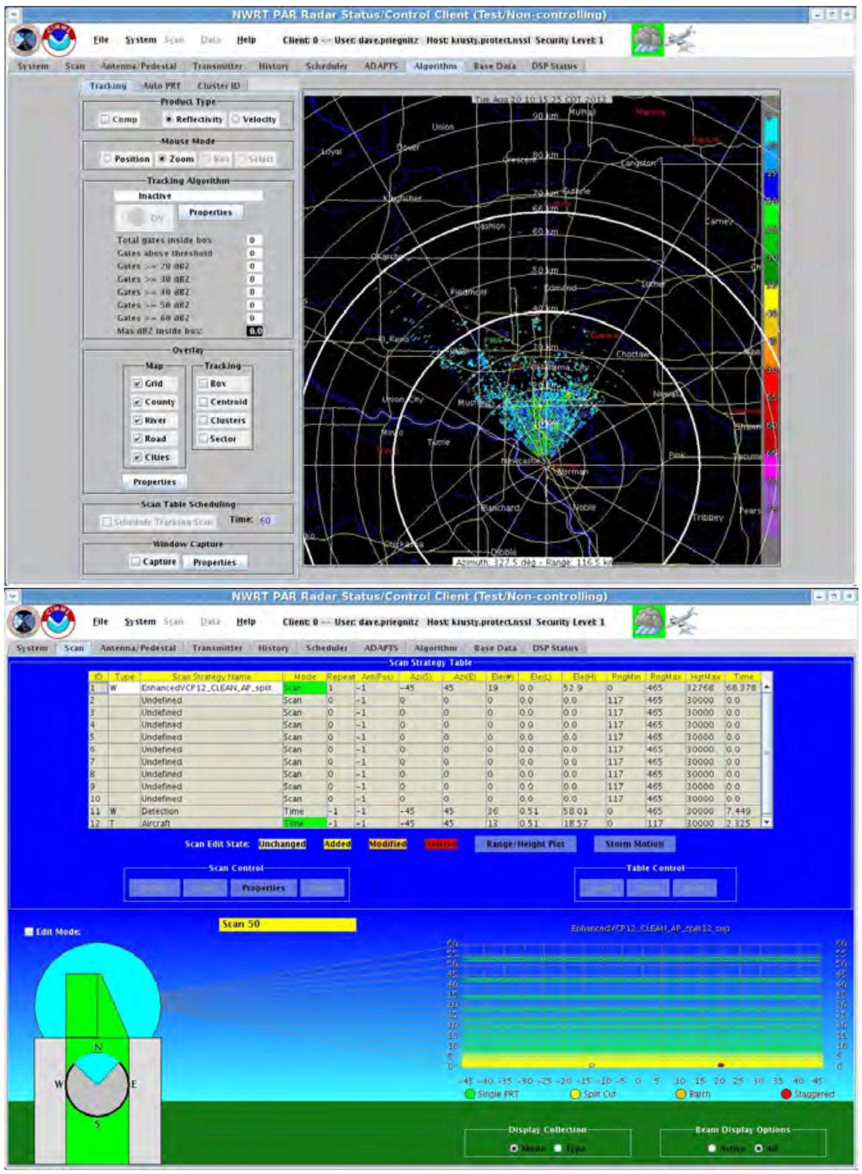
Performance of the Cluster Identification Algorithm. Reflectivity display with main clusters outlined (left) and cluster analysis with main clusters identified (right).

Signal Processing (Warde and Curtis): The NWRT DSP code provides a forum to demonstrate innovative signal processing and adaptive sensing techniques to improve the quality, coverage, accuracy, and timeliness of meteorological products from weather radars. In addition, new science developed by CIMMS scientists and demonstrated using the NWRT DSP eases the transfer of technology from research to operations into existing radar systems for government, public, and private organizations. For example, several scientific algorithms that migrated into or are scheduled for future DSP upgrades to the NEXRAD system (i.e., CBT, RBRN, CLEAN-AP, SPRT, and range oversampling) have been demonstrated first using the NWRT DSP. In FY13, the NWRT DSP was upgraded to include processing for either single- or dual-polarization systems; i.e., the NWRT DSP code was extended this year to add dual polarization processing. Although the NWRT is a single-polarization radar, the DSP code is now a radar-independent processing platform that can be used to process NEXRAD data and data from future dual-polarization phased array antennas. The upgrade includes changes for ingesting the new radar-independent pulse groups that were developed to represent both NWRT and NEXRAD data. The dual polarization adaptive pseudowhitening algorithm was also implemented on this new DSP, and data from the research KOUN radar was processed. The single-polarization upgrades provide adaptive weather sensing improvements aimed at faster updates through focused and timely observations of weather. Additionally, an innovative spectral analysis technique developed by CIMMS based on the autocorrelation spectral density (ASD) provides the framework for both single- and dual-polarization unbiased spectral and autocorrelation estimates.



Comparison of traditional (left panels) and advanced spectral analysis (right panels) techniques of the weather spectrum. The power spectral density (PSD) using rectangular (top left) and Blackman (bottom right) data windows tend to “smear” the spectrum; whereas, the autocorrelation spectral density (ASD) using rectangular (top right) and Blackman data windows (bottom left) better represent the structure of the weather by mitigating these smearing effects.

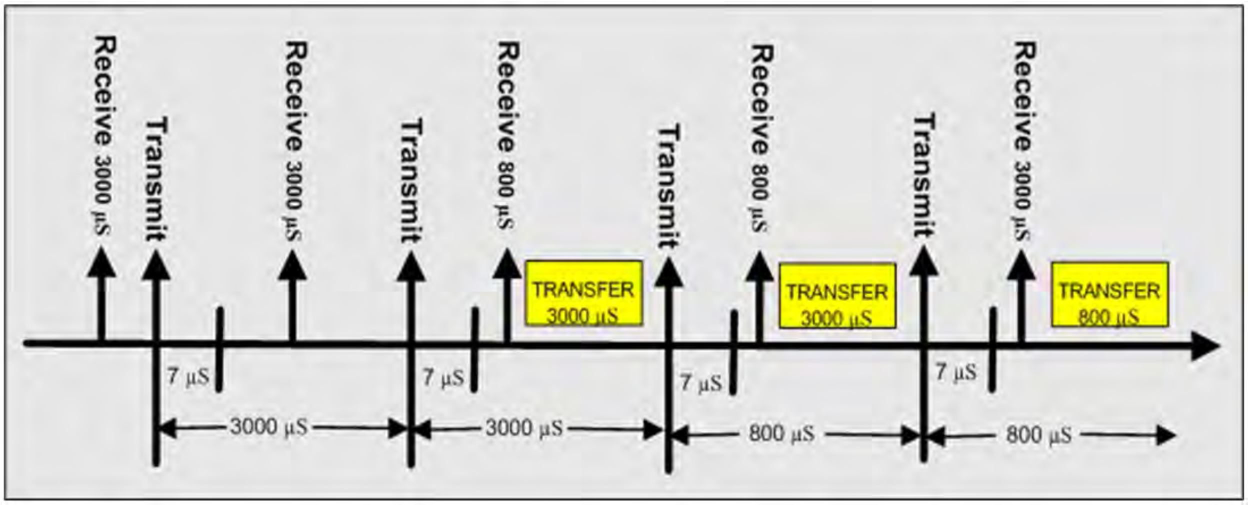
User Interface (Priegnitz): The Radar Control Interface (RCI) is continually updated to support new functions and capabilities. During the fall of 2012 and spring of 2013, major changes were made to the RCI client to support algorithms. A new "Algorithm" tab panel was added to support existing and future algorithms. A sample algorithm tab panel display is presented in the figure below. The "ADAPTS" tab panel was updated to support the display of the detection-scan beam map. In addition, a new category was added to the beam display map to show new detections (see figure below). The "Scan" tab panel was updated to support time-based scheduling and show the properties of the new detection and aircraft scans. A sample scan tab panel display is shown in below; it was expanded to include the detection and aircraft scans.



NWRT user interface enhancements. Sample "Algorithm" tab panel display (top) and sample "scan" tab panel (bottom).

Real Time Controller (Priegnitz and Forren): The Real Time Controller (RTC) is the NWRT PAR subsystem used to interface with radar hardware and to control the sequence and properties of beams being scanned. The RTC software is continually being updated to make it more robust and to support new capabilities. Prior to the spring 2013 software release, considerable work was done to solve an issue with the RTC that limited the system's ability to switch between PRTs and collect data inside a range of 10 km. This problem was attributed to both the design of the original digital receiver software and the RTC hardware itself. Addressing these problems was important for data analysis, capturing severe events at close ranges, improving data quality, and providing faster scan times by allowing small sector scans and beam-to-beam PRT changes. The problems turned out to be extremely difficult to isolate because of the real-time nature of the software, the intermittent symptoms, and the root causes of the problems. The intermittent nature of the problems required persistence and the development of real-time logging software that allowed us to capture what the software was doing in microsecond/sub-microsecond time scales during long runs. Eventually, after extensive testing on the MVME5100, it was clear that the command to tell the receiver to gather data was happening too late because the hardware was too slow to transfer the data from the RTC to the signal processor and receive data at the same time. The software was modified so that the time window for setting up the receiver was as large as ~500 microseconds and set up commands for the receiver never occurred during data transfers from the receiver to the RTC.

To support improvements to ADAPTS, a detection scan was designed and code was added to the RTC to build the detection scan command queue at system start up. The scan table processing function was modified so that when ADAPTS is active, a detection scan is executed at a user-specified time interval. A detection scan will not interrupt any active weather scans. It is started after an active weather scan has completed and the specified time interval has been reached. To support the new auto PRT function, modifications were made to the RTC scan processing modules to change the short-PRT pulse group in split/batch cuts when enabled. The RCI server sends a new PRT to the RTC upon receipt of new information from the auto-PRT algorithm running at the signal processor. The scan table module has been updated to support time-based scanning. Weather scans are run from the scan table in a round-robin fashion. An independent repeat count can be defined for each scan in the table. Now, a scan can be either repeated by a count or repeated for a specified time interval. To support the upcoming multifunction demonstration this fall, an aircraft scan was designed and the RTC was modified to build the aircraft-scan command queue at system start up. A new aircraft scan processing mode was added to the main processing loop. Aircraft-scan processing is based on a timer and is not part of the round-robin procedure used for weather scans. Modifications were made to the scan-table module to allow interrupting active weather/detection scans to run an aircraft scan at a user controlled frequency. Aircraft scanning can be run with or without weather scanning. Finally, the RTC was modified to support research and data collection with the multi-channel receiver system passively connected to the NWRT PAR.



Real-time-controller timing after the software modifications that enabled the use of multiple pulse repetition times and the collection of data within 10 km of the radar. In addition to the software modifications that moved the receiver setup back to the previous pulse but before the transfer starts, the RTC computer was upgraded to get faster data transfers.

Software Infrastructure and Real-Time DSP (Forren): Significant modifications were made to our radar-independent DSP to handle problems specific to rotating reflector antennas and radars that scan the entire 360-degree azimuthal space. Along with changes to support horizontal and vertical channels for dual polarization, changes were also made to make our radar-independent I/Q-pulse and pulse-group formats more consistent and flexible. Additionally, the preprocessor in the signal processor was optimized significantly to support aircraft scanning for the multi-function demonstration. The modifications to support rotating antennas involved implementing a “beam offloading” scheme that allows the preprocessor to keep a very large number of beam positions “open” at the same time. This allows different dwells for the same radial to be spaced much further apart in time, which may be useful in some more advanced DSP processing schemes that might process I/Q data across different elevations within a volume scan. It also involved implementing a scheme to support split cuts that accumulates dwells in a surveillance cut and matches them with appropriate dwells from the Doppler cut. The modifications to support horizontal and vertical channels were relatively minor, because of the flexibility of our high speed, self-descriptive data formats. The changes to make our time-series data formats more flexible were mostly cosmetic, but required some work because it changed how information was accessed in several of our applications. The preprocessor was optimized to better deal with real-time response times needed for faster data streams produced by aircraft scans. It involved pipelining the “read” and “write” portions of the preprocessor so that each could execute concurrently. More optimization and refinement may be important in the future to support very short dwell times that may be required by non-meteorological applications.

System Testing (Adams): Testing is an important factor in our research to operations success and has continued this year. After research ideas are accepted and designed

for integration into the system for each software release, software developers begin writing code towards that design. Separate implementations are built into a development system that is tested as they are added. Once the developers are satisfied that they have accomplished the design, an integrated software build is created and loaded onto our test system. An independent approach to system testing is used so that flaws are identified and corrected in a timely fashion. After the team is satisfied that the system is robust and meets the design objectives, the software is moved into operations. Testing continues during the operations phase as system activity is increased, which can sometimes uncover minor errors that need to be addressed.

All of these projects are ongoing.

b. NWRT PAR Operations

David Priegnitz and Richard Adams (both CIMMS at NSSL), and Pam Heinselman (NSSL)

Routine troubleshooting and data collection support have been provided annually for formal NWRT PAR experiments. Troubleshooting involves 24/7 support to NWRT PAR operators, solving software/hardware issues as they arise through telephone conversations, or by actually driving to the NWRT PAR facility to resolve hardware issues. Data collection support has also been done on a 24/7 basis. With the remote capability of the RCI client software, some informal late-night data collections have been performed from home. In most instances, during formal experiments, data collection has been performed in the Hazardous Weather Testbed to provide visibility to other scientists and forecasters. The table below lists the formal data collection activities that were supported during the period 1 July 2012 to 30 June 2013 along with the initials of the primary operator(s) (DP: David Priegnitz, RA: Ric Adams, PH: Pam Heinselman).

Date	Operator(s)	Experiment	Event
08-16-12	DP & RA	GOES Rapid Scan	Collect data from sunrise to sunset
09-13-12	DP	Algo. Evaluation	Ordinary convection
04-10-13	DP	PARISE	Non-severe multicell clusters
04-17-13	DP	PARISE	Hail/Wind
04-26-13	DP	PARISE	Hail/Wind
05-01-13	DP	PARISE	Hail/Wind
05-08-13	DP	PARISE	Hail
05-09-13	RA	PARISE	Hail
05-15-13	DP	PARISE	Hail
05-18-13	DP	PARISE	Hail
05-19-13	DP & PH	PARISE	Tornado
05-20-13	DP	PARISE	Tornado
05-21-13	DP	PARISE	Hail
05-23-13	DP & PH	PARISE	Hail/Wind
05-29-13	DP	PARISE	Hail/Bow Echo
05-31-13	DP & PH	PARISE	Tornado

c. PAR Dual-Polarization Issues

Igor Ivić and David Warde (both CIMMS at NSSL), and Dusan Zrnić (NSSL)

NSSL and CIMMS scientists and engineers are investigating the next replacement for the aging WSR-88D as part of a national interdepartmental collaboration to combine weather and air surveillance missions on a single platform. Promising is the multi-functional phased array radar (MPAR), which incorporates high temporal and spatial resolution needed for improved weather sensing. The MPAR design will surely include a dual-polarization capability, as in the current WSR-88D system, allowing for improved rainfall estimation, precipitation classification, data quality, and weather hazard detection. One of the main challenges to the use of phased array radar technology for weather observations is the implementation of dual-polarization with acceptable isolation between orthogonal channels. Simulations and measurements on phased array antennas imply that such isolation cannot be achieved only by antenna hardware. Hence, additional modifications to the radar system are required to attain supplementary isolation of orthogonal channels. To achieve this, the following options were identified and are being evaluated: (1) application of phase codes within the transmitted pulses in the horizontal and vertical channels, (2) pulse-to-pulse (or interpulse) phase coding of the transmitted pulses in the horizontal and vertical channels, or (3) time-multiplexing in which the vertical transmitter port is immediately energized after energizing the horizontal port or vice versa. In FY13, the traditional application of the first approach was evaluated and it was concluded that this approach is not feasible. In-depth investigation of the second approach showed that it is capable to provide additional isolation. To investigate the third approach, collaboration was established with the ARRC at OU. Through this collaboration, the ARRC will provide hardware capability to collect time-multiplexed time-series data, which will then be analyzed by CIMMS/NSSL scientists.

As mentioned above, the desire to incorporate dual-polarization capabilities into the MPAR requires that adequate cross-polar isolation exists between the horizontal and vertical elements of the antenna. Previous work in this area has shown that the cross-polar isolation required for simultaneous transmit and receive (STAR) is much more stringent than the alternate horizontal and vertical (AHV) transmission scheme. Use of STAR would allow much of the signal processing used on the WSR-88D system to be readily transferable into the MPAR; however, cross-polar isolation requirements may dictate AHV transmission. If AHV is adopted, signal processing techniques will need to be developed to address the limitations of such transmission mode such as the increase in estimate error, the lowered unambiguous Doppler velocity, the coupling of Doppler velocity with differential phase, and the ability to mitigate clutter contamination. As part of a risk-reduction study, we have shown that much of these concerns can be addressed through signal processing. In FY13, we generalized the autocorrelation spectral density (ASD) developed by CIMMS scientist to process AHV transmission waveforms. The new processing scheme allows the reuse of the CLEAN-AP filter and provides an increased unambiguous Doppler velocity. Moreover, the combining of

covariance estimates from multiple PRTs was shown to increase the quality of dual-polarization variable estimates.

d. MPAR Program

Sebastian Torres (CIMMS at NSSL)

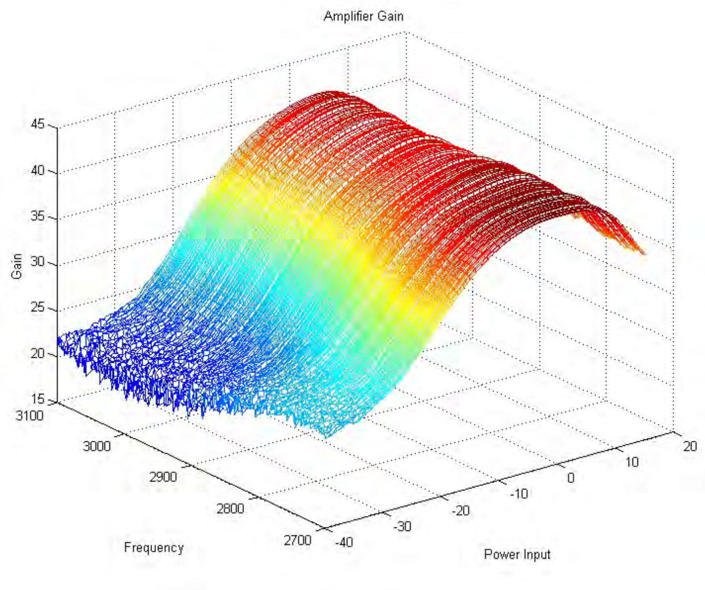
CIMMS continues to support the MPAR program on several technical fronts. Support consists of actively participating in the MPAR Government Engineering Team (GET), giving presentations at meetings with industry and other government organizations, reviewing proposal and technical documents, participating in internal and external technical discussions, and assisting the program manager with various programmatic issues. This project is ongoing.

e. Cylindrical Polarimetric Phased-Array Radar (CPPAR)

Matt McCord and Sebastian Torres (both CIMMS at NSSL), and Allen Zahrai, Dusan Zrnić, Richard Doviak, Michael Jain, and Kurt Hondl (all NSSL)

CPPAR Demonstrator: The goal of building the CPPAR demonstrator is to create a small 2-meter diameter cylindrical polarimetric phased array radar to demonstrate the benefits for polarization purity that a cylindrical array provides versus a planar array. This year the ARRC built the electronics, antennas and trailer for the demonstrator. CIMMS/NSSL engineers participated in the project by writing all of the automated test setups that enabled the characterization of all the RF electronic components, including the up/down converters, the RF front end and the power amplifier. We have additionally helped to integrate all the electronics in to the trailer and have worked on configuring the servers used for recording all of the data and processing it.

CPPAR Design Study: The CPPAR demonstrator has come a long way and is looking promising. However, in order to have a stronger influence in the MPAR program, the ARRC is looking into the feasibility of designing and building a large-scale cylindrical radar. The design study (in collaboration with CIMMS and NSSL scientists and engineers) has been focused on a high-level architecture and defining the functional blocks that will be required for such radar. We have begun to define the physical systems that will be involved and where the functions will be placed in hardware. Finally, some preliminary evaluation of an active array LRU has been investigated.



Power amplifier characterization as measured by the automated test system for the CPPAR design study.

f. PAR Clutter Characterization and Mitigation

Chris Curtis and Sebastian Torres (both CIMMS at NSSL)

An advantage of phased-array radars that has not been fully investigated is the application of digital beamforming for weather observations. With adaptive beamforming, the radar can change the beam pattern to reduce the impact of ground clutter and other interference on the estimation of meteorological variables. Many adaptive beamforming methods have been developed for applications involving signals that can be modeled as point sources. However, the received signal by weather radars is from distributed targets, namely the hydrometeors that fill spaces much larger than the radar resolution volume. Thus, direct application of adaptive beamforming methods intended for point sources to weather radars could lead to significant biases in estimated signal parameters. In collaboration with the ARRC, data collected by the Atmospheric Imaging Radar (AIR) was used to demonstrate the feasibility of utilizing adaptive beamforming for weather observations.

A new ground clutter model is being developed to characterize ground clutter for stationary antennas. The model captures both the shape of the ground clutter in the spectral domain and other aspects such as the decorrelation time of the clutter. This model is especially appropriate for stationary phased array antennas with electronic scanning and could lead to new approaches for mitigating ground clutter contamination for phased array weather radars.

g. Radar Data Management

Dan Suppes (CIMMS at NSSL)

CIMMS continues to support the archiving and distribution of radar data for NSSL and the ROC. During FY13, data from KOUN, operational WSR-88D, NWRT PAR, and mobile radars were archived. We actively coordinated with IT staff for the maintenance and development of the RAID systems. We also maintained a web-based catalog of radar data for distribution. This catalog is available on the Internet to the general public.

Among the activities involved in this effort are: 1) determine the usefulness of PAR observations for forecasts and warnings. Develop PAR parameter thresholds for severe weather and compare them to WSR-88D thresholds; 2) investigate the impact of higher-temporal resolution PAR data on the warning decision process of National Weather Service forecasters during severe weather, and 3) obtain sufficient PAR background knowledge of convectively driven high-wind events to measure and analyze them.

h. PAR and WSR-88D Comparisons for a VORTEX2 Case

Don Burgess (CIMMS at NSSL) and Christopher Schwarz (CIMMS Temporary Employee)

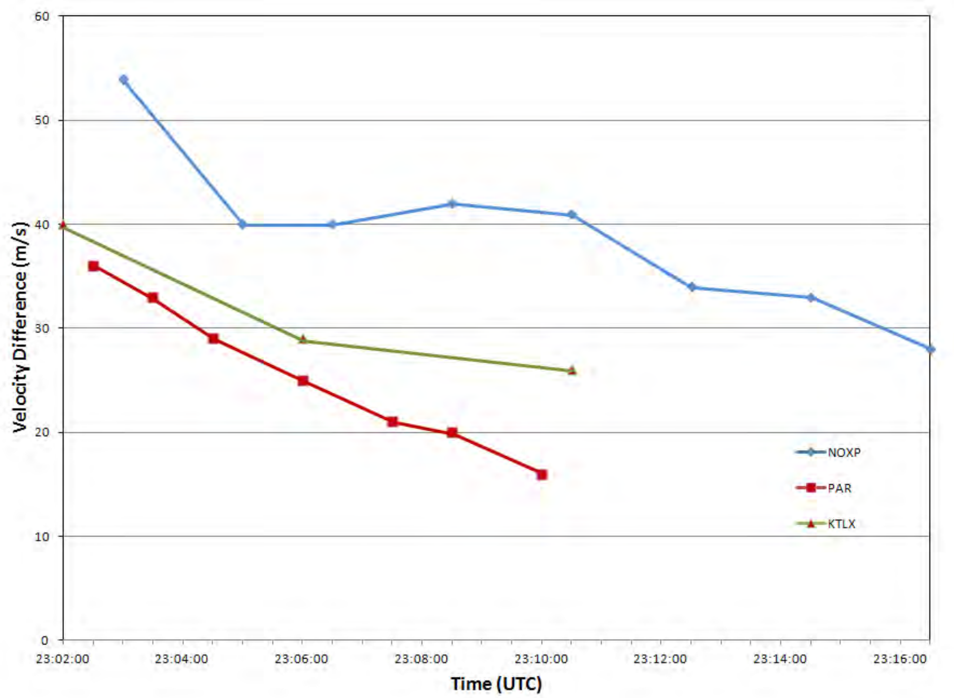
On 19 May 2010, two tornadic supercells occurred in north-central Oklahoma and were observed by the VORTEX2 research project. Included in VORTEX2 observations were data from several mobile Doppler radars, operating at close range to the storms. The VORTEX2 close-range radar data provided ground truth with which to compare farther-range PAR and WSR-88D observations. Spatial and temporal resolution and time trends of mesocyclone strength were compared.

Concerning spatial resolution, results show that for low levels the WSR-88D has an advantage over PAR because of antenna beamwidth (1^0 for WSR-88D and 1.5^0-2^0 for PAR) and super-resolution scanning (0.5^0 Azimuthal sampling for WSR-88D and 0.8^0-1.0^0 azimuthal sampling for PAR). For middle and high levels, the WSR-88D spatial sampling advantage is reduced because WSR-88D legacy-resolution scanning (1^0 azimuthal sampling) is equivalent to or slight worse than PAR (0.8^0-1.0^0 azimuthal sampling).

Concerning temporal resolution, results show that PAR has a decided advantage. For the May 19 case, using similar scanning strategies, PAR's volume scan was completed in 1.4 min while WSR-88D's volume scan was completed in 4.25 minutes…approximately a 3 to 1 advantage. Much temporal information about storm evolution is lost to warning forecasters when WSR-88D data are compared to PAR data. This is particularly true since in other studies PAR has provided updates as fast as 1.0 min. PAR/WSR-88D comparisons are illustrated in the figure below for the low-level declining stage of a tornadic mesocyclone. As expected, the close-range VORTEX2 radar (NOXP) observed stronger wind shears, but both PAR and WSR-88D

captured the weakening trend. Note the many additional PAR observations (compared to WSR-88D) are available with which to evaluate the weakening of the circulation.

For a few observations near weak echo regions and echo overhangs, PAR suffered from antenna side-lobe contamination, particularly when observing angles well off boresight. This is an issue that needs further investigation; possibly including ways to minimize antenna side-lobes in future PAR prototype development.



Velocity Difference/Time Plot for the Orlando, OK tornadic mesocyclone. The analysis covers only the declining phase of the circulation.

i. 2013 Phased Array Radar Innovative Sensing Experiment

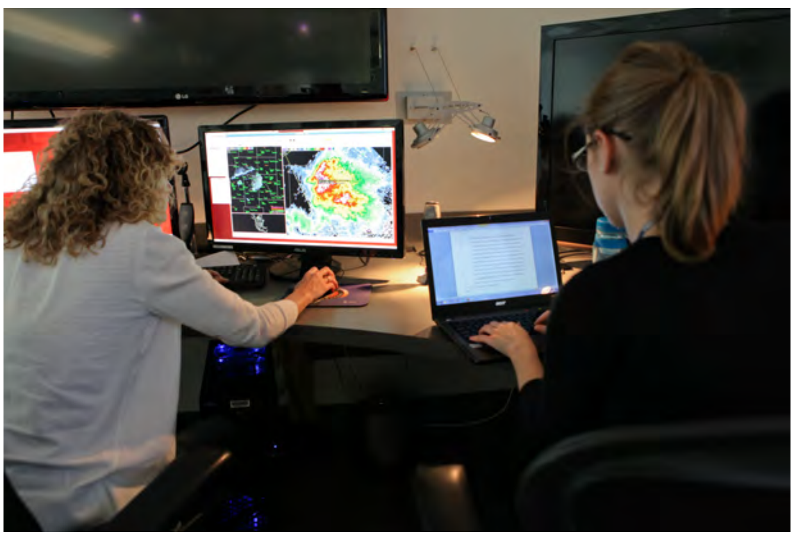
Pam Heinselman (NSSL) and Katie Bowden (OU School of Meteorology at CIMMS)

With the current WSR-88D approaching the latter phases of its lifetime, scientists have been exploring the option of replacing the national radar network with MPAR. A major difference between the MPAR and the current WSR-88D is that the beam is electronically steered rather than mechanically, allowing for non-contiguous and faster surveying of the atmosphere. As a result, the PAR is capable of providing higher-temporal resolution radar data with a potential update time of less than 1 min.

Over six weeks during this past summer, twelve NWS forecasters visited the National Weather Center to participate in the 2013 Phased Array Radar Innovative Sensing Experiment (PARISE; see figure below). The goal of this experiment was to learn about the impact of this rapid data on the warning decision process of NWS forecasters. Both the 2010 and 2012 PARISEs reported promising results of improved forecaster

performance when utilizing this faster data during tornadic events. To broaden the focus of PARISE and address the impact of this rapid data on other types of severe weather, the 2013 experiment presented severe wind and hail events to participants.

All of the participants were presented three weather case studies to work in simulated real time. Depending on whether participants were assigned to the experiment group (N=6) or control group (N=6), the volumetric update time was either 1 min or 4 min, respectively. Quantitative analysis of forecaster performance, such as warning verification and lead times, will enable a numerical comparison between the two groups. However, to really understand the impact of the rapid data on the warning decision process of each forecaster, this experiment also collected rich qualitative information that will provide greater insight into why forecasters performed the way that they did. Upon finishing each case, forecasters completed the case walk-through procedure. This is a form of cognitive task analysis which was also utilized during the 2012 PARISE and was found to be an effective tool for eliciting forecasters' warning decision processes upon completion of a case. Thematic coding of these timeline-designed accounts will enable us to evaluate the macro-cognitive aspects that feed into and are crucial to warning decisions. Attention will be particularly drawn to how the temporal resolution of the data plays a role in the way forecasters engage in dynamic tasks.



A 2013 PARISE participant working with student researcher Katie Bowden.

j. Rapid Sampling of Radar Precursor Signatures Associated with Downbursts in Central Oklahoma

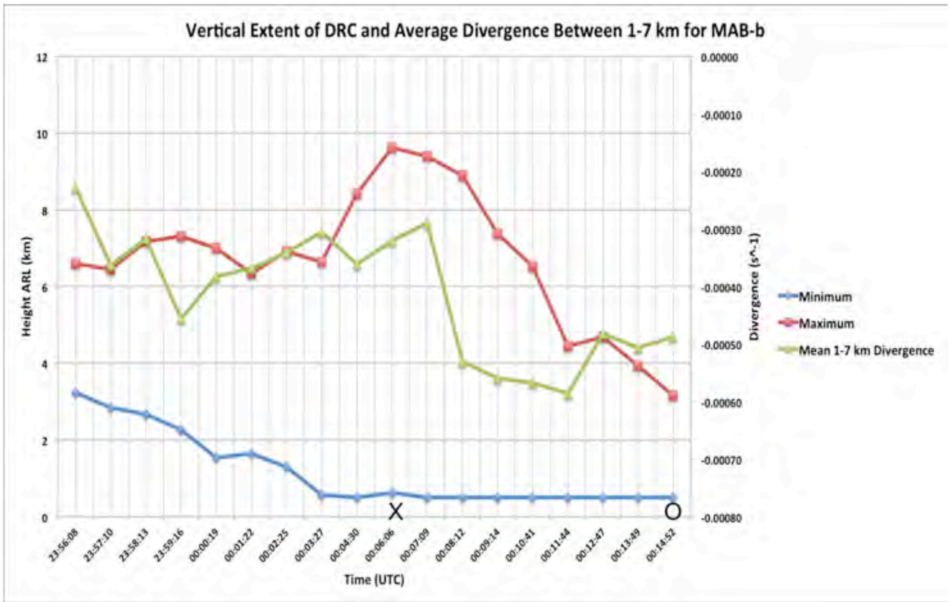
Pam Heinselman (NSSL), Terry Schuur (CIMMS at NSSL), and Charles Kuster (OU School of Meteorology at CIMMS)

Severe downbursts produce damaging winds at the surface, which can damage roofs, fences, and power lines while causing dangerous conditions for anyone outdoors. Understanding and identifying precursor signatures present with these events could

lead to increased predictability of downbursts associated with single cell and multicell thunderstorms thereby lessening the risk to life and property. Therefore, during 2013, the primary goals for the project included obtaining sufficient background knowledge of convectively driven high-wind events and the tools, specifically radar, used to measure such events, as well as begin analysis on a downburst event in central Oklahoma. After consideration of multiple cases and the available NWRT PAR and KOUN data sets, a family of downbursts in central Oklahoma on 14 June 2011 served as the most suitable option for the first case study. Subsequent analysis of the data set examined precursor signatures such as descending reflectivity cores, mid-level convergence, Zdr troughs, and reflectivity notches. Any methods and constraints necessary to quantitatively measure these features were also developed.

An in depth analysis of a downburst event in central Oklahoma during the early evening hours of 14 June 2011 commenced upon completion of the literature review. A chronology of all of the downburst events, severe and non-severe, was compiled. From this time line, precursor signatures associated with each event were analyzed. The maximum and minimum extent of the 65-dBZ isosurface for each volume scan showed the evolution and descent of the high reflectivity core associated with each downburst. For all of the severe events, the upper extent of the 65-dBZ isosurface descended rapidly only minutes prior to divergent winds near the surface. In order to quantitatively measure midlevel convergence associated with downbursts, values of the divergence field, produced in WDSSII, at every elevation angle near the high reflectivity core of each downburst were outputted. All volume scans between one and seven km above ground level were then averaged to produce a volume averaged value for convergence for each volume scan. The results of this ongoing portion of the research revealed a difference in the magnitude and evolution of the volume-averaged mid-level convergence between severe downbursts and non-severe downbursts. Volume averaged mid-level convergence with severe downbursts displayed a maximum in magnitude minutes before the downburst began (see figure below). In contrast, volume averaged mid-level convergence with non-severe events did not display a clear maximum in magnitude before the initial sampling of near surface divergence and the magnitude of the convergence itself was noticeably less than that associated with the severe events. Other features analyzed included three-body scatter spikes, which indicated the presence of hail within the high reflectivity core well before a downburst occurred. Multiple reflectivity notches and the collocated rear inflow jets were also examined. In this case, the rear inflow jet did not play a large role in initiating or intensifying any downdraft, but it did affect the organizational structure of the multicell thunderstorm and likely increased the convective complex’s longevity.

Dual-polarization data provided by KOUN served as a supplemental data set for the 14 June 2011 case. This data provided “snapshots” during the evolution of features as depicted in the NWRT PAR data, which allowed for the determination of hydrometeor composition throughout the high reflectivity cores associated with each downburst. Any precursor signatures, such as Zdr troughs, were also noted for each downburst.



Maximum and minimum extent of the 65 dBZ isosurface and magnitude of volume averaged mid-level convergence between 1-7 km for a severe downburst on 14 June 2011. The "X" indicates time of initial sampling of the divergent flow associated with the downburst at the .51 degree tilt, while the "O" marks the time of maximum downburst intensity.

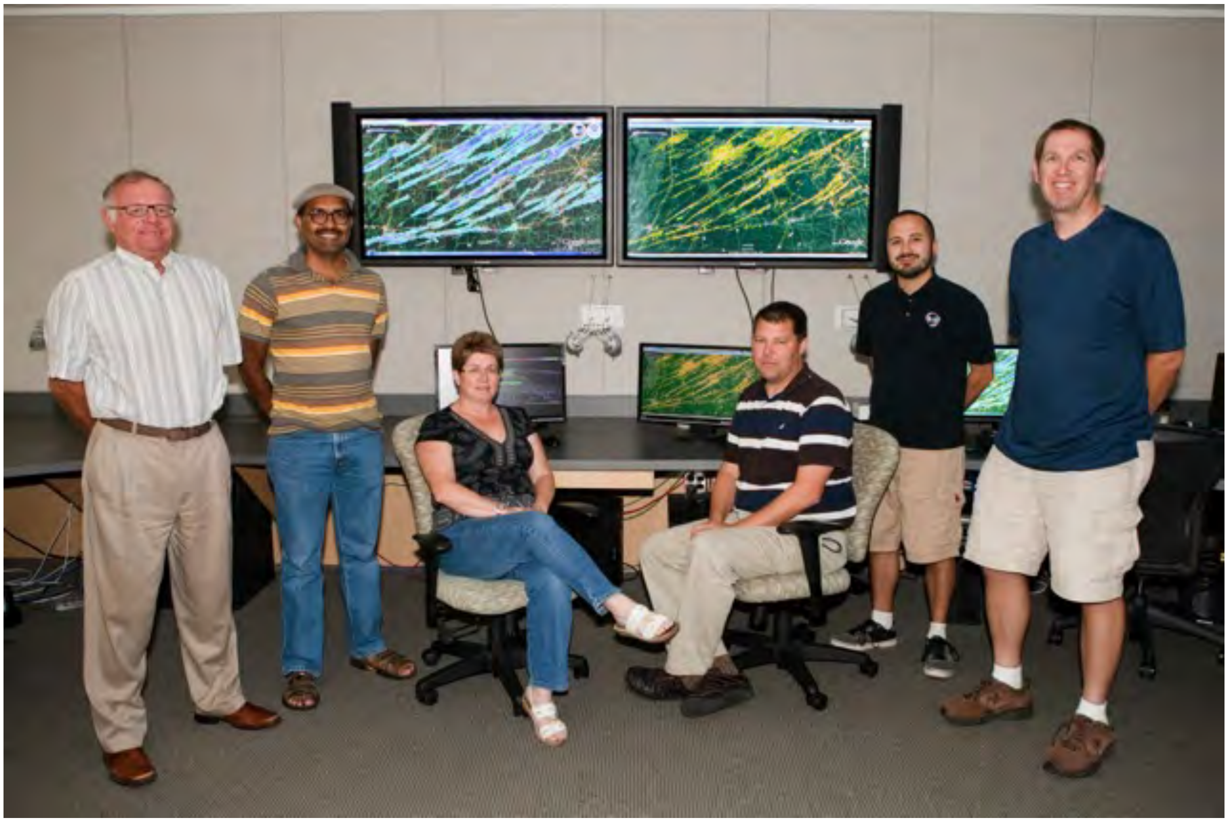
All of these projects are ongoing.

PAR Publications

Heinselman, P. L., D. S. LaDue, and H. Lazrus, 2012: Exploring impacts of rapid-scan radar data on NWS warning decisions. *Weather and Forecasting,* **27**, 1031-1044.

Awards

Travis Smith (CIMMS at NSSL), Kiel Ortega (CIMMS at NSSL), Valliappa Lakshmanan (CIMMS at NSSL), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), Kevin Manross (former CIMMS at NSSL, now at Unidata), and Karen Cooper (INDUS), David Jorgensen (NSSL), Madison Miller (OU School of Meteorology at CAPS), and John Cintineo (former OU School of Meteorology at CIMMS, now at CIMSS/University of Wisconsin), received the 2013 NOAA Technology Transfer Award for "leading the development of an on-demand, near real-time, web-based tool for tracking severe weather and hail swaths across the continental US." (http://www.nssl.noaa.gov/briefings/2013/09/nsslcimms-team-receives-2013-noaa-technology-transfer-award/)



Several members of the team that won the 2013 NOAA Technology Transfer Award: from left, David Jorgenson, Valliappa Lakshmanan, Karen Cooper, Travis Smith, Kiel Ortega, and Greg Stumpf.

Valliappa Lakshmanan received the 2012 Innovator Award presented by the University of Oklahoma Office of Technology Development for developing “groundbreaking (WDSS-II) software [that] is used worldwide to help predict weather phenomena including hail, precipitation, mesocyclones, and tornadoes. Used by private companies, research labs, National and International governments across the globe, this technology provides users across the world with the information needed to make property and life-saving decisions in the event of hazardous weather.

NSSL Project 2 – Hydrometeorology Research

NOAA Technical Leads: Jian Zhang and Kenneth Howard (both NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives

Hydrometeorology Research objectives center on dual polarized radar and quantitative precipitation estimations (QPEs). Specifically:

- Evaluate the improvements in accuracy of precipitation estimates using dual-polarization radar parameters;
- Enhance S-band single-polarization radar QPE and develop an optimal mosaic scheme for combining observations from S-band and C-band radars for the Taiwan Central Weather Bureau and Water Resources Agency;
- Improve the quality of the base reflectivity fields for the Canadian radar networks;
- Improve the quality of the base reflectivity fields for the WSR-88D network by mitigating non-standard beam blockage and using dual-polarization parameters to filter non-hydrometeor signals;
- Evaluate possible improvements to radar based QPEs using satellite radar;
- Build a verification database of precipitation type and other hazards using the mPING mobile app;
- Improve classification of winter precipitation types using NWP analysis and dual polarization radar parameters; and
- Improve accuracy of QPEs in different storm environments using NWP analysis information.

Accomplishments

1. Evaluating Dual Polarization Precipitation Estimates Using the Q3 Verification System

Brian Kaney and Carrie Langston (both CIMMS at NSSL), and Steve Vasiloff (NSSL)

a. Single Radar Processing

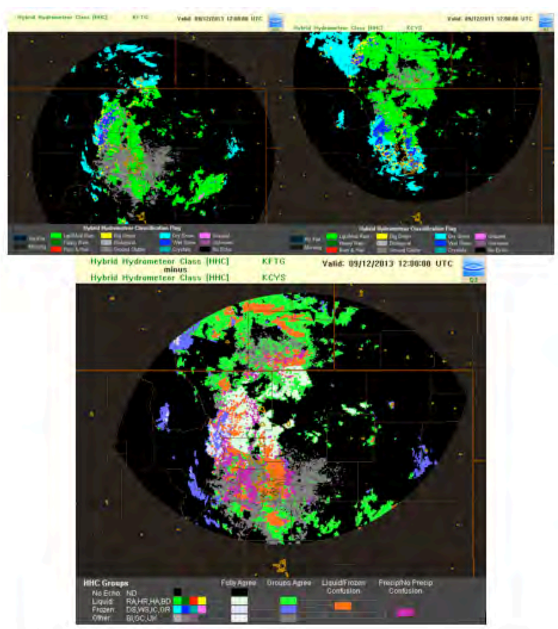
Work continued on evaluating dual polarization variables for use in improving QPE. For this year, a total of 62 radars were added to National Mosaic & Multi-Sensor QPE (NMQ) Level III dual polarization processing. Processing includes decoding Level III data to NMQ's custom polar binary format, deriving precipitation rates from Level II Digital Hybrid Reflectivity (DHR), computing 1 and 24-hr QPEs based on DHR and

Digital Precip Rate (DPR) fields, and storing data on the NMQ Q3 Verification System (QVS) archive. All are single radar products. The following is a list of the radars added:

```
KABR KBHX KBIS KCBW KCBX KCLX KCXX KCYS KDAX KDFX
KDGX KDMX KEOX KEPZ KEVX KFCX KFDR KFSD KFSX KFTG
KFWS KGGW KGJX KGRK KGSP KGWX KGYX KHDX KHGX KHNX
KHPX KICX KILN KILX KIND KINX KJKL KLRX KLTX KLVX
KLZK KMAX KMBX KMOB KMPX KMSX KMTX KMVX KNKX KPAH
KPOE KRAX KRGX KRLX KSFX KSHV KSRX KTLH KTLX KTYX
KUDX KVWX
```

This brings the total of radars displayed on NMQ QVS to 127, which accounts for approximately 89% the CONUS 88D radars.

A new capability was added where the dual polarization generated Hydrometeor Classification flag (HCA) from two overlapping radars can be compared on a map. The imagery is done in a similar manner to maps of the difference between two products as has been done in the past with reflectivities and QPE's. But in this case the flags themselves are integer indices whose specific numerical values have no meaning beyond the type for which they code, and hence a numerical difference has even less meaning. But instead the level of agreement (exact match, not exact match, but liquid/solid phase matches, liquid/solid phase mismatch) was color-coded. The figure below shows a sample triplet of images with the HCA for Denver, CO (KFTG) and Cheyenne, WY (KCYS), and then how well they agree in the region where they overlap. This project is ongoing.



Three panels adapted from QVS imagery showing the HCA product for two neighboring WSR-88D's and then a map showing how they compare in the region of overlapping coverage. The panels show Denver, CO (KFTG) data (top left), Cheyenne (top right), WY (KCYS) data and their comparison (bottom).

b. Multi Radar Processing

From December 2012 to January 2013, the following 2D mosaic products were added to NMQ processing and displayed on QVS: 1) DPR; 2) DPR-based 1,3,6,12,24,48,72-hour QPE; and 3) Hybrid HCA. The DPR and Hybrid HCA single radar data are mosaicked using a nearest neighbor scheme. The DPR-based QPEs are derived from the gridded multi-radar DPR field. In early August 2013, these products were updated to match the new MRMS domain. The QPE accumulations were reduced to 1,6,24-hours.

This project is ongoing.

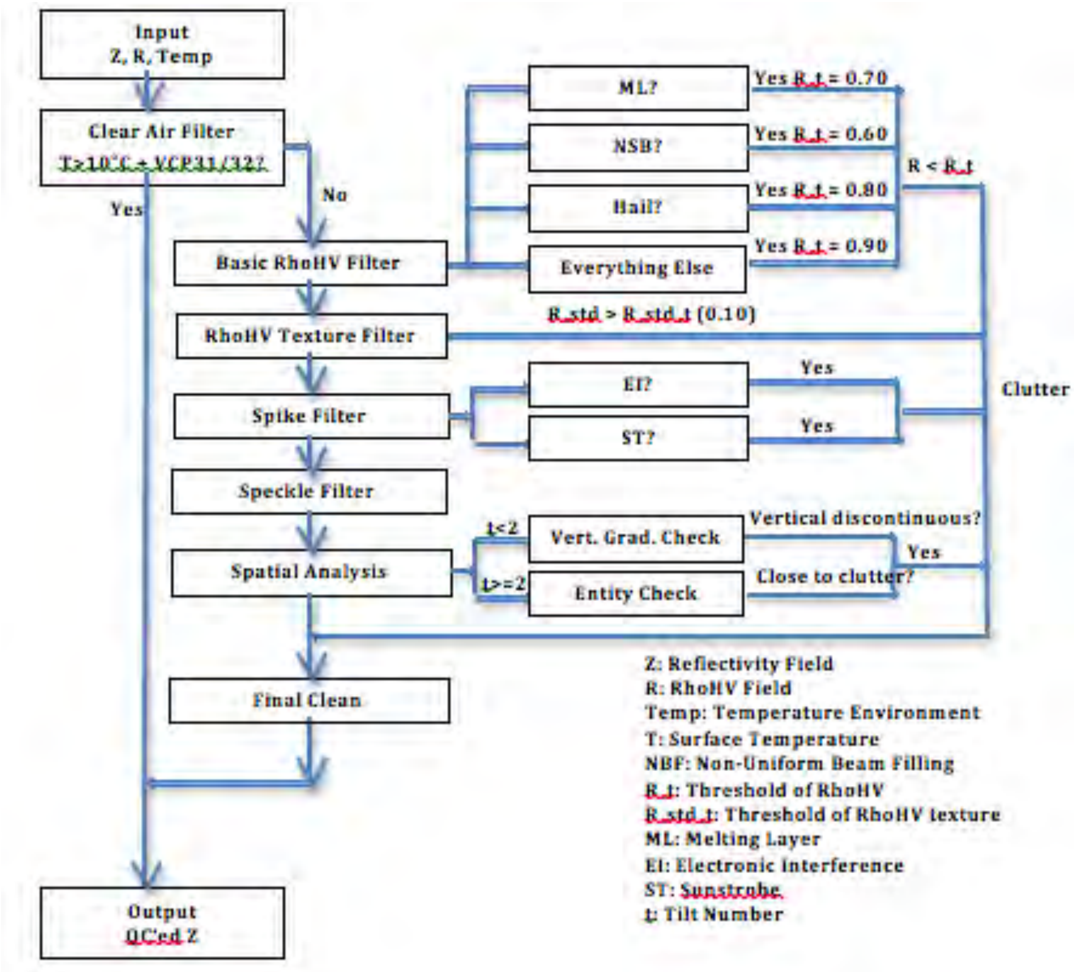
2. WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities

Lin Tang and Carrie Langston (both CIMMS at NSSL), and Jian Zhang and Kenneth Howard (both NSSL)

Polarimetric radar observations provide information regarding the hydrometeor shape, size, and phase, as well as an improved skill in differentiating radar returns of hydrometeors from those of non-hydrometeors. In this research, we explore a physically based dual-polarization radar quality control approach that segregates precipitation and non-precipitation echoes using correlation coefficient, reflectivity, atmospheric sounding data, and a set of explicit meteorological principles.

Correlation coefficient (RhoHV) is one of three polarimetric base moments. It measures the synchronicity of signal fluctuations at orthogonal polarizations. It also provides evidence on the quality of the dual-polarization data fields and contains information on the nature of the scatterers. Generally, pure rain or pure snow is associated with high values close to 1. Low RhoHV values, alternatively, represent a spectrum of scatterers that are likely non-meteorological. A large amount of clutter can be censored with a simple RhoHV thresholding approach. However, there are cases where either power returns from non-meteorological objects exhibit high correlation between the horizontal and vertical directions or weather echoes are associated with low cross-correlation coefficients. Therefore, a fixed RhoHV threshold would lead to false alarms or misses in clutter detection. Additional steps were devised to handle exceptions to the simple RhoHV filter: 1) low RhoHV in hail; 2) low RhoHV associated with non-uniform beam filling; 3) low RhoHV in wet snow aggregations; 4) high RhoHV with severe anomalous propagation; 5) high RhoHV in weak echoes; and 6) clutter at far ranges and other limitations.

The figure below illustrates an overview flowchart of the dual-polarization quality control (dpQC) algorithm. The new algorithm was evaluated using 16 independent events and showed high accuracy (Heidke Skill Score of 0.83) in segregating precipitation and non-precipitation echoes. This project is ongoing.



Flow chart of the dpQC algorithm.

3. Reflectivity Quality Control for the Canadian Radar Networks

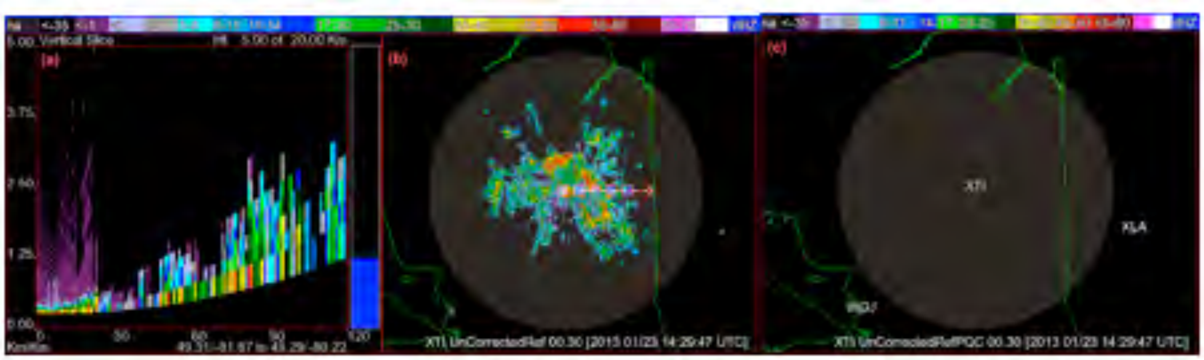
Lin Tang and Carrie Langston (both CIMMS at NSSL), Jian Zhang (NSSL), and Valliappa Lakshmanan (CIMMS at NSSL)

Anomalous propagation (AP) is a type of ground clutter caused by strong vertical temperature and moisture gradients or temperature inversions in the lower troposphere. The "anomalous propagation" of the radar beam causes part of it to intersect the ground resulting in ground clutter contamination. The removal of AP clutter poses a significant challenge because of the similarity between AP intensity and texture and those of strong and isolated convective cells. Severe AP clutter is a major issue with the Canadian radar network. The Canadian radars' base level data does not contain velocity and spectrum width information, nor is signal-to-noise data is available. Hence, an automated quality control processing algorithm to address AP clutter for Canadian radars is limited to the reflectivity field in contrast to WSR-88Ds for which all three moments are available.

One spatial characteristic of AP is the rapid decrease of echo areas from lower to upper tilts. In other words, the strong power returns from the ground are confined in the lowest tilts and lack vertical discontinuities. This is a combined effect of vertical distributions of AP echoes and the radar sampling geometry. Two polar-grid reflectivity maps are selected from the lowest tilts that are at least 1-degree apart in elevation angles. If the reduction in the size of reflectivity area from the two tilts exceeds a threshold, then the echoes on the 1st tilt are considered as pure (or being dominated by) AP or other clutter and are completely removed. The figure below shows an example of AP removed from radar XTI. After the pure clutter is censored at the low tilts, the echoes are completely removed.

Clutter maps are applied to remove persistent or semi-persistent ground clutter in the Canadian radar reflectivity field. However, the static clutter appears more severely during anomalous propagation. The residual ground clutter changes with the temperature and moisture environment. The texture of AP is different from pure precipitation echoes and characterizes the magnitude of the small-scale fluctuations of reflectivity (dBZ) along the radial. Therefore, a texture test is able to identify this type of AP clutter after the persistent clutter filter is applied.

This project is ongoing.



Clutter observed by the radar XTI at UTC 14:29 on 23 January 2013. (a) The range height indicator (RHI) along the line shown in the (b); (b) is the plan position indicator (PPI) of the scan at the elevation angle 0.30 degrees; (c) the quality controlled field of the lowest tilt after clutter removal.

4. A Three-Dimensional Aviation In-Flight Weather Hazard Product Based on the Hydrometeor Classification Algorithm (HCA)

Lin Tang (CIMMS at NSSL), Jian Zhang (NSSL), and Kim Elmore and Carrie Langston (both CIMMS at NSSL)

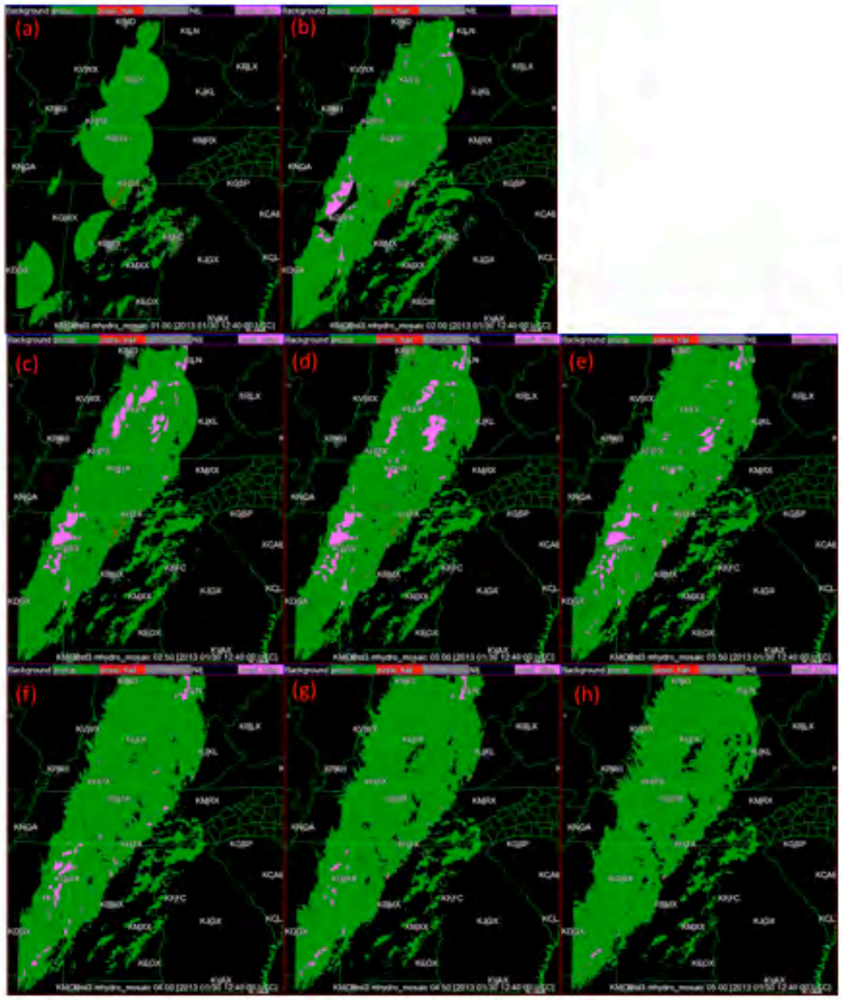
The operational HCA discriminates between 10 classes of radar echoes: 1) ground clutter, including that due to anomalous propagation (GC/AP); 2) biological scatters (BS); 3) dry aggregated snow (DS); 4) wet snow (WS); 5) crystals of various orientations (CR); 6) graupel (GR); 7) “big drops” (BD); 8) light and moderate rain (RA); 9) heavy rain (HR); and10) a mixture of rain and hail (RH).

The detailed classification provides users with a product that identifies important precipitation classes. Knowledge of the hydrometeor type within the radar resolution volume is required for choosing an appropriate polarimetric rain rate relation to accurately quantify the amount of precipitation. However, the detailed classification of different hydrometeor species might not be required for aviation applications. Instead of complex precipitation types, simple and explicit depictions of flight safety concerns would be more preferable for pilots. Therefore, the current HCA categories are collapsed into four types: 1) clutter/non-meteorological echoes; 2) non-hazardous precipitation resulting in visibility reduction (dry snow, wet snow, rain, big drops, crystals); 3) possible hail (HCA hail signature); and 4) possible icing (HCA graupel signature implying presence of super-cooled liquid water), after consultations and discussions with the National Center for Atmospheric Research (NCAR) Icing Product Development Team. With reduced classifications, the four collapsed hydrometeor categories show better consistence between the adjacent radars and are more practical for aviation applications.

Due to the reduced sampling resolution with beam broadening in polar coordinates, artificial circles appeared on horizontal cross sections of the mosaic field around the height of melting layer. Combing the non-hazardous precipitation largely eliminated the rain-snow alternating artifact, and image-processing techniques are used to mitigate the artifact in the classification of possible icing (graupel).

An example of the collapsed field is shown in the figure below using a large storm complex from 30 January 2013. The sub-figures are the mosaicked field at the heights of (a) 1.0 km, (b) 2.0 km, (c) 2.5 km, (d) 3.0 km, (e) 3.5 km, (f) 4.0 km, (g) 4.5 km and (h) 5.0 km. The new mosaicking field provides important and useful aviation information with simplified classifications. The collapsing method will be tested using more cases and evaluated by pilot reports in future work.

This project is ongoing.



Three-dimensional mosaicked field with four collapsed hydrometeor classifications.

5. QPE Scheme for Merging Observations of Radars Operating at Different Wavelengths

Yadong Wang and Carrie Langston (both CIMMS at NSSL), and Jian Zhang and Kenneth Howard (both NSSL)

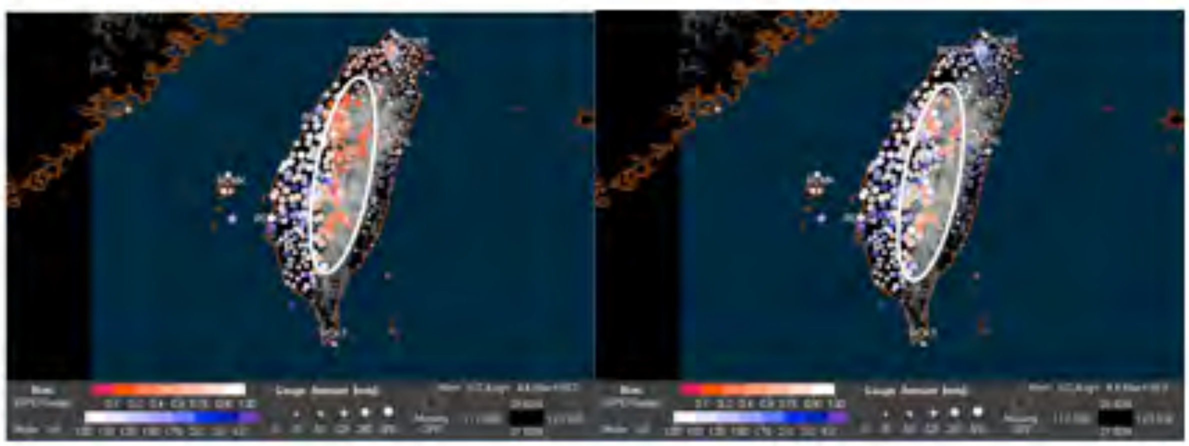
During 2012-2013, the main effort for this objective was focused on improving the accuracy of QPE using two C-band dual-polarization radars located in Taiwan. Severe beam blockage, miscalibration, and attenuation are major challenges for QPE using these two C-band radars. Therefore, a novel rainfall rate estimation approach using specific attenuation (*A*) was developed in this work. In this algorithm, the *A* field is utilized in the rainfall rate estimation directly, and the parameters used in the *A* field calculation were estimated using the local drop size distribution (DSD) and drop shape relation (DSR). This *R(A)* approach is found to be immune to biases caused by radar miscalibration, attenuation, partial beam blockage, and a wet radome.

In areas of complex terrain where the lowest tilts are completely blocked, observations from higher tilts are used for radar QPE, and correction of the vertical profile in rainfall from the *R(A)* approach (VPRA) is applied to account for vertical variations in the rainfall field. Comparing to existing rainfall estimation approaches such as *R(Z)* and *R(KDP)*, the *R(A)* method was able to provide more accurate and robust rainfall estimation from different precipitation types such as typhoon, stratiform, and convective rain.

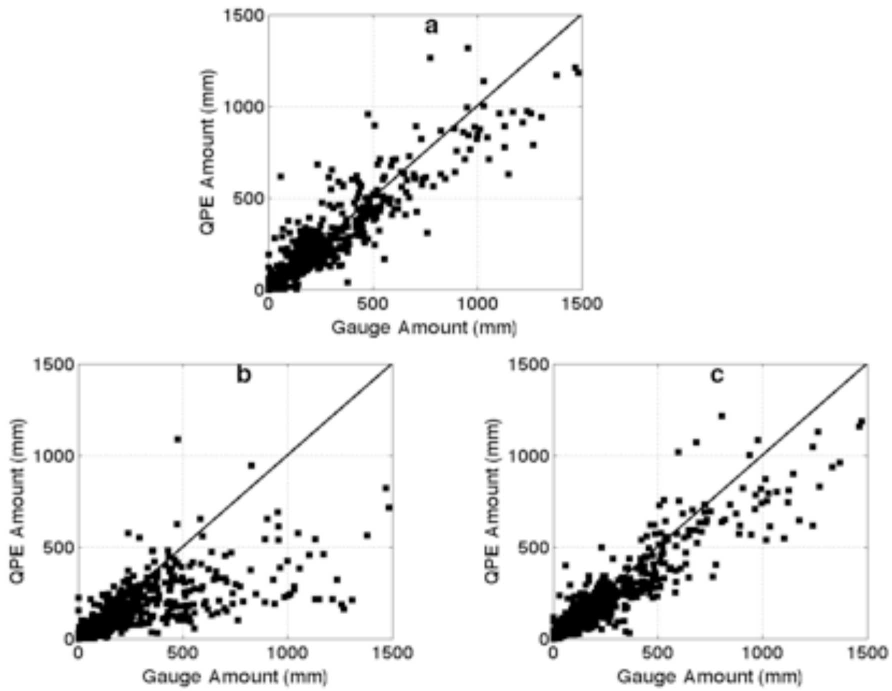
This project is ongoing.

Publications

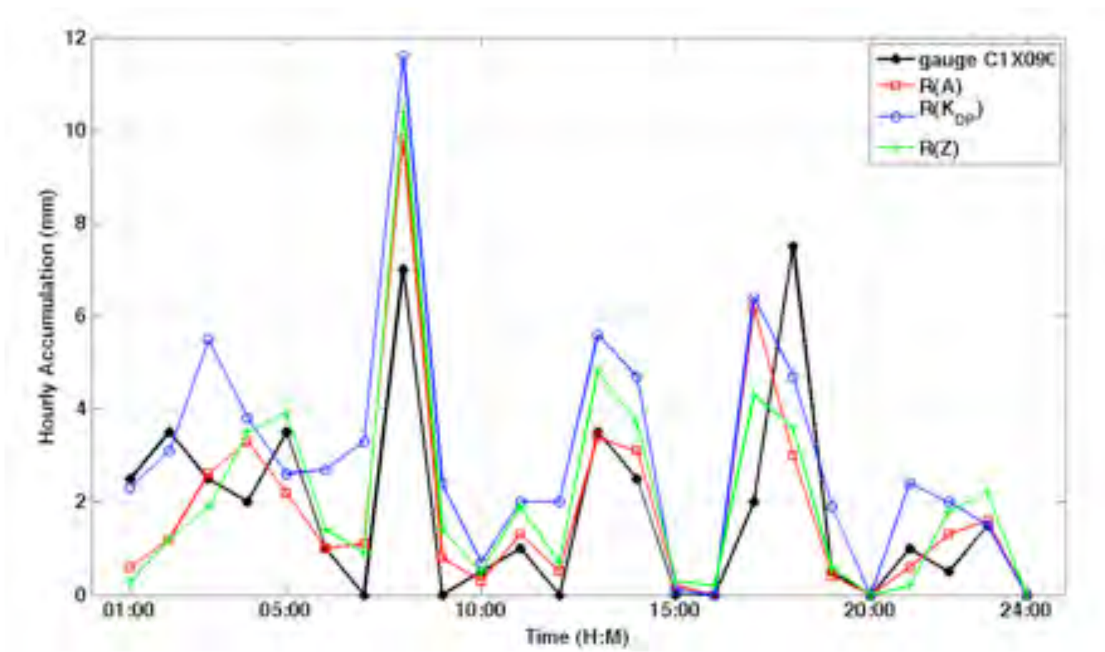
Wang, Y, J. Zhang, P.-L. Zhang, C. Langston, B. Kaney, and L. Tang 2013: Operational C-band dual-polarization radar QPE for the sub-tropical complex terrain in Taiwan. *Quarterly Journal of the Royal Meteorological Society*, in revision.



The spatial distribution of radar QPE vs. gauge observations without (left) and with (right) VPRA correction. The underestimation from the central mountain range region (within the white circle) is mitigated through the VPRA approach.



Scatter plots of QPE vs. gauge observations using (a) R(A), (b) R(Z), and (c) R(KDP). Two typhoon precipitation events of Morakot and Nanmadol were used in this example. R(A) had the best total bias (0.97) and root mean square error (98 mm), and was only slightly lower than R(KDP) for correlation coefficient (0.92).



Hourly comparison between gauge observations (black) and QPE using R(A) (red), R(Z) (green), and R(KDP) (blue).

6. Ground Radar-Based QPE Improvement Using Satellite Radar Data

Youcun Qi, Brian Kaney, and Carrie Langston (all CIMMS at NSSL), and Jian Zhang and Kenneth Howard (both NSSL)

Mesoscale Convective Systems (MCSs) contain both regions of convective and stratiform precipitation, and a bright band (BB) is often found in the stratiform region. Inflated reflectivity intensities in the BB often cause positive biases in radar QPE. A vertical profile of reflectivity (VPR) correction is necessary to reduce such biases. However, existing VPR correction methods for ground-based radars often perform poorly for MCSs due to their coarse resolution and poor coverage in the vertical direction, especially at far ranges (first figure below). Space-borne radars such as the Tropical Rainfall Measuring Mission Precipitation Radar (TRMM PR), on the other hand, can provide high resolution VPRs.

The current study explores a new approach of incorporating the TRMM VPRs into the VPR correction for the WSR-88D radar QPE. High resolution VPRs derived from the Ku-band TRMM PR data are converted into equivalent S-band VPRs using an empirical technique (second figure below). The equivalent S-band TRMM VPRs are resampled according to the WSR-88D beam resolution and the resampled (“apparent”) VPRs are then used to correct for BB effects in the WSR-88D QPE when the ground radar VPR cannot accurately capture the BB bottom. The new scheme was tested on six MCSs from different regions in the United States and was shown to provide effective mitigation of the radar QPE errors due to BB contamination (third figure below).

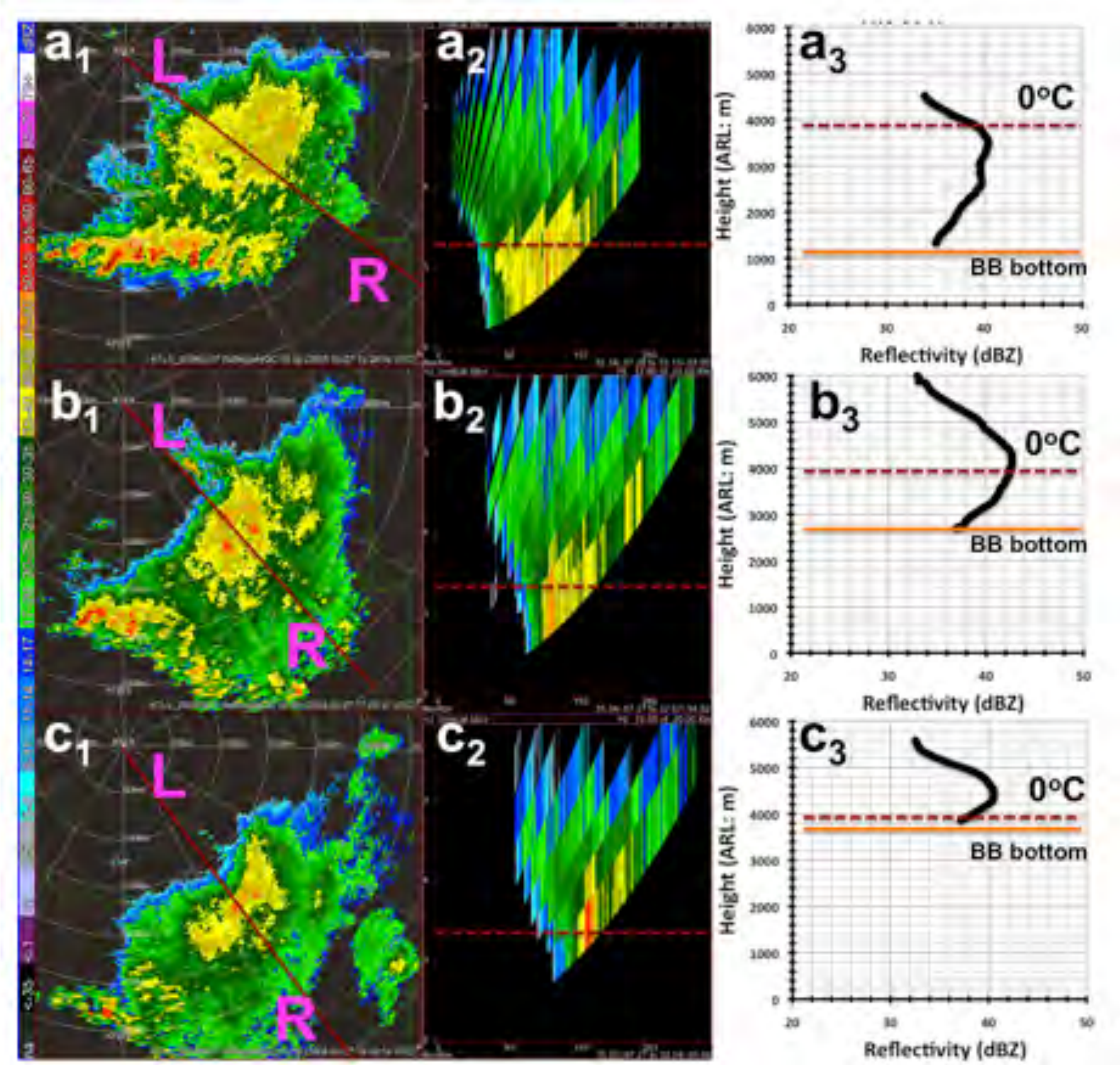
This project is ongoing.

Publications

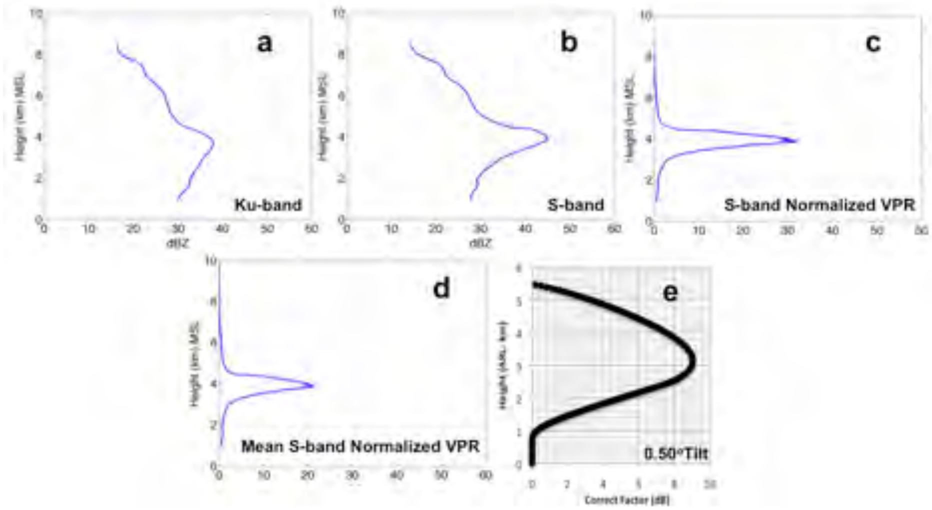
Qi, Y., J. Zhang, Q. Cao, Y. Hong, and X. Hu, 2013: Correction of radar QPE errors for non-uniform VPRs in mesoscale convective systems using TRMM observations. *Journal of Hydrometeorology,* in press. doi:10.1175/JHM-D-12-0165.1.

Awards

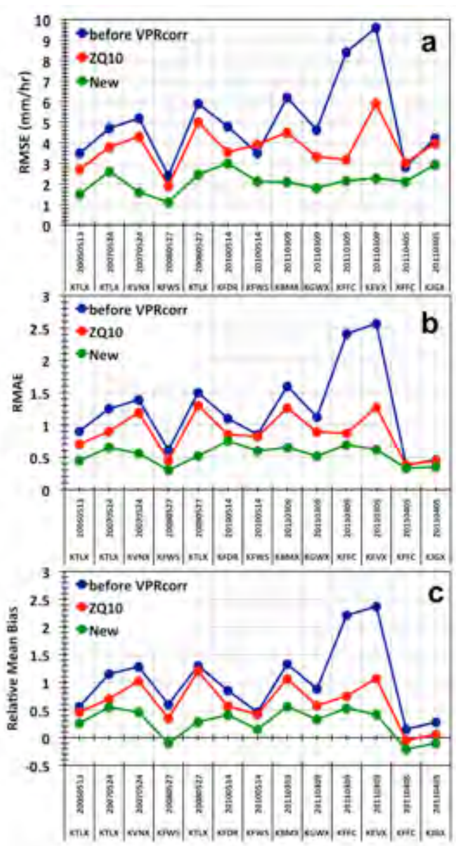
The Youcun Qi et al. paper titled “Correction of radar QPE errors for non-uniform VPRs in mesoscale convective systems using TRMM observations” that is in press in *Journal of Hydrometeorology* was referred to NOAA/OAR Headquarters as a “Significant” contribution.



KTLX radar at (a) 1524 UTC, (b) 1709 UTC, and (c) 1832 UTC 27 May 2008: (left) base reflectivity on 0.50^o tilt, (middle) vertical cross sections along the brown lines in the left column, and (right) apparent vertical profile of reflectivity (AVPR) derived from brightband area with ZQ10. The purple letters ''L'' and ''R'' in the left column indicate the left and right ends of the cross sections in the middle column. The brown dashed lines in the middle and right columns represent the 0^{o}C height level at the radar site, and the orange solid lines in the right column represent the BB bottoms derived from AVPR with ZQ10.



(a) Ku-band vertical profile of reflectivity (VPR) from one TRMM PR pixel at 1900 UTC 27 May 2008 and (b) S-band VPR converted from (a) using empirical relations derived in the three regions (Cao et al. 2013b). (c) Normalized S-band VPR from (b). (d) Mean normalized S-band VPR calculated from all identified stratiform rainfall; see details in the text. (e) Reflectivity correction factor on the 0.50^o tilt.



(a) RMSE, (b) RMAE, and (c) relative mean bias scores for radar precipitation estimates before (blue) and after the ZQ10 (red) and the new (green) AVPR corrections.

7. Crowd-Sourcing Reports of Hydrometeor Type and Location using mPING

Kim Elmore and Brian Kaney (both CIMMS at NSSL), and Zac Flamig (OU Civil Engineering and Environmental Science)

During this year, a mobile application for the general public to report precipitation type was launched. The mPING (mobile precipitation identification near the ground) App became available for both iPhone and Android platforms. The project received significant publicity, initially from the lab and then by word of mouth. At one point a Google search for 'mPING application' yielded relevant links for this CIMMS project for the first 10 pages of results. To date, the app has been downloaded between 37,000 and 38,000 times, and between 294,000 and 295,000 reports have been logged. A BAMS paper describing mPING is currently in review.

The goal of the project was to provide ground truth reporting of hydrometeor type to aid in the task of improving the hydrometeor classification skill using the new dual pol variables collected by the WSR-88D radar network. A large sample of high-density reports is difficult but important to obtain for these studies.

This project has also been a valuable learning experience in 'crowd-sourced' science. There is a balance between keeping the app simple and non-technical in its use and explanatory text, but making the data scientifically valuable enough that user feel they are making a real contribution. The quality of the reporting also exceeded the group's expectations. Spurious reports are seen occasionally, but the vast majority of them agree well with surrounding reports and other data sources. The reports provide many case studies (especially in and around large cities) of complicated winter weather events with a high spatial and temporal density and mixtures of rain, ice and snow. We found some classifications were much more reliable than others – for instance, the type 'graupel' did not appear to be used very consistently or accurately by the public.

From informal feedback it seems that having quick feedback in the form of users being able to see their reports appear on a public web display within minutes is a significant factor in the project's success. Two different web displays were developed. A smaller simpler display was designed for use on the mobile device itself. It only displays recent (the last 4 hours) data and can only be zoomed on the users current location. It responds to a touch screen and provides a quick and simple way to view your report and those of others in your area. A much more capable display designed for use on a laptop or desktop machine allows more thorough investigation of the data. Data near real-time and as far back in the archive as exists can be displayed with equal ease. The URL's for the two displays are:

http://www.nssl.noaa.gov/projects/ping/display/phone.html
http://www.nssl.noaa.gov/projects/ping/display

Based on analysis of research needs and user comments, a new release of the app was made in March 2013 that includes more precipitation types and better geo-location

capabilities. New reporting categories now include wind damage, flooding, tornadoes/waterspouts and landslides. Two precipitation categories, graupel and wet snow, were removed based on an analysis that indicates poor discrimination between graupel vs. ice pellets and wet snow vs. snow.

mPING reports were used by a Research Experiences for Undergraduates student, Deanna Apps, in a first-ever analysis of numerical model forecast precipitation type. The analysis is based on selected cases and is of high enough quality that it will be presented at the AMS Annual Meeting in February by the student in the Weather and Forecasting conference; it will ultimately be turned into a publication in *Weather and Forecasting* after a more thorough analysis is completed.

The two figures below show screen shots of each of these display pages. This project is ongoing.

Sample screen from the mobile phone version of the mPING report viewer.

Sample screen from the desktop version of the mPING report display.

8. Evaluating Dual-Polarization Precipitation Estimates vs. the Legacy Precipitation Processing System

Kim Elmore (CIMMS at NSSL) and Steve Vasiloff (NSSL)

Work in 2013 compared the performance of the WSR-88D algorithms as well as the experimental Q2 QPE product from the NSSL MRMS system. The PPS algorithm has five rainfall relations (RR) that can be changed locally at each NWS forecast office while Q2 uses a different precipitation process identification algorithm to switch between four RRs at each grid point and volume scan.

The evaluation period spanned April through September 2013, limited primarily by the dual-polarization (DP) deployment schedule. The analysis includes storms that are primarily east of the Rocky Mountains with the exception of several events in southern Arizona. In total 135 radar-storm events are examined within 150 km of the radar in order to mitigate QPE artifacts from the DP Melting Layer Detection Algorithm. Ground truth includes 24-hr rain gauge data from the Hydrometeorological Automated Data System (HADS) gauge network, CoCoRaHS observers, COOP observers, and local mesonets such as the Oklahoma Mesonet.

Overall, DP QPE demonstrates a 19% improvement in RMS error over the PPS for all gauge amounts and a 23% improvement for gauge amounts greater than 2”. Q2 is statistically equal to DP. Storms are grouped by imputed microphysical characteristics in order to provide insight to algorithm functionality. DP outperformed PPS for all storm types except for quiescent “pulse” storms containing no hail. In addition, select cases of superior and inferior performance are described in detail.

While these results are very encouraging, further analysis is needed that includes investigating performance using “continental” vs. “tropical” RR relations, increasing reliance on the use of specific differential phase (Kdp), and introducing a RR equation based on specific attenuation. Longer-term solutions include monitoring and correcting for differential reflectivity bias errors, evaluating methods for mitigating the melting layer discontinuity, and conducting precipitation verification analysis on an hourly and sub-hourly basis.

This project is ongoing.

9. Winter Surface Hydrometeor Classification Algorithm

Kim Elmore (CIMMS at NSSL)

The Winter Surface Hydrometeor Classification Algorithm (WSHCA) is intended to merge analyzed soundings from the High-Resolution Rapid Refresh (HRRR) model with polarimetric radar data. This part of the work aims at the “background” classification problem, defined as generating a conditional surface precipitation type classification given only a sounding under the condition that precipitation is falling. This process underlies radar-based classification schemes because any the radar data itself can be ambiguous. A sounding-only classification is also necessary because radar data in shallow winter precipitation may extend only 50 km (or less) from the radar, leaving any area not covered by radar without any precipitation classification guidance.

For the background classification problem, mPING observations provide the validation data. All the various precipitation types are collapsed to only four: rain, snow, freezing rain and ice pellets and these appear to be the most reliable interpretation. Various classifiers have been tested and, of the various classification methods available, ensemble classifiers are far more robust than any deterministic classification model. The overall "best" ensemble classifier is the random forest and the random forest is considered a baseline classifier. Random forests have many desirable characteristics that make then very difficult to "beat." Except for very special cases (many noisy predictors relative to the number of cases), random forests do not over fit, which means they generalize very well -- over fitting is what prevents a statistical model from performing well when it is presented with new data. A random forest consists of many (several hundred) decision trees that are "grown" in a very special way: each tree uses a different bootstrap sample of the data and a small random sample of the available predictors. The "special" part comes in at each node (a node is where the tree "splits") because at every node, a new small random sample of predictors is chosen. This allows a tree to "recover" from a poor random choice of predictors.

Unfortunately, the contents of the resulting random forest cannot be explicitly extracted because there is no way to extract the individual trees from the forest. This appears to be a feature of the available random forest classifiers, which is a disappointing oversight. While it is possible to link a random forest model built using, for example, R to programs in C, FORTRAN, C++, JAVA, Python, etc., there is no way to reveal -- to a

funding agency -- exactly what's inside of the classifier and any future software must link to the same version object, something that may not be possible as versions are updated.

When there are many cases but relatively few predictors (like what we have when working with soundings) there is a very similar process called random subspace sampled forests (RSSf). In an RSSf, the choice of a small random sample of predictors is done for each tree in its entirety instead of each node. The RSSf do not work well if the number of predictors is on the order of the number of cases, but we enjoy "big" data sets. In our case, the number of cases is at least two and sometimes three orders of magnitude larger than the number of predictors. In principle, this makes the RSSf nearly equal to the Rf.

The resulting RSSfs always produce results on par with the associated Rf in terms of accuracy or hit rate, and always have slightly more skill. As is done with Rfs, sampling weights with the RSSfs to get the best results. Like Rfs, the RSSfs are relatively insensitive to the number of predictors used (within limits) and to the proportion of the total sample used for building the bootstrap aggregate, which is in turn used to build each individual tree.

The process of defining precipitation classes may also benefit the overall Q2 QPE product from the NSSL Multi-Radar/Multi-Sensor (MRMS) system. A major objective of the recent dual polarization technology upgrade to the Weather Surveillance Radar – 1988 Doppler (WSR-88D) system is to improve QPE. Using dual polarization variables derived from vertical and horizontal reflectivity (ZV and ZH), different rain rate relations are invoked, while the traditional legacy Precipitation Processing System (PPS) algorithm uses the single variable ZH.

This project is ongoing.

10. Probabilistic Identification of Enhanced Rain Rates From Warm Rain Processes using Analysis of the Near-Storm Environment

Heather Moser Grams (CIMMS at NSSL) and Jian Zhang (NSSL)

While an initial version of the probabilistic warm rain enhancement product (now known as Probability of Warm Rain, or POWR) has been running in real-time on the MRMS QPE Verification System for over a year, work continues to refine the algorithm and adapt it to changes in the environmental analysis from the NWP model that is used for input. Namely, the transition from the Rapid Update Cycle to the Rapid Refresh in 2012 requires an update to the ensemble of statistical classifiers used to derive the probability field.

In 2013, the MRMS Q3 method of deriving precipitation rates from single-polarization-based Z-R functions was upgraded to incorporate the POWR method for delineating rain rates in tropical environments. The new precipitation type algorithm now segregates

between tropical stratiform and tropical convective rainfall rather than assigning a single tropical Z-R function to both, and delineation of all tropical Z-Rs is based on the POWR rather than from vertical profiles of reflectivity. Evaluation on the new precipitation type scheme is ongoing.

Additionally, the POWR algorithm's segregation of tropical and drier, more continental, environments has shown some initial skill for identifying different biases in dual-polarization rainfall rates derived from the HCA.

CIMMS Task III Projects – Next Generation Weather Radar Technology Research at OU

Staff: Robert Palmer (OU ARRC/School of Meteorology/ECE), Phillip Chilson (OU ARRC/School of Meteorology), Yang Hong (OU CEES/ARRC/HyDROS), Tian-You Yu (OU ARRC/ECE/School of Meteorology), Guifu Zhang (OU ARRC/School of Meteorology), Yan (Rockee) Zhang (OU ARRC/ECE), Qing Cao (OU ARRC/HyDROS), Boon Leng Cheong (OU ARRC/ECE), Richard Doviak (NSSL), Sebastian Torres (CIMMS and ARRC at NSSL), Valery Melnikov (CIMMS at NSSL)

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NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/NSSL; NOAA Congressional Earmark)

Overall Objectives
Develop several complementary technologies that are essential to the forward progress of phased array systems for weather sensing.

These projects are ongoing.

1. MPAR Resource Management and Adaptive Weather Sensing

Tian-You Yu and Sebastian Torres

Objectives
Multi-function Phased-array radar (MPAR) can execute multiple tasks that are traditionally carried out by individual and independent radars. In addition, MPAR is also ideal for adaptive weather sensing given the capability of dynamic and semi-instantaneous beam steering. In this project, the overarching goal is to investigate

resource management for MPAR to optimize its performance. A closed-loop framework of adaptive weather sensing has been developed by the team, which consists of storm identification, storm tracking, task configuration, and a scheduler. During this project period, the goal is to determine the optimal update time and task time in task configuration.

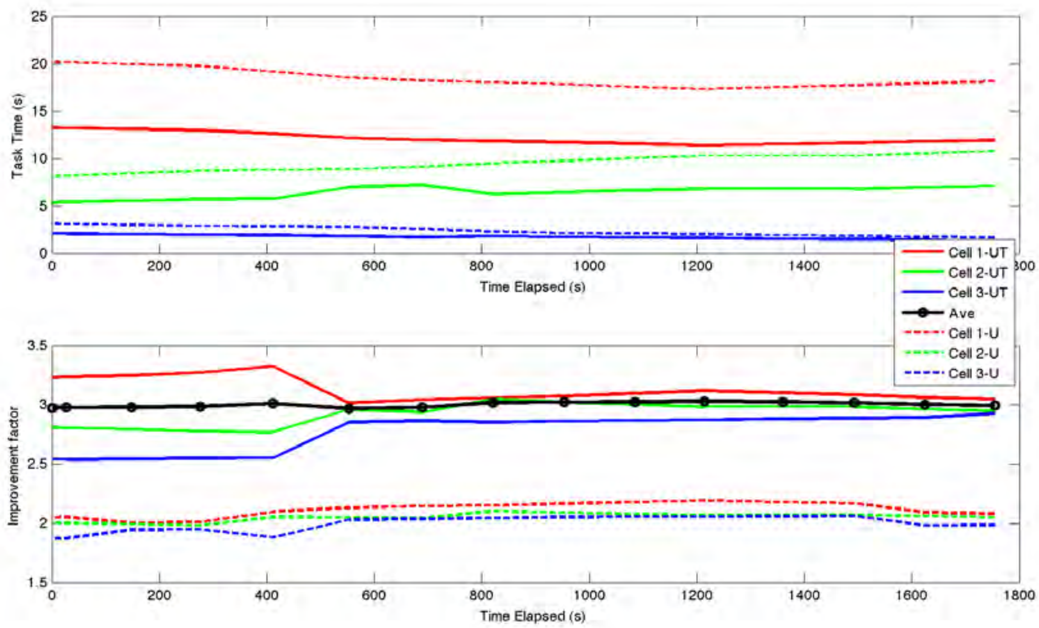
Accomplishments

A framework of adaptive weather sensing has been developed by the team to automatically and adaptively schedule multiple tasks of tracking multiple storms and surveillance. Two quality measures of revisit improvement factor and acquisition time were introduced to assess the gain of adaptive sensing with MPAR compared to conventional sensing (CS) carried out by WSR-88D. Previously, a rudimentary method was developed to determine the update time of each task, in which the average revisit improvement factor is maximized and the acquisition time is comparable to the CS. However, one of the drawbacks of such approach is that often the smaller storm is revisited much more frequently than large storms. Moreover, the task time of each storm is fixed to be the same as if CS is used, so that the data quality from both adaptive sensing and CS is the same in the storm region. In this work, the optimization was modified to alleviate such limitations with other added benefits.

For adaptive weather sensing, the trade-offs among the three fundamental factors of data quality, temporal resolution (i.e., update time), and spatial sampling, need to be considered. In this work, it is first assumed the spatial sampling of MPAR is the same as the WSR-88D. As such, the focus is the trade-off between the number of revisits and data quality. Secondly, it is assumed that the priority of each storm is given, which can be based on their severity and/or precursor of hazardous weather events, if present. Specifically, three levels of priority (high, medium, and low) were considered. Subsequently, a generalized optimization was developed to maximize the sum of the revisit of storms with respect to both update time and task time of storms under the following constraints: (1) The total occupancy of storm tracking and surveillance is 100% to maximize the radar usage and avoid overload; (2) The surveillance should not be performed too frequently, so its occupancy is set between 5% and 10%; (3) Storms with higher priority should have larger revisit improvement factor; (4) Storms with the highest priority should have revisit improvement factor larger than one; (5) The standard deviation of radar estimates in storms should meet a given set of requirements. Note that the last constraint allows data quality to be lower than the one required in the WSR-88D if it is desirable. This provides the flexibility to further gain revisit improvement factor. In this work, 1 dBZ for reflectivity for true spectrum width of 4 ms^{-1} and a pre-defined signal-to-noise ratio (SNR) of 30 dB has been used. Furthermore, if no solution was found in the optimization, CS will be performed to ensure the continuity of MPAR operation.

Numerical simulations were performed to demonstrate and verify the proposed approach. One example of three storm cells is shown in the figure below. The task time for the three storm cells before optimization is indicated by dashed lines on the upper panel, where storm cell #1 is the largest (also assumed to have the highest priority), cell

#2 is medium in both size and priority and cell #3 is the smallest and has the lowest priority. In order to demonstrate the effectiveness of constraint (5), an optimization without such constraint was also performed, and the resulting improvement factors are denoted by dashed lines in the lower panel. In other words, the task time of each storm cannot be adjusted. On the contrary, the proposed approach can adjust the task time to further improve the revisits. The resulting task times and revisit improvement factors for each storm are indicated by solid lines in the upper and lower panels, respectively. In this example, it is evident that the task time can be lowered, which in turn can be used to improve the revisit improvement from approximately two to three in average. Note that neither optimization produced large revisits for the small cell, which is alleviated by the addition of priority.



The task time and revisit improvement factor of three storms are shown on the top and bottom panels, respectively, over a period of approximately 30 min. In this example, the priority of the three storm cells is high, medium, and low. Results from the proposed approach are denoted by solid lines. It is evident that the proposed method can adjust the task time to further achieve higher revisits of storms. Please see text for more detailed discussion.

2. Multi-Mission Observations of the Clear-Air Environment

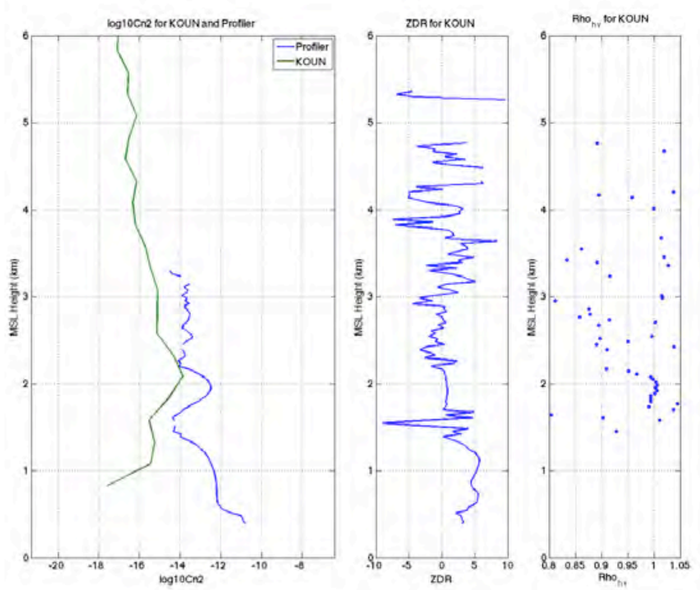
Phillip Chilson, Eric Jacobsen, and Valery Melnikov

Objectives

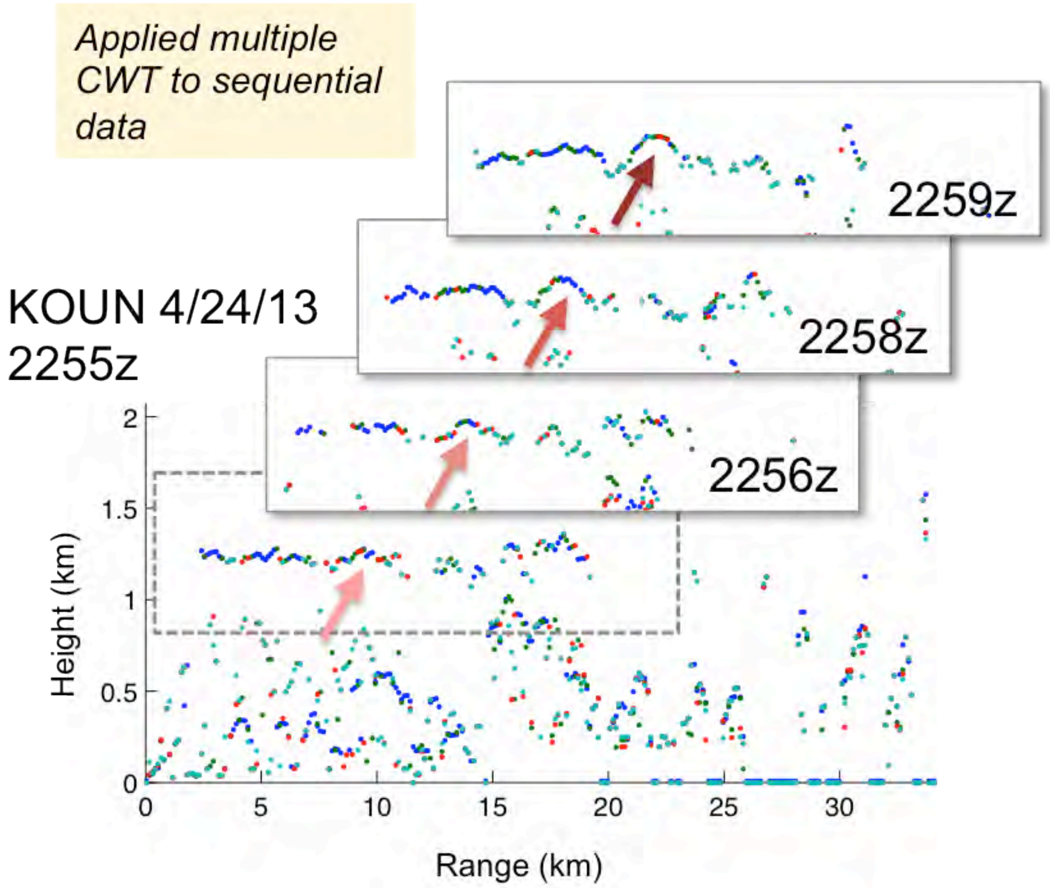
The objective of this study has been to determine how well weather radars could be used to observe the hydrometeor-free, cloudless planetary boundary layer and its evolution. Used during meteorologically calm conditions, a technique for locating the boundary layer height would serve well in model initiations, and also present little to no competition for remote sensing resources.

Accomplishments

Last year, progress was made in validating that S-band weather radars, such as MPAR, had sufficient sensitivity to detect weak clear-air signatures arising from refractive index fluctuations, in particular near the top of the boundary layer. Since then, further processing of specially collected RHI scans from OU's S-band research radar, KOUN, has confirmed the quantitative reliability of these measurements, suggesting that dual-polarimetric observations have the ability to essentially identify entrainment regions (first figure below). Shifting to a broader representation of the boundary layer morphology, subsequent efforts employing image processing techniques have been able, in some cases, to very successfully identify not only the general mixing height (in comparison with radiosonde measurements), but also the temporal and spatial variation of that interface to a resolution which seems likely to be on the order of a minute and several kilometers or less (second figure below). Though these successes depended on clarity of the boundary layer with respect to bugs and other scatterers, the complementary analysis of other data fields (such as radial velocity) suggest various reinforcing means of collecting this crucial height measurement, even in less than ideal conditions. We believe these results to be introducing a heretofore unused but powerful capability of the weather radar network, which can be robustly leveraged by incorporation of specialized scan strategies on the MPAR platform and object recognition algorithms to identify the observed boundary layer features.



A sample vertical profile of (left) the structure function Cn2 calculated from both KOUN (S-band) observations in blue and the nearby Purcell wind profiler in green, (middle) ZDR from KOUN, and (right) correlation coefficient from KOUN. In addition to quantitatively similar peaks in Cn2 between the profiler and KOUN, the near-zero ZDR and near-unity correlation coefficients are theoretically consistent with observations of inertial subrange turbulent variations in the refractive index.



A collection of time samples from KOUN RHI data, processed with image analysis techniques, which identifies orderly structures and motions particularly at the height estimated by radiosondes to be the mixing depth. The relatively high temporal and spatial resolution demonstrated here may enable identification of significant boundary layer features.

3. Ground/Space-Based Radar Precipitation Measurements

Yang Hong, Qing Cao, and Y. Berry Wen

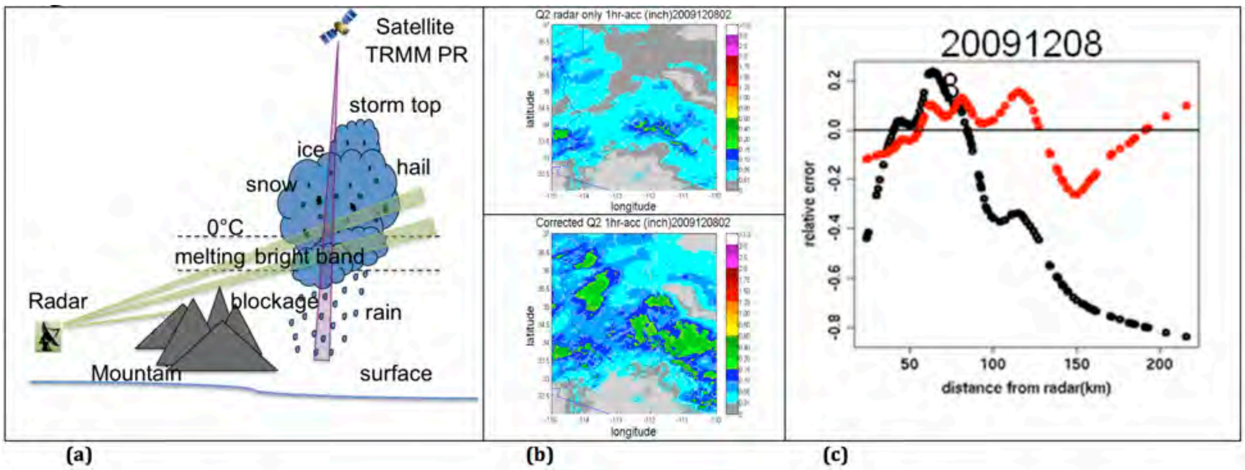
Objectives

The overarching goal of this project is to create synergy between NOAA emerging ground- and NASA space-based weather radar precipitation measurements.

Accomplishments

The team successfully conducted cross-validation of the NASA spaceborne radar TRMM and ground-based polarimetric radar KOUN. The team has proposed physics-based VPR conversion and investigated the reflectivity conversion from Ku-band to S-band, and has successfully developed the VPR Identification and Verification (VPR-IE) method to improve the QPE from NMQ/Q2 system in mountainous regions where beam blockage is a serious problem. Also, the team has successfully integrated VPR_IE into

the operational precipitation system with an automated VPR selection method to pick proper VPR type based on different rain type and intensity



(a) Schematic of VPR_IE method. (b) Example of 1-h radar precipitation accumulation estimated (upper) before and (lower) after adjustment using the VPR-IE method. (c) QPE error [(radar –rain gauge)/rain gauge] in terms of range for the 8 December 2009 case.

4. MPAR System and Cost Models

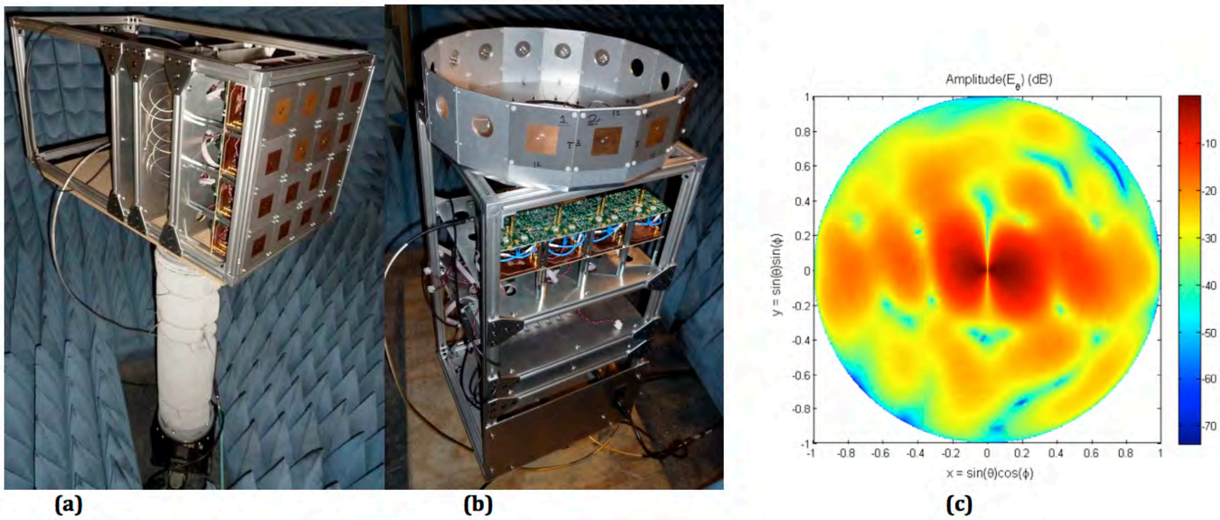
Yan Zhang, Yu Pan, and Sudantha Perera

Objectives
Develop scalable and high fidelity MPAR system performance and cost prediction models based on laboratory test-beds and experiments.

Accomplishments
MPAR front-end: The team successfully conducted a series of lab measurements with the low-cost, 4 by 4 Configurable Polarimetric Array Demonstrator (CPAD) and proved that, with simple patch antenna radiating elements, co-pol and cross-pol performance is comparable to Lincoln Laboratory's transmit/receive panel of similar size. CPAD is now reconfigured to circular and sparse manifold for further pattern comparisons (see figure below). An FDTD-based large array pattern predictor is being developed based on incorporating lab measurement data.

MPAR back-end: The team has successfully implemented real-time long-pulse compression into Spartan 6 and other FPGAs, and tested basic backend processing with a software-defined radio platform. We have developed joint relation with IDT with support of RapidIO backend models for scalable real-time systems data handling.

Reflectarray: The team has developed innovative solutions to both feed blockage analysis and cross-polarization control, and has begun to work on multiple beams and electronically steered beam designs.



Laboratory front-end test-bed. (a) Planar array configuration. (b) Circular array configuraiton. (c) Example 3D cross-polarization radiation pattern measured.

5. Biases in Precipitation Estimates using Polarimetric Cylindrical Arrays

Guifu Zhang, Richard Doviak, and Lei Lei

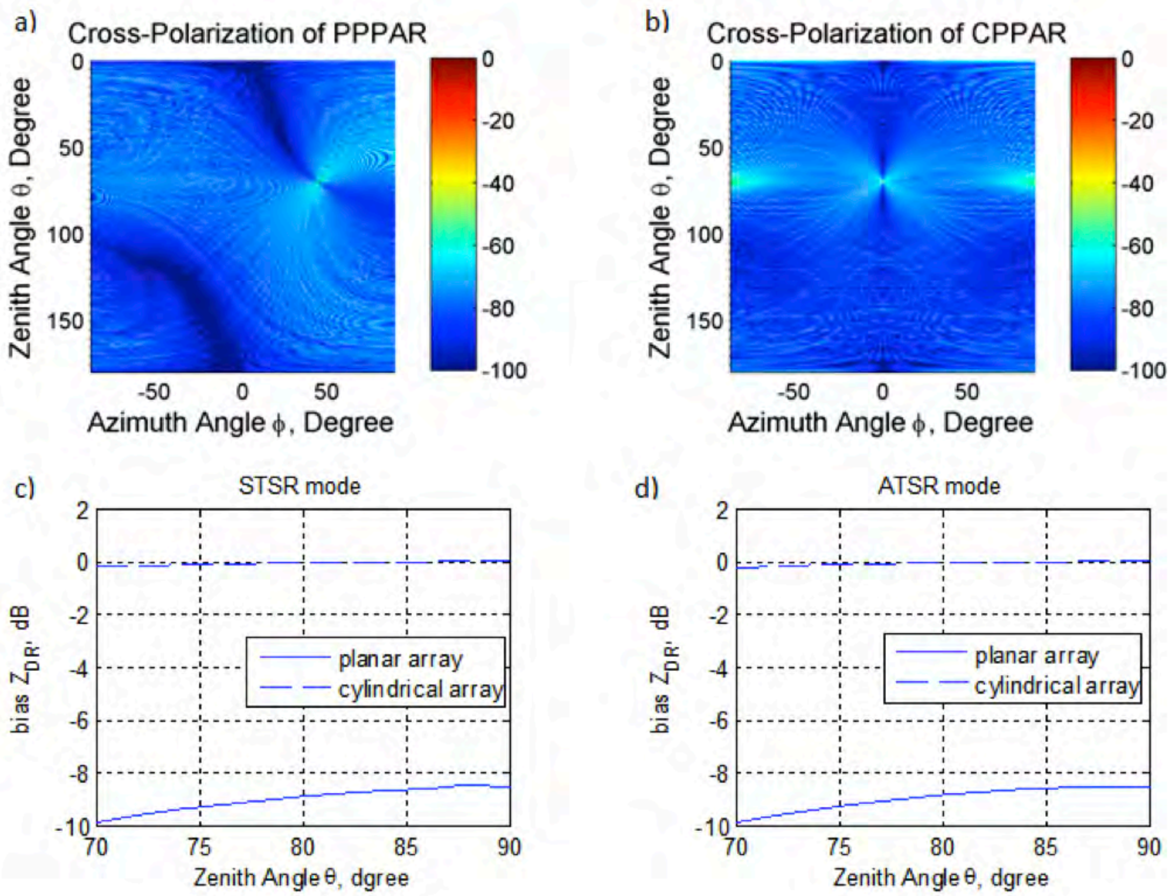
Objectives

Planar or Cylindrical Phased Arrays are two candidate antennas for future polarimetric weather radar. These two candidate antennas have distinctly different attributes when used to make quantitative measurements of the polarimetric properties of precipitation. Of critical concern is meeting required polarimetric performance for all directions of the electronically steered beam. The copolar and cross-polar radiation patterns and polarimetric parameter estimation performances of these two arrays are studied and compared showing superior performance of the cylindrical array.

Accomplishments

Herein we calculate the polarimetric parameter estimate biases for the PPPAR and CPPAR having an array of patch element. Biases associated with geometrically induced cross-polar fields can be partially corrected by applying the projection (or correction) matrix to fields along the boresight (Zhang et al. 2009). To null the cross-polar field along the boresight, the amplitudes of the weather signals transmitted and received in the H and V channels needs to be adjusted on a pulse-to-pulse basis to obtain estimates of the scattering matrix elements which are then averaged to obtain estimates of the polarimetric parameters (e.g., Z_{DR} and ρ_{hv}, Lei et al. 2012, see panels a and b of the figure below). Alternatively we could correct the biases given the measurements of the polarimetric parameters (Lei et al. 2013a, see panels c and d of figure below). In our research, we use the integration of array patterns to study the bias of radar parameters. Zrnić et al. (2010) and Galletti et al. (2011) have calculated the bias of Z_{DR} and ρ_{hv} for a

parabolic reflector antenna when either the STSR or the ATSR modes was applied. They used a Gaussian function to simulate the array's pencil beam. In our research, we follow their calculations but use the more realistic array pattern to calculate the bias of Z_{DR} and ρ_{hv}. The element pattern is a patch and is obtained from full wave solvers (HFSS). What's more, our results of biases are also compared with the results by Zhang et al. (2009) and Lei et al. (2013b). It is found that the integration contributions are very similar to the boresight contributions. These two only have very slight differences. The reason is that most of the power is located at boresight, while the sidelobes have very limited contributions.



(a) PPPAR after correction. (b) CPPAR after correction. (c) Z_{DR} bias for STSR mode. (d) Z_{DR} bias for ATSR mode.

6. Bayesian Approaches to Detect and Mitigate Ground Clutter in Weather

Guifu Zhang, Richard Doviak, and Yinguang Li

Objectives

This line of MPAR research started with jointly utilizing the NWRT/PAR sum and difference signals for crossbeam wind measurement and inhomogeneity detection using Spaced Antenna Interferometry (SAI) (Zhang and Doviak 2007 & 2008). In the past

year, our focus has been mainly on developing rigorous algorithms for ground clutter detection and mitigation, which is applicable to MPAR.

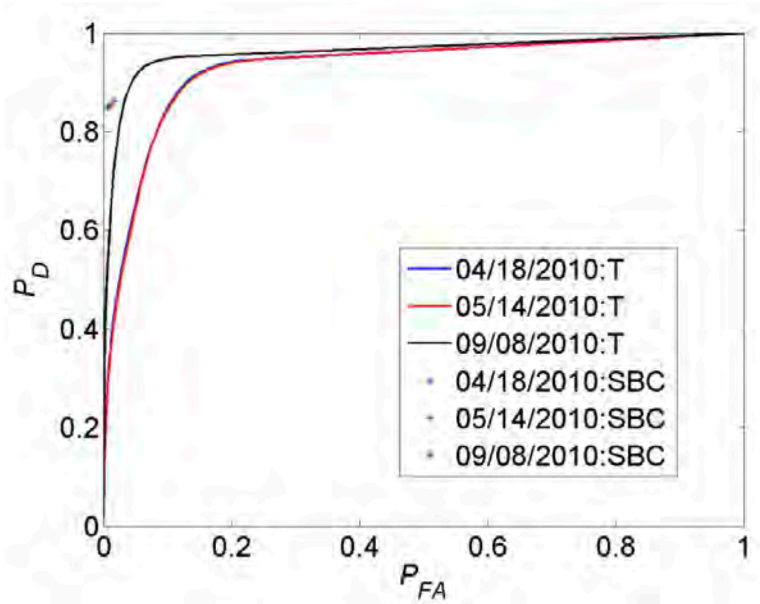
Accomplishments

We have developed and proposed four ground clutter detection algorithms that are applicable to MPAR: the Spectrum Clutter Identification (SCI) algorithm (Li et al. 2013a), the scan-to-scan correlation technique (Li et al. 2013b), the Generalized Likelihood Ratio (GLR) detection (Li et al. 2013c), and the Simple Bayesian Classifier (SBC) with inputs derived from the statistical properties of the received signals (Li et al. 2013c), which is an extension of the multi-pattern technique (Zhang et al. 2011).

To test for the presence of ground clutter, there are two hypotheses: a) the sampled echo is the combination of weather signal and noise (null hypothesis H_0), or b) the sampled echo is the combination of ground clutter, weather signal, and noise (alternative hypothesis H_1), which can be assumed to be true. The selected hypothesis should better account for the measurement than the other. Because the weather signal, clutter, and noise are described statistically, the analysis starts with the modeling of the probability density function (PDF) that describes the sampled echoes to be tested under each of the two hypotheses. The next step is to decide the rule to be used in determining an optimal choice between the two hypotheses. The likelihood ratio test (LRT) is the optimal detector (Kay 1993) according to the Neyman-Pearson theorem because it provides maximum P_D given a specified P_{FA}. However, in real-world applications, we do not always have the knowledge of the parameter values describing the PDFs under the two hypotheses, and thus a generalized likelihood ratio test (GLRT) is used instead of the LRT. In using the GLRT, unknown parameters are replaced by their maximum likelihood estimates (MLEs). In the figure below, the receiver operating curves (ROC) of the test statistic T for three controlled data sets are shown.

In the figure, the stars represent the results obtained by using the SBC with inputs derived from the statistical properties of the received signals. From the figure, we can conclude that the SBC outperforms the single parameter test statistic T. It is difficult to distinguish ground clutter from narrow-band zero-velocity weather signals by using T. It is expected that T alone would produce satisfactory results if there were few narrow-band zero-velocity weather signals, because more than 90% of false detections are caused by narrow-band zero-velocity weather signals if T is used.

The GLR detection can also be used to detect aircraft, considering that both the aircraft surveillance and weather surveillance functions will be combined into one polarimetric phased array radar in the future. In the figure, the theoretical performance of a Polarization-Space-Time (PST) GLR detection has been shown (Park et al. 1995).



Evaluation of ROC using parameters T applied to controlled data collected on 3 days.

7. Pulse Compression Waveforms for High-Sensitivity Weather Observations

Robert Palmer, James Kurdzo, Boon Leng Cheong, and Guifu Zhang

Objectives

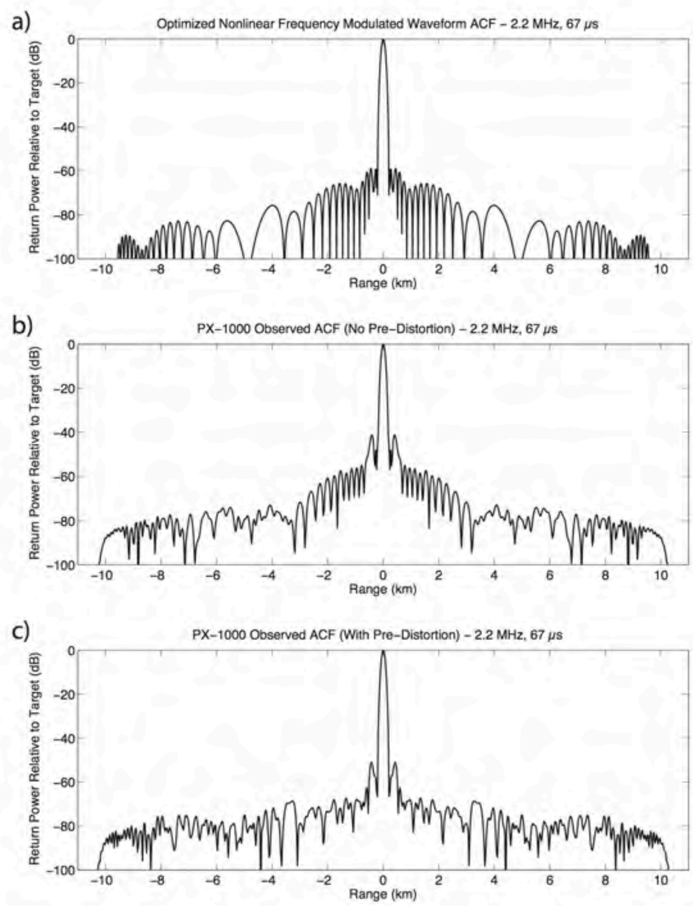
In order to provide adequate sensitivity in low-power radar systems, pulse compression has been used for decades in military applications. Until recently, pulse compression waveforms were rarely used in weather radar platforms due to the inherent lack of sensitivity from amplitude modulation. The goals of this project include the development of optimized nonlinear frequency modulated waveforms for use in weather radars with minimal amplitude tapering, allowing for the development of redundant array systems with cost-effective transmit/receive modules.

Accomplishments

Over the past year, the ARRC has been developing novel waveform design techniques for weather radar platforms that provide excellent sidelobe performance while maintaining power efficiencies as high as 95%. Such waveforms are capable of dramatically lowering price points on all types of radar systems, including phased array antennas. These waveforms have been implemented on the PX-1000 transportable, solid-state, polarimetric X-band dish radar, which operates at 100 Watts on each channel, as well as the Atmospheric Imaging Radar, a mobile X-band tornado-scale imaging system with a 20-degree vertically distributed 3.5 kW TWT fan beam on transmit and a phased array capable of digital beamforming on receive (Kurdzo et al. 2013). Due to low transmit powers, both platforms require the use of long-pulse waveforms in order to achieve acceptable sensitivity. On PX-1000, a theoretical waveform with peak sidelobes of -59 dB with 2.2 MHz of bandwidth and a 67-µsec pulse has been developed. In practice, these sidelobes degrade in quality, however, with the

use of a pre-distortion technique, operational peak sidelobes are as low as -52 dB (see figure below).

Both systems observed significant tornadoes and numerous severe local storms in 2013, including the 20 May Moore, Oklahoma EF-5 tornado, as well as the 31 May El Reno, Oklahoma EF-3 tornado. Data from these cases are currently being analyzed, with specific focus on polarimetric data with multi-lag processing from PX-1000, as well as the effects from Doppler tolerance in tornadoes and challenges surrounding waveform design in imaging and phased array systems.



ACFs of an optimized waveform for the PX-1000 system. (a) The original waveform after optimization with no pre-distortion taken into account. (b) The theoretical waveform from (a) after it has been sent through the transmitter. The ACF is calculated using a coupled pulse. Note the distortion which takes place, causing sidelobes to rise from -59 dB to -42 dB. (c) The actual coupled ACF of the same optimization technique used for (a), but while taking into account pre-distortion. Note that the peak sidelobes have been brought down to -52 dB, a 10 dB increase in performance compared with not accounting for pre-distortion in (b).

Publications

Cao, Q., Y. Hong, J.J. Gourley, Y. Qi, J. Zhang, Y. Wen, and P. Kirstetter, 2013: Statistical and physical analysis of vertical structure of precipitation in mountainous west region of US using 11+ year spaceborne TRMM PR observations. *Journal of Applied Meteorology and Climatology*, **52**, 408-424.

Cao, Q., Y. Hong, Y. Qi, Y. Wen, J. Zhang, J. Gourley, and L. Liao, 2013: Empirical conversion of vertical profile of reflectivity (VPR) from Ku-band to S-band frequency. *Journal of Geophysical Research*, **118**, 1-12.

Kurdzo, J. M., B. L. Cheong, R. D. Palmer, G. Zhang, and J. B. Meier, 2013: A pulse compression waveform for improved-sensitivity weather radar observations. *Journal of Atmospheric and Oceanic Technology,* under review.

Lei, L., G. Zhang, and R. J. Doviak, 2013: Bias correction for polarimetric phased-array radar with idealized aperture and patch antenna elements. *IEEE Transactions on Geoscience and Remote Sensing*, **51**, 473-486.

Lei, L., G. Zhang, and R. J. Doviak, 2013: Theoretical biases in estimates of precipitation properties when using polarimetric planar and cylindrical array antennas for weather radar, to be submitted.

Li, Y., G. Zhang, R. J. Doviak, and D. S. Saxion, 2013: Scan-to-scan correlation of weather radar signals to identify ground clutter. *IEEE Geoscience and Remote Sensing Letters,* **10**, 855-859.

Li, Y., G. Zhang, R. J. Doviak, L. Lei, and Q. Cao, 2013: A new approach to detect ground clutter mixed with weather signals. *IEEE Transactions on Geoscience and Remote Sensing,* **51**, 2373-2387.

Li, Y., G. Zhang, and R. J. Doviak, 2013c: Ground clutter detection using the statistical properties of signals received with a polarimetric weather radar. *IEEE Transactions on Signal Processing,* submitted.

Wen, Y., Q. Cao, P. Kirstetter, Y. Hong, J. J. Gourley, J. Zhang, G. Zhang, and B. Yong, 2013: Incorporating NASA spaceborne radar data into NOAA national mosaic QPE system for improved precipitation measurement: A physically based VPR identification and enhancement method. *Journal of Hydrometeorology*, **14**, 1293–1307.

Yu, P., and Y. Zhang, 2013: Analysis of blockage effects in a center-fed reflectarray. *Microwave and Optical Technology Letters*, **55**, 1921-1926.

Awards

James Kurdzo, Boon Leng Cheong, Robert Palmer, and Guifu Zhang filed a *Provisional Patent* in 2012 titled “Optimized pulse compression waveforms for high-sensitivity radar observations.”

James Kurdzo was awarded a McNair’s Choice Award and Second Place Overall (Science Category) at the OU Student Research and Performance Day in spring 2013.

CIMMS Task III Project – Support for the MPAR Wind Shear Study

Boon Leng Cheong (OU ARRC)

NOAA Technical Leads: Kurt Hondl, Kevin Kelleher, and Michael Jain (all NSSL)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/NSSL; NOAA Congressional Earmark)

Objectives
Use the PX-1000 ARRC radar to assist data collection for the 2012 MPAR Wind Shear Study. When permitted, the instrument shall collect datasets that overlap with the NWRT during operations. Moments and polarimetric data will be packaged in NetCDF format for sharing with the MIT-LL and FAA.

Accomplishments
The primary function of using the proposed instrument, i.e., the PX-1000, was to aid the collection of weather events for the wind shear study. While the primary instrument was the NWRT, it was deemed necessary to have a secondary instrument operating side by side for validation of some measurements. The PX-1000 participated the campaign from 1 May to 30 June 2012. Volume coverage patterns that are similar to NWRT's collection strategy were implemented on the PX-1000 for the wind shear study. During operations, real-time moments and polarimetric data were transported to the MIT-LL, which is the primary party for data analyses, through LDM (Local Data Manager). This project is completed.

A snapshot of reflectivity (left panel) and Doppler velocity (right panel) collected by the PX-1000 on 05/30/2012 03:00:49 UTC. A severe wind-gust can be seen at the circled region. It was reported that ground speed of over 60 mph, i.e., approximately 27 ms^{-1} was recorded.

CIMMS Task III Projects – Digital Backend Design and Demonstration for Next-Generation Weather Radar Systems

Mark Yeary (OU ARRC/ECE), and Redmond Kelley and John Meier (both OU ARRC)

NOAA Technical Leads: Kurt Hondl, Kevin Kelleher, and Michael Jain (all NSSL)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

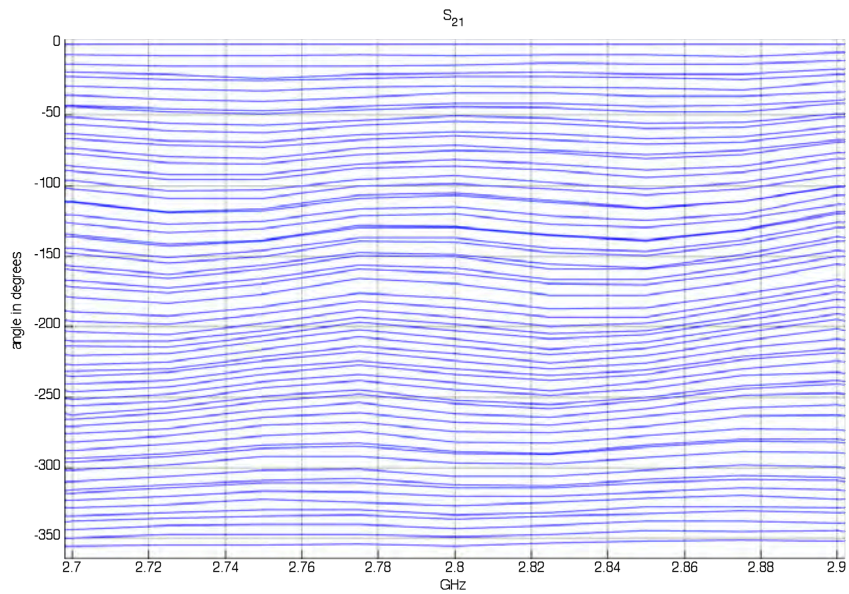
Funding Type: CIMMS Task III (NOAA/NSSL; NOAA Congressional Earmark)

Objectives

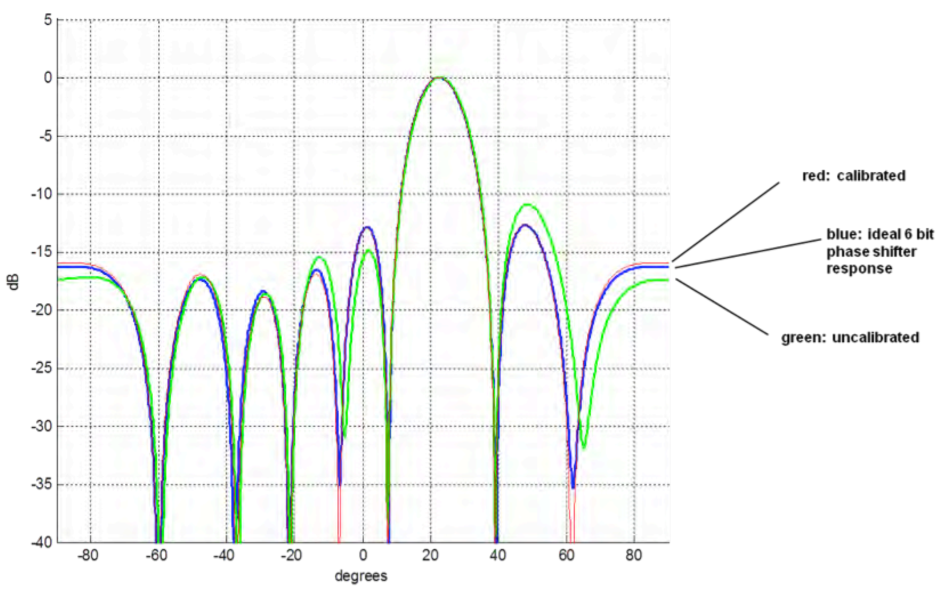
To help with the Gen2 panel project at MIT-LL in view of the backend, activities mainly focused on: FPGA based control for Gen2 panel operations, single-element data collection, associated data studies, and development of digital calibration procedures. Weather sensitivity calculations for two-panel tests were also prepared.

Accomplishments

A variety of accomplishments were achieved, as discussed next. Research for the FPGA that governs a Gen2 Lincoln Laboratory panel's back-plane printed circuit board were completed. For example, digital tables to control the digital attenuators and digital phase shifters have been prepared. To test this, Matlab code was been written to control a spectrum analyzer and signal generator for characterizing the digital attenuator and digital phase shifter on an element on the array, using either a desktop computer or a laptop. Subsequently, experiments were established at MIT-LL's near-field chamber for collecting S21 PNA data (where the complex valued S21 is defined as the forward transmission coefficient). An open-ended waveguide (OEWG) was operated as a transmit aperture in a frequency band of approximately 2.4 GHz to 3.4 GHz, and 41 sampling points were taken at regularly spaced frequency intervals in this band, i.e., 25 MHz. Although the panel is designed to operate between 2.7 GHz and 2.9 GHz, the boundary data was also collected. All sixteen states of the digital attenuators and all 64 states of the digital phase shifters were exercised. For control, the bits on the elements (1,1), (2,1), and (1,2) were controlled by establishing a Tool Command Language (TCL) Client/Server architecture for the Spartan6 FPGA between a laptop computer through a JTAG cable. As an example, element (1,1) was operated in these modes: in-line V, crossover V, in-line H, cross-over H, and dual in-line H & V. The first figure below illustrates the collected data for the 64 states of the panel's (1,1) RX2 phase shifter, in its in H in-line mode. Given the phase shifter data, how would a far-field pattern look from an 8x1 array? It is assumed that all eight of the elements would have data models that are similar to the (1,1). As such, the second figure below depicts the calibrated and uncalibrated responses of such an array for a single polarization. The ideal case, assuming a set of 6 bit phase shifters, has also been plotted. The uncalibrated case looks especially promising. The calibrated case is even better.

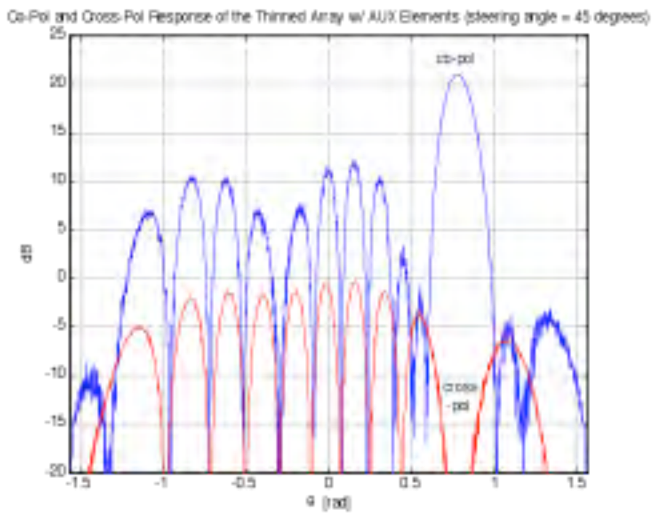


Phase shifter data were collected between approximately 2.4 GHz and 3.3 GHz (These are S21 PNA measurements). Although the panel is designed to operate between 2.7 GHz and 2.9 GHz, the boundary data was collected for completeness. The figure on the right depicts the 64 states of the RX2 digital phase shifter. As expected, the shifter produces reliable increments over a small frequency band.



Synthetic far-field response of an 8 element array (using the In-line H data, mode 4100). The particular phase data was at 2.7 GHz. Here, it is assumed that each of the elements have phase characteristics similar to the measurements taken on element (1,1). It is desired to steer 22.5 degrees.

As presented at an IEEE conference, a new method for improved cross-pol isolation based on the use of auxiliary elements has been developed. It describes a method to answer the following questions: can several of the elements of a phased array be employed as auxiliary (AUX) elements and how can the phase of each be adjusted so that the (a.) cross pol-isolation is minimized to 40 dB, (b.) the sidelobe levels of the main lobe are minimally impacted, and (c.) the width and height of the main lobe are minimally impacted? Devoting a few of the elements to serve as the auxiliary (AUX) channels to specifically operate to mitigate the effects of the cross-pol influence, the distributed sidelobe levels will not suffer much impact; yet the impact of the AUX elements will have deepen the cross-pol isolation at the peak of the co-polar beam can occur because the AUX elements can achieve a high degree of narrowband angular resolution. The figure below depicts the results of the proposed calibration process. The approach works well when the array is steered. It is robust against phase jitter and additive system noise, as shown. At the time of this writing, a 239-page PointPoint slide presentation is available that elaborates on the previous topics.



Results of the dual-pol calibration process when the array is steered and includes additive noise and additive phase jitter.

This project is ongoing.

Theme 2 – Stormscale and Mesoscale Modeling Research and Development

NSSL Project 3 – Numerical Modeling and Data Assimilation

NOAA Technical Leads: Louis Wicker, Don MacGorman, Ted Mansell, and Conrad Ziegler (all NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Accomplishments

1. Influence of Mesonet Observations on the Accuracy of Surface Analyses Generated by an Ensemble Kalman Filter

David Stensrud (NSSL) and Kent Knopfmeier (CIMMS at NSSL)

We sought to clarify the impact of National Mesonet data on the accuracy of surface analyses using an Ensemble Kalman Filter (EnKF) data assimilation approach via comparison to the Real-Time Mesoscale Analysis (RTMA) product produced by the National Centers for Environmental Prediction (NCEP).

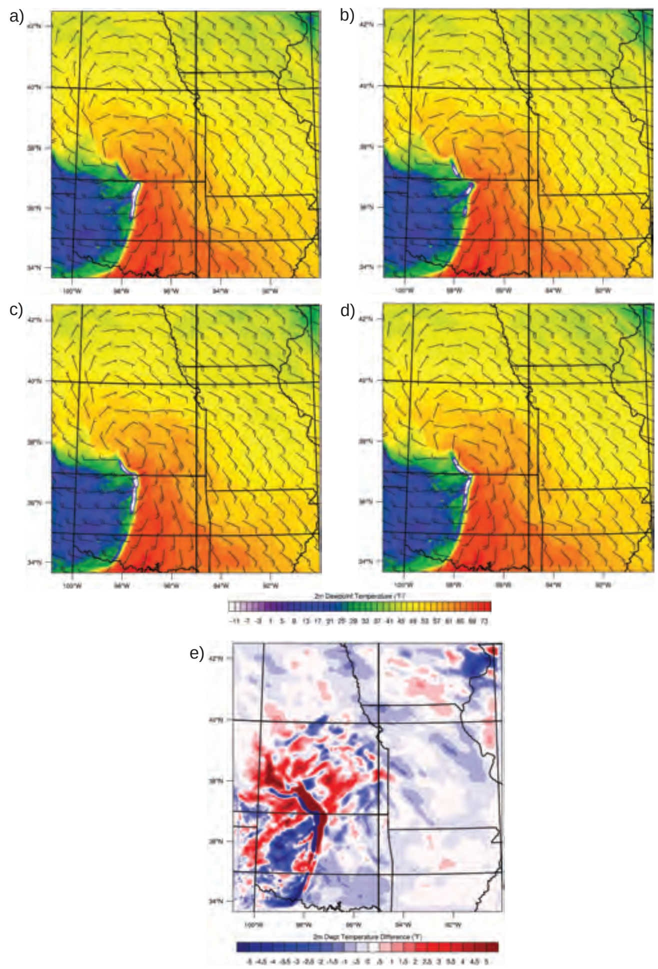
Results show general similarity between the EnKF analyses and the RTMA, with the EnKF exhibiting a smoother appearance with less small-scale variability. Root-mean-square (RMS) innovations are generally lower for temperature and dewpoint from the RTMA, implying a closer fit to the observations. Kinetic energy spectra computed from the two analyses reveal that the EnKF analysis spectra matches more closely the spectra computed from observations and numerical models in earlier studies.

Data-denial experiments completed for the first week of the warm and cold season, as well as for two periods characterized by high mesoscale variability within the experimental domain, show that mesonet data removal imparts only minimal degradation to the analyses. This is due to the localized background covariances computed for the four surface variables having spatial scales much larger than the average spacing of mesonet stations. Results show that removing 75% of the mesonet observations has only minimal influence on the analyses.

This project is ongoing.

Publications

Knopfmeier, K. H., and D. J. Stensrud, 2013: Influence of mesonet observations on the accuracy of surface analyses generated by an ensemble Kalman filter. *Weather and Forecasting*, **28**, 815-841.



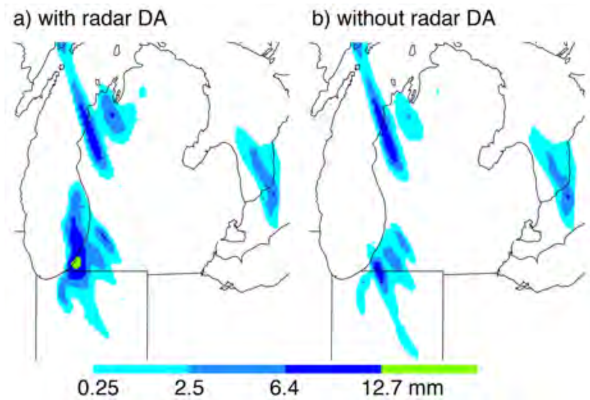
2-m temperatures (℉; see label bar) and 10-m winds from the a) 10%, b) 25%, c) 50%, and d) 75% Mesonet data-denial experiments valid at 0000 UTC 11 May 2010. e) 2-m dewpoint temperature differences (℉; see label bar) between the full EnKF data assimilation and the 50% Mesonet data-denial experiments. Warm colors indicate that the dewpoint temperature from the data-denial experiment is higher, whereas cold colors show regions where the full-data EnKF dewpoint temperature is higher.

2. Testing of Radar Data Assimilation for a Case Study of Lake-Effect Snow

Heather Reeves and Nusrat Yussouf (both CIMMS at NSSL)

Different approaches to assimilating radar data for a case study of lake-effect snow are tested. These include using different localizations and withholding some radars from the assimilation. Comparisons of experiments with and without the radar data assimilation show some improvement in earlier hours of the forecast cycle and an increase in the amount of 12-h accumulated precipitation over southwest Michigan. Other results are forthcoming.

This project is ongoing.



The 12-h accumulated liquid-equivalent precipitation for the experiments with (left) and without (right) radar data assimilation.

3. Assessing High-Resolution Ensemble Forecasts of Low-Level Supercell Rotation Within an Observing System Simulation Experiment (OSSE) Framework

Corey Potvin (CIMMS at NSSL) and Louis Wicker (NSSL)

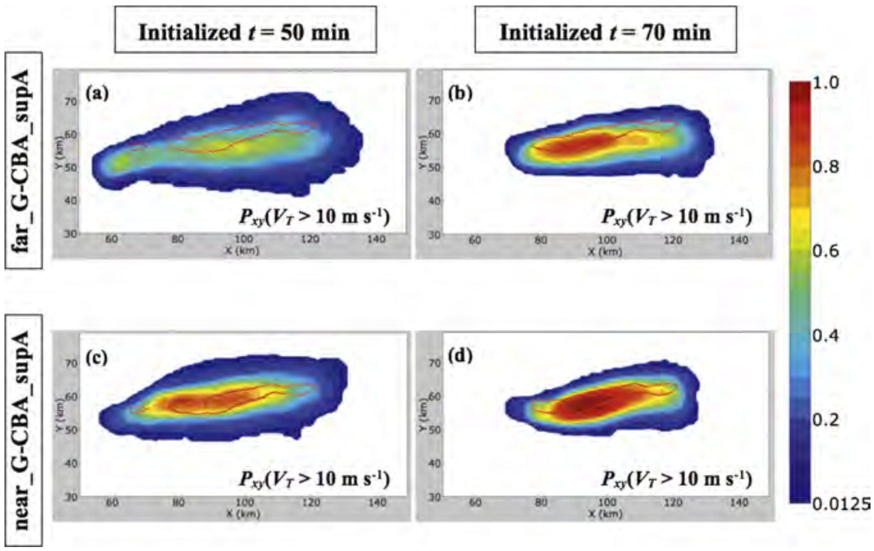
Under the envisioned Warn-n-Forecast (WoF) paradigm, ensemble model guidance will play an increasingly critical role in the tornado warning process. While computational constraints will likely preclude explicit tornado prediction in initial WoF systems, real-time forecasts of low-level mesocyclone-scale rotation appear achievable within the next decade. Given that low-level mesocyclones are significantly more likely than higher-based mesocyclones to be tornadic, intensity and trajectory forecasts of low-level supercell rotation could provide valuable guidance to tornado warning and nowcasting operations.

The efficacy of such forecasts was explored using three simulated supercells having weak, moderate, or strong low-level rotation. The results suggest early WoF systems may provide useful probabilistic 30–60-min forecasts of low-level supercell rotation, even in cases of large radar–storm distances and/or narrow cross-beam angles. Given the idealized nature of the experiments, however, they are best viewed as providing an *upper-limit* estimate of the accuracy of early WoF systems. We've begun setting up experiments that will explore impacts of physical parameterization and mesoscale analysis errors to obtain a better understanding of WoF capability given present model and observational limitations.

This project is ongoing.

Publications

Potvin, C. K., and L. J. Wicker, 2013: Assessing ensemble forecasts of low-level supercell rotation within an OSSE framework. *Weather and Forecasting*, **28**, 940-960.



Probability of low-level rotation exceeding 10 m s^{-1} (shading) for simulated forecasts initialized after (left) 50 and (right) 70 min of ensemble Kalman filter (EnKF) data assimilation: (a),(b) both radars far from storm, and (c),(d) one radar far from, and one radar near to storm. The red contours enclose the regions where the true low-level rotation exceeds 10 m s^{-1} during the forecast period.

4. Objective Detection and Characterization of Tornadoes and Mesocyclones in High-Resolution Model Wind Fields

Corey Potvin (CIMMS at NSSL), Brittany Dahl (OU Computer Science), and Louis Wicker (NSSL)

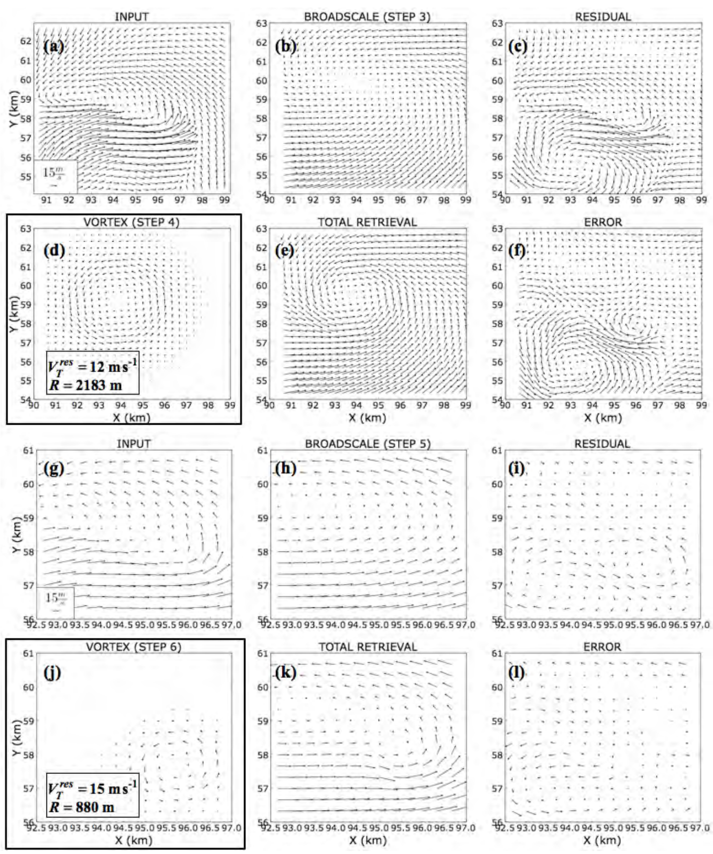
Vortex detection algorithms are required for both research and operational applications in which data volume precludes timely subjective examination of model or analysis fields. Unfortunately, objective detection of convective vortices is often hindered by the strength and complexity of the surrounding flow. To address this problem, I modified a variational vortex-fitting algorithm that I'd previously developed to detect and characterize vortices observed by Doppler radar to operate on gridded horizontal wind data. The latter are fit to a simple analytical model of a vortex and its proximate environment, allowing the retrieval of important vortex characteristics. This permits the development of detection criteria tied directly to vortex properties (e.g., maximum tangential wind), rather than to more general kinematical properties that may poorly represent the vortex itself (e.g., vertical vorticity) when the background flow is strongly sheared. Thus, the vortex characteristic estimates provided by the technique should permit more effective detection criteria while providing useful information about vortex size, intensity, and trends therein. Potential applications of the technique include investigating relationships between tornado characteristics and mesocyclone attributes, environmental parameters or model settings in simulations, and detecting tornadoes, mesocyclones and mesovortices in real-time ensemble analyses and forecasts (vital for Warn-on-Forecast).

The technique was tested and developed using supercell simulations with horizontal grid spacing ranging from 1000 m to 50 m. The method proficiently detects and characterizes tornado- and mesocyclone-like vortices in the simulations, even in the presence of highly complex flow (e.g., vortices embedded within larger vortices). The algorithm will be applied to simulations created by Brittany Dahl for her M.S. thesis project, the primary objective of which is to investigate whether model resolutions that are too coarse to effectively resolve tornadoes and low-level mesocyclones can nevertheless provide information about tornadogenesis potential. That work may further understanding of the predictability of tornadoes and yield important implications for the Warn-on-Forecast project.

This project is ongoing.

Publications

Potvin, C. K., 2013: A variational method for detecting and characterizing intense vortices in Cartesian wind fields. *Monthly Weather Review*, **141**, 3102-3115.



Retrieval of a vortex obscured by strong deformation north of the apex of the rear-flank downdraft outflow in a simulated supercell: (a) input (simulated) wind field; (b) broadscale wind retrieval; (c) residual (input - broadscale) wind field; (d) vortex wind retrieval; (e) total (broadscale + vortex) retrieval; (f) difference between input and total retrieved wind fields (errors); (g)-(l) as in (a)-(f) but for retrieval domain customized to preliminary vortex retrieval. The retrieved maximum tangential wind and radius of maximum wind are shown in (d) and (j).

5. Removing Acoustic-Mode Pressure Oscillations from Storm-Scale Ensemble Kalman Filter Analyses

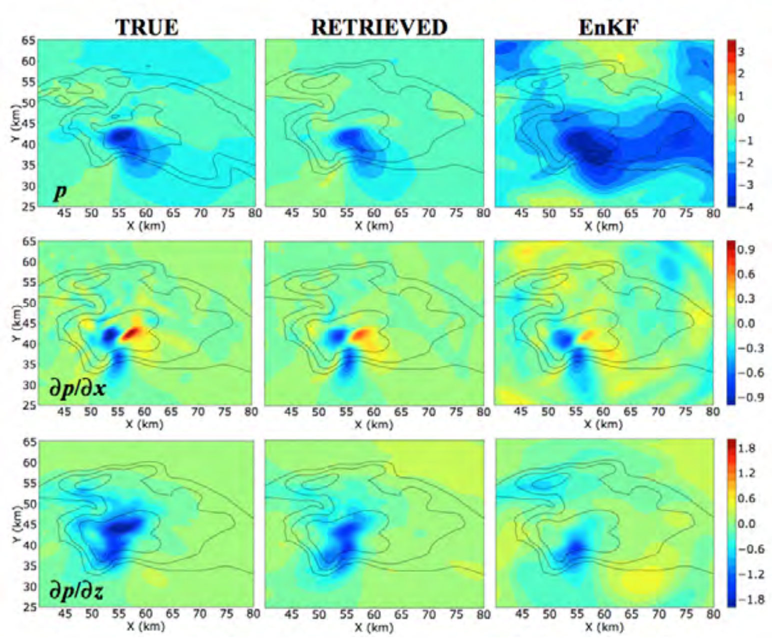
Corey Potvin (CIMMS at NSSL) and Louis Wicker (NSSL)

When an ensemble Kalman filter (EnKF) and compressible model are used to assimilate storm-scale radar data, dynamically unbalanced analysis increments can incite high-amplitude acoustic waves and attendant pressure oscillations that preclude analysis of the pressure field within storms. This inhibits investigation of pressure-gradient-driven processes critical to storm evolution. To address this problem, we modified thermodynamic retrieval techniques traditionally applied to dual-Doppler wind analyses to diagnose the balanced (uncontaminated) portion of EnKF pressure analyses, thereby eliminating the fast-mode oscillations. We tested the technique using a high-resolution supercell simulation as well as simulated and real EnKF supercell analyses. The technique code was used by Patrick Skinner (Ph.D. candidate, Texas Tech University) to correct EnKF pressure analyses of a real supercell as part of his dissertation work.

This project is ongoing.

Publications

Potvin, C. K., and L. J. Wicker, 2013: Correcting fast-mode pressure errors in storm-scale ensemble Kalman filter analyses. *Advances in Meteorology*, in press. http://www.hindawi.com/journals/amet/aip/624931/



True (left column), retrieved (middle column) and EnKF mean posterior (right column) p (top row), $\partial p/\partial x$ (middle row; hPa km^{-1}) and $\partial p/\partial z$ (bottom row; hPa km^{-1}) at z = 0.9 km AGL. Radar reflectivity factor is contoured at 10, 30, and 50 dBZ.

6. Exploring the Impact of Assimilating Phased Array Radar Data on Storm-Scale Ensemble Prediction

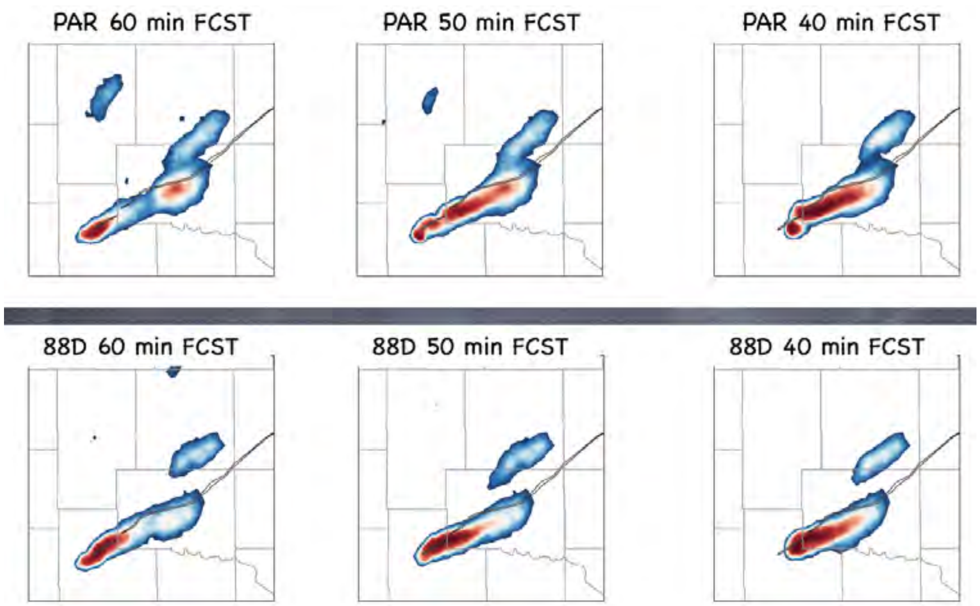
Louis Wicker (NSSL), Corey Potvin (CIMMS at NSSL), Therese Thompson (OU School of Meteorology at CIMMS), and David Stensrud and Pamela Heinselman (both NSSL)

The past decade has seen the development of two major technologies toward enabling real-time prediction of severe convective storms. Since 2003, NSSL has been actively developing a Phased Array Radar (PAR), a potential next-generation operational weather radar system using phased array panels to enable volume scan periods of 30-60 s. During the same period, data assimilation techniques originally designed for the synoptic and meso scales have been extended to nonhydrostatic scales.

In an OSSE study by Yussouf and Stensrud (2011), assimilating simulated rapid-scan radar data using an ensemble Kalman filter (EnKF) produced better analyses and forecasts than assimilating radar data synthesized using a typical WSR-88D scan strategy. Demonstrating impacts from real PAR data, however, has proven more challenging, due partly to an early lack of high-quality datasets. In addition, assessing PAR impact in real-data studies requires careful experiment design, availability of cases where the mesoscale background is accurately estimated, and a convective-scale forecast model whose errors are relatively small. If these requirements are not met, our experiments have shown that environmental and model errors dominate initial condition errors during the forecasts, thereby limiting the impact of PAR data assimilation.

Assimilation experiments are being performed with the 24 May 2011 El Reno, Oklahoma, tornadic storm, which was sampled by a long time series (> 3 hours) of MPAR volumes (~ 1 min periods) within 100 km of the radar. Our focus is on the impact of assimilating rapid-scan versus WSR-88D data on 40-min ensemble forecasts of low-level circulation track and intensity. This is the first real-data demonstration of the potential impact from a PAR observing capability for storm-scale numerical weather prediction.

This project is ongoing.



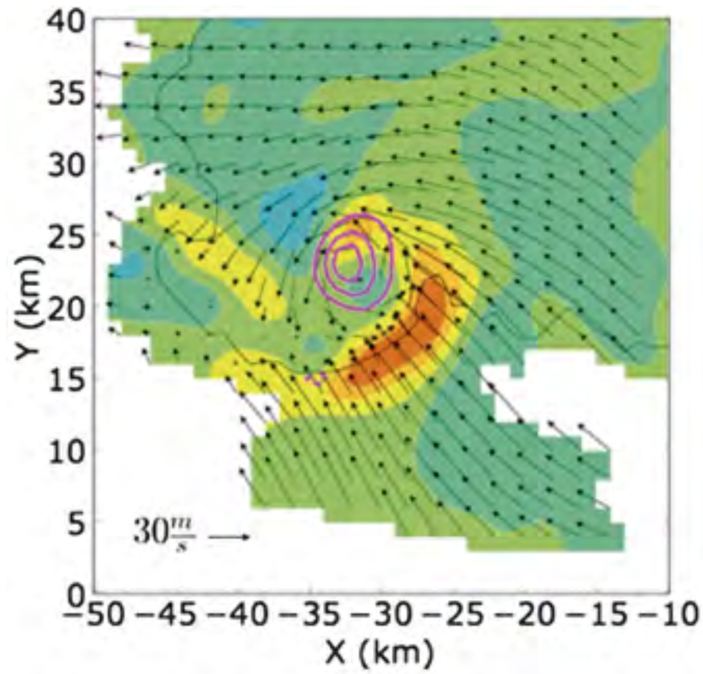
Probabilistic vorticity forecasts for a real tornadic supercell, generated from EnKF analyses obtained from assimilating (top) PAR volume scans and (bottom) simulated 88D volume scans obtained by sub-sampling the PAR scans. Forecasts initialized after (left) 20 min, (middle) 30 min and (right) 40 min of data assimilation. Results are preliminary.

7. Development of a Community Variational Dual-Doppler Wind Retrieval Code

Corey Potvin (CIMMS at NSSL)

Variational dual-Doppler wind retrieval has been shown to be superior to traditional dual-Doppler retrieval techniques. It is necessary to use the most sophisticated analysis techniques available to fully exploit high-quality dual-Doppler datasets such as those collected during the VORTEX2 experiment. Yet, variational dual-Doppler retrieval methods are rarely used. The variational dual-Doppler retrieval code developed by Potvin and Alan Shapiro (OU School of Meteorology) was refined for use by the storm-scale research community. The code has been shared with researchers at OU and Pennsylvania State University for use with mobile radar datasets. It is hoped the availability of this code will facilitate the adoption of the variational dual-Doppler retrieval approach by the community.

This project is ongoing.



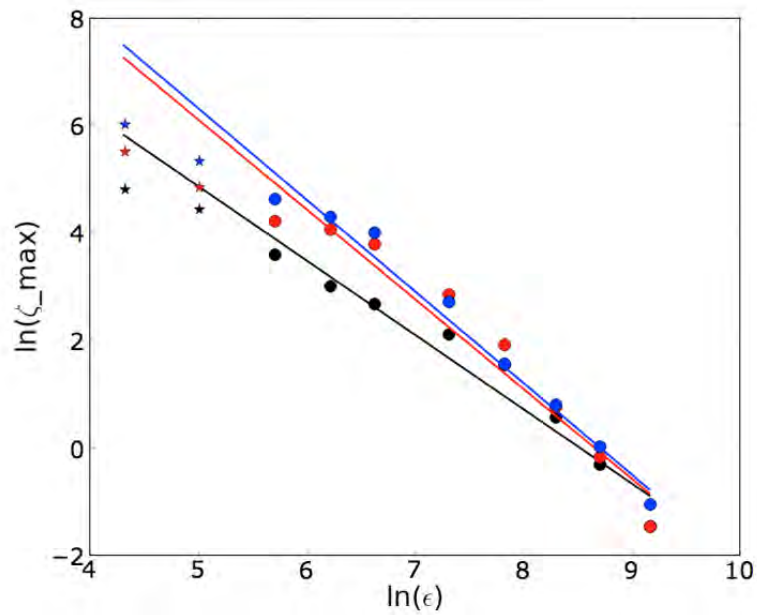
Variational dual-Doppler wind retrieval of the 29-30 May 2004 Geary, Oklahoma, tornadic supercell. Horizontal velocity (arrows) and vertical velocity (shading) are shown.

8. Investigating Implications of a Vortex Gas Model and Self-Similarity for Tornadogenesis and Maintenance

Doug Dokken, Misha Shvartsman, and Kurt Scholz (University of St. Thomas Department of Mathematics), Pavel Belik (Augsburg College Department of Mathematics), Corey Potvin (CIMMS at NSSL), and Brittany Dahl (OU Computer Science)

Doug Dokken is leading an effort to describe tornado formation and maintenance using a 3-dimensional vortex gas model and the hypothesis that tornadoes exhibit self-similarity associated with the organization of smaller vortices around large vortices over a range of scales. Potvin is using a supercell simulation created by Brittany Dahl to test some of the hypotheses of the theory. The work may provide insights into tornadogenesis and the predictability of tornadoes. Important implications for Warn-on-Forecast may arise.

This project is ongoing.



Maximum vertical vorticity vs. scale computed within the low-level mesocyclone of a simulated supercell (75 m grid spacing) at t = 134 min (black), prior to the development of a discernable surface vortex; at t = 154 min (red), by which time a relatively weak surface vortex is present; and at t = 169 min (blue), near the time of tornadogenesis. Points used to create the least-squares fit lines are denoted by dots, while points not used in the vorticity line computation (ε < 300 m) are denoted by asterisks.

9. Storm-Scale Data Assimilation and Ensemble Forecasting for Warn-on-Forecast

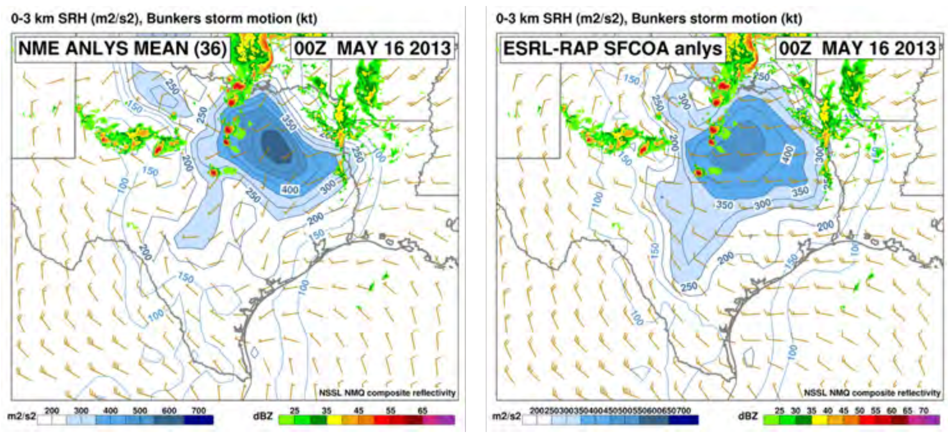
Dustan Wheatley, Kent Knopfmeier, and Gerry Creager (all CIMMS at NSSL)

One task of the NOAA Warn-on-Forecast program is the development of realistic mesoscale backgrounds for downscaling to high-resolution (of order 1 km or less) radar data assimilation experiments. Toward this end, the NSSL Mesoscale Ensemble (NME) has been developed using the Weather Research and Forecasting (WRF) model. A variety of quasi-realtime model output from the NME is examined during this year's Hazardous Weather Testbed Spring Forecast Experiment, to better understand the impact of conventional observations on mesoscale analyses and forecasts of severe weather events.

The NME has been run daily for period 6 May to 7 June 2013 to produce three-dimensional analyses over a CONUS domain with a horizontal grid spacing of 18 km. The 36-member ensemble is constructed from initial and boundary conditions provided by the Earth System Research Laboratory-Rapid Refresh (RAP-ESRL, i.e., RAPv2) forecast cycle starting 1200 UTC. Initial condition perturbations are used to account for uncertainties in the RAP-ESRL analysis, and the WRF physics options are also varied amongst the ensemble members to address deficiencies in model physics. Routinely available observations of altimeter setting, temperature, dewpoint, and horizontal wind components from land and marine surface stations, rawinsondes, and aircraft—as well

as satellite winds—are assimilated using an ensemble Kalman filter (DART software) at hourly intervals from 1300 UTC to 0300 UTC the following day. Mesoscale ensemble forecasts are also launched from the 1400, 1600 and 1800 UTC mesoscale analyses, and all terminate at 0300 UTC the next day.

This project is ongoing.



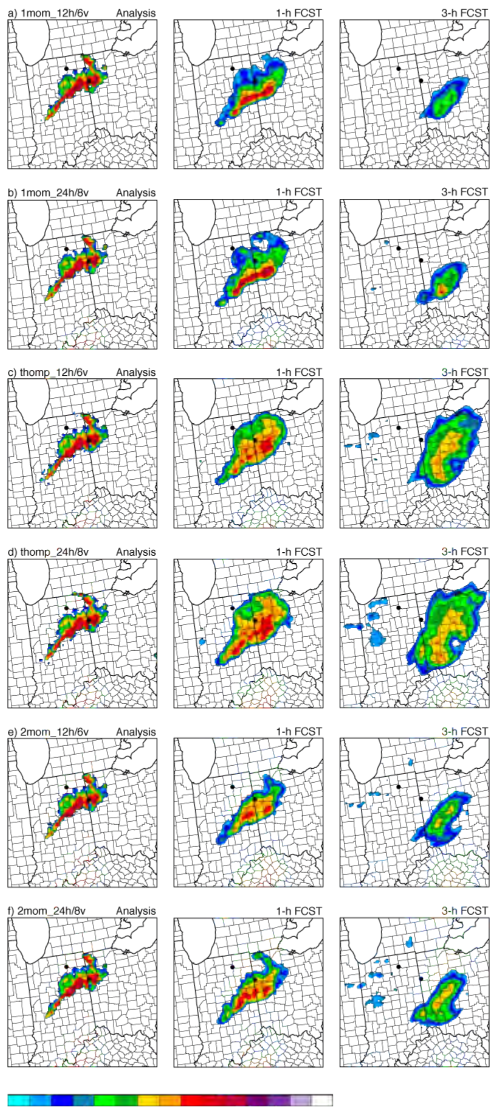
Analyses of 0-3 km storm-relative helicity (m^2/s^2; see color bar), Bunker storm motion vectors (knots), and observed radar reflectivity factor (dBZ; see color bar), at 0000 UTC 16 May 2013, from the (left panel) NSSL Mesoscale Ensemble (NME) and the (right panel) SPC's surface objective analysis scheme (SFCOA), which incorporates the experimental ESRL Rapid Refresh version 2 (RAPv2).

10. Ensemble Kalman Filter Analyses and Forecasts of a Severe Mesoscale Convective System Observed During BAMEX

Dustan Wheatley and Nusrat Yussouf (both CIMMS at NSSL), and David Stensrud (NSSL)

A WRF-based ensemble data assimilation system is used to produce storm-scale analyses and forecasts of the 4-5 July 2003 severe mesoscale convective system (MCS) over Indiana and Ohio, which produced numerous high wind reports across the two states. Single-Doppler observations are assimilated into a 36-member, storm-scale ensemble during the developing stage of the MCS with the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). The storm-scale ensemble is constructed from mesoscale EnKF analyses produced from the assimilation of routinely available observations from land and marine stations, rawinsondes, and aircraft, in an attempt to better represent the complex mesoscale environment for this event. Six EnKF simulations were performed using the NSSL 1- and 2-moment and Thompson microphysical schemes, with two different choices of horizontal/vertical covariance localization for the assimilated radar data. All six experiments produce a linear convective segment in the final analysis time, similar to the observed system at 2300 UTC 4 July 2003. Those experiments utilizing the longer horizontal and vertical localization radii produce more persistent systems throughout the

forecast period. The higher-order schemes—in particular, the Thompson scheme—are better able to reproduce both the convective and stratiform components of the observed system, and produce the smallest temperature errors when comparing surface observations and dropsonde data to corresponding model data. It is also noted that only the higher-order microphysical schemes produce any appreciable rear-to-front flow in the stratiform region that trailed the simulated systems. Work related to this project has produced one paper that has been submitted to *Monthly Weather Review*, This project is ongoing.



Simulated (ensemble-mean) radar reflectivity at 2300 UTC 4 July 2003 (EnKF analysis), 0000 UTC 5 July 2003 (1-h fcst), and 0200 UTC 5 July 2003 (3-h fcst) for six different radar data assimilation experiments: (row a) 1mom_12h/6v, (row b) 1mom_24h/8v, (row c) thomp_12h/6v, (row d) thomp_24h/8v, (row e) 2mom_12h/6v, and (row f) 2mom_24h/8v. Two black dots indicate locations of special BAMEX dropsondes.

11. Storm-Scale Cloud Water Path Assimilation

Thomas Jones (CIMMS at NSSL), David Stensrud and Louis Wicker (both NSSL), Steve Goodman (NOAA/NESDIS), and Patrick Minnis (NASA Langley Research Center)

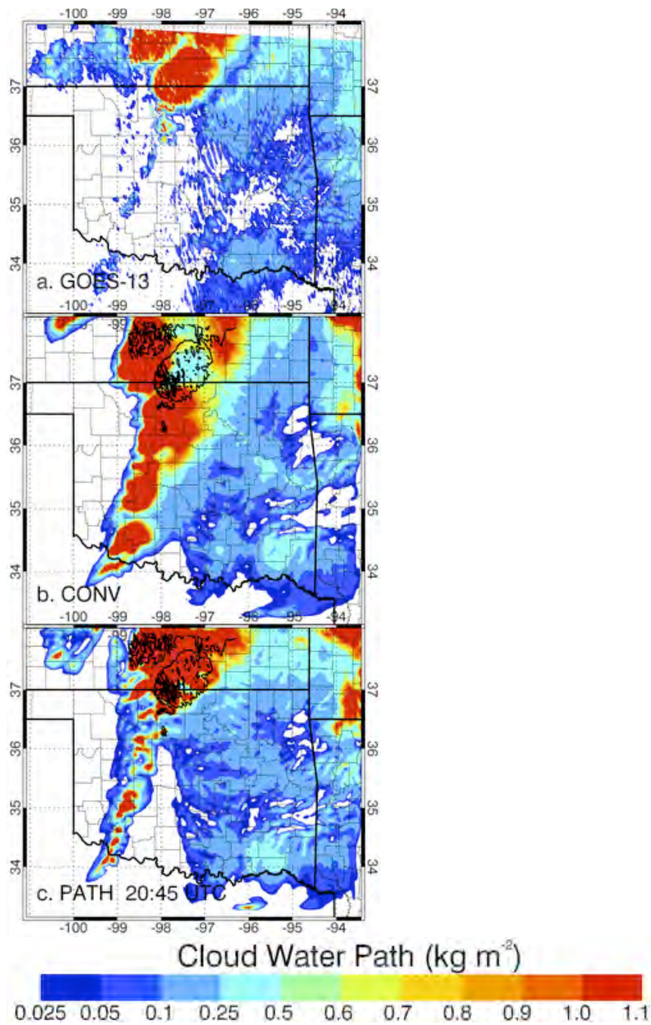
This project focused on developing methods to assimilate cloud properties retrieved from GOES satellite data into storm-scale NWP models (Jones et al. 2013a). Retrieved cloud properties considered include cloud top and cloud base pressure (CTP, CBP), cloud water path (CWP), and cloud phase. CTP and CBP represent the pressure level near which the top and bottom of a cloud layer are located. CWP represents the column integrated cloud water mixing ratio within a cloud layer while cloud phase indicates whether the cloud is comprised of either liquid or frozen hydrometeors. Assimilating satellite retrieved cloud properties requires the development of a new forward operator, with the main challenge being to translate from a column integrated CWP value into a vertical distribution. A forward operator is created that integrates the model mixing ratios of cloud liquid water (QCLOUD), cloud ice (QICE), graupel (QGRUAP), rain (QRAIN), and snow (QSNOW) from cloud base to cloud top defined from satellite retrievals. Both liquid and frozen variables are summed into a single CWP variable to better approximate the characteristics of the satellite retrieval. The vertical extent of the cloud layer at each observation location is defined by CTP and CBP and is passed to the forward operator and used to constrain the CWP calculated from the model.

The new forward operator was first tested on the 10 May 2010 case, which produced severe weather and tornadoes in the Southern Plains. For this experiment, 4 km resolution CWP data were assimilated at 15-minute intervals between 1800 and 2100 UTC into the 3 km nested grid with forecasts generated thereafter. The effects of the CWP assimilation are assessed by comparing two identical model experiments: one with (PATH) and one without the satellite data (CONV). During this 3 h period, over 40,000 CWP retrievals are assimilated with roughly two-thirds corresponding to cloudy conditions. In cloud-free regions, a CWP of 0 kg m^{-2} is assimilated. Comparing the ensemble mean model CWP from CONV and PATH with the actual GOES retrievals shows that assimilating these data are having a significant impact (see figure below). In the PATH analysis at 2045 UTC, the magnitude and coverage of CWP is much lower along the line of developing convection, which is in much better agreement with the satellite observations (see figure below). The maxima in CWP in central and southern Oklahoma are displaced slightly westward of their location in CONV, indicating that PATH might be somewhat slower in its progression of its convective features. The decrease in analyzed CWP compared to CONV is a direct result of assimilating zero values of CWP in this experiment. Overall, PATH is much less aggressive in developing convection during the analysis period as it is suppressed at each assimilation cycle.

This project is ongoing.

Publications

Jones, T. A., D. J. Stensrud, P. Minnis, and R. Palikonda, 2013a: Evaluation of a forward operator to assimilate cloud water path into WRF-DART. *Monthly Weather Review*, **141**, 2272–2289.



GOES-13 CWP retrievals at 2045 UTC (a) with corresponding posterior ensemble mean CWP generated from CONV (b) and PATH (c) model analyses at the same time. Black contours in panels b and c corresponding to 0.5 kg m^{-2} CWP contour from GOES observations in panel a. From Jones et al. (2013a).

12. Mesoscale GOES-ABI Radiance Assimilation OSSE Experiments

Thomas Jones (CIMMS at NSSL), David Stensrud (NSSL), and Jason Otkin (CIMSS-University of Wisconsin)

Research has included assessing the impacts of assimilating both satellite and radar data using an ensemble Kalman filter approach. While radar and satellite data are highly correlated, each provides unique information about the atmosphere not available from the other. The relative impacts of radar vs. satellite data assimilation are not well understood prompting the need for a detailed comparison study. The initial comparison uses simulated WSR-88D Doppler radar reflectivity and radial velocity data and GOES-R brightness temperatures (T_B) between at 6.95 µm from a 6 km resolution truth

analysis. These data are then assimilated into a 15 km resolution mesoscale WRF model with a CONUS domain using 48 ensemble members. The case selected occurred on 24 December 2009 during which blizzard conditions occurred in the Southern Plains with convection and some severe weather further east in the warm sector. This case provides multiple weather regimes in which to test the various affects of radar vs. satellite data assimilation.

Four experiments were conducted. One assimilates only conventional observations (CONV), one with conventional and satellite T_B (SAT), one with conventional and radar (RAD), and a final experiment with assimilating all three data types (RADSAT). The figure below shows ensemble mean simulated 6.95 μm T_B for each experiment at the end of the assimilation period at 1200 UTC as well as the corresponding Truth data. Truth 6.95 μm T_B indicates the presence of high atmospheric moisture content in the eastern portion of the domain roughly along the 91°W meridian where T_B < 230 K (figure part a below). In Oklahoma, T_B are warmer indicating less mid-tropospheric moisture, which is consistent with the lower altitude of these clouds. Several finer details are also visible with the Truth simulation resolving linear banding features in Oklahoma and possibly individual convective cells farther east. The CONV experiment generates a similar T_B simulation overall, but either misses or incorrectly analyzes several important details (figure part b), generating the much colder T_B (< 220 K) associated with the convection in the eastern portion of the domain (figure part b). In northwest Oklahoma, CONV generates a region of very cold T_B that does not exist in the Truth simulation. Finally, much of the finer scale detail apparent in the Truth simulation is lost in the CONV experiment. The excessively cold T_B in the eastern portion of the domain results in an overall cold bias.

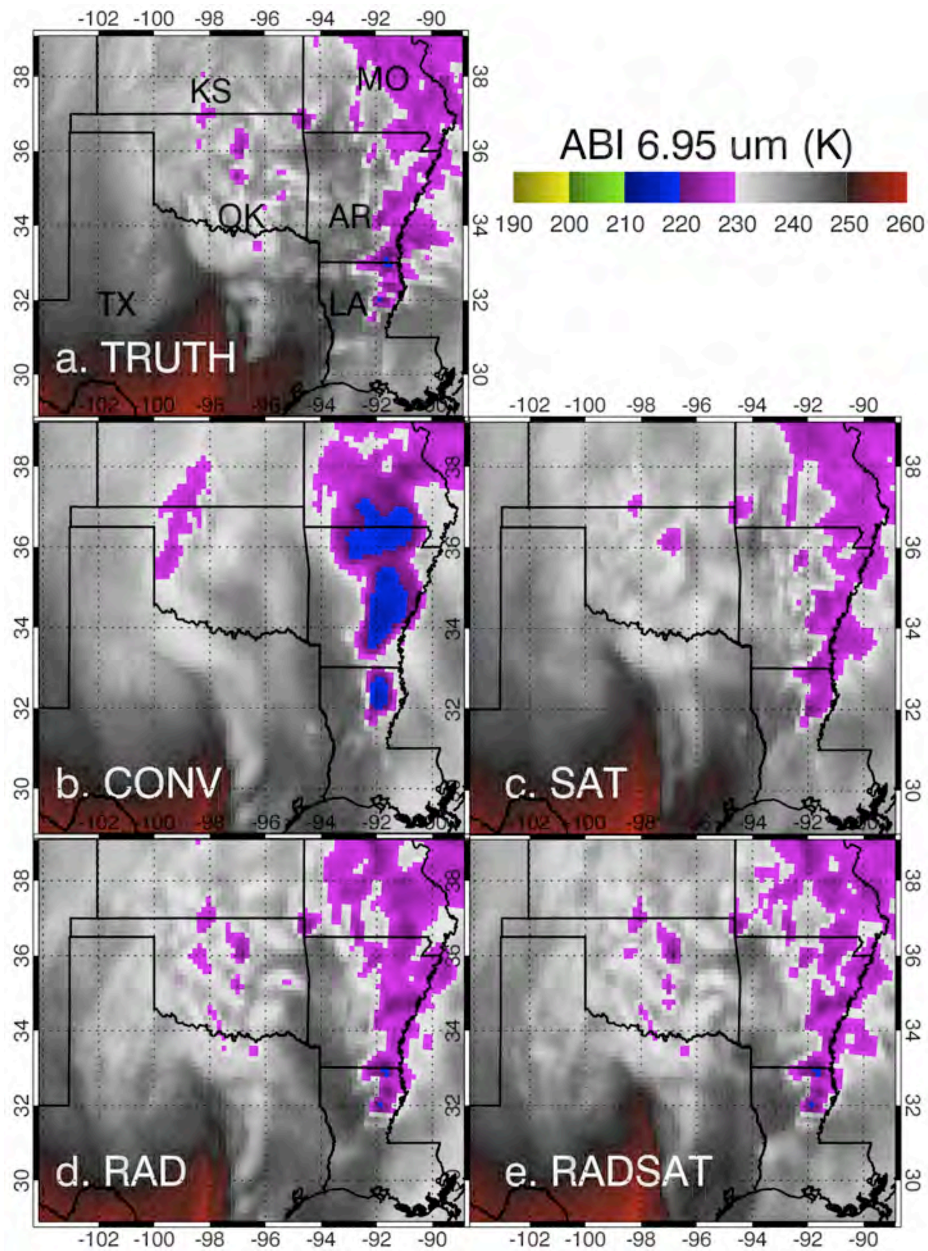
The SAT experiment shows a much better representation of 6.95 μm T_B compared to CONV (figure part c). The erroneously cold (< 220 K) T_B in the eastern potion of the domain have been eliminated and the location of colder T_B shifts farther east in much better agreement to the Truth simulation. To the west, the area of colder T_B in northwestern Oklahoma is no longer present while several of the smaller scale features in this region are correctly analyzed. Since the 6.95 μm T_B from Truth are being assimilated in SAT, it is expected that they would have a large impact on the corresponding analysis. The objective statistics support the visual interpretation and show a large reduction in bias and RMSD. Assimilating radar data also produces a significant impact to the 6.95 μm T_B analysis (figure part d). Compared to CONV, the RAD experiment exhibits a similar cold bias, but does not have the large region with T_B < 220 K. The RMSD decreases, but is still nearly twice as high as the SAT case. The fact that assimilating radar data alone increases skill in simulated satellite T_B is very encouraging, and depicts their influence on the cloud field. The assimilation of both radar and satellite data in RADSAT reduces bias and RMSD compared to the SAT experiment (figure part d). Results of this research have been accepted for publication in *Monthly Weather Review* (Jones et al. 2013b,c).

This project is ongoing.

Publications

Jones, T. A., J. Otkin, D. J. Stensrud, and K. Knopfmeier, 2013b: Assimilation of satellite infrared radiances and Doppler radar observations during a cool season Observing System Simulation Experiment. *Monthly Weather Review,* in press. doi: http://dx.doi.org/10.1175/MWR-D-12-00267.1

Jones, T. A., J. Otkin, D. J. Stensrud, and K. Knopfmeier, 2013c: Forecast evaluation of an Observing System Simulation Experiment assimilating both radar and satellite data. *Monthly Weather Review,* in press. doi: http://dx.doi.org/10.1175/MWR-D-13-00151.1



Simulated GOES-R ABI 6.95 µm T_B (K) for the Truth simulation and each experiment at 1200 UTC 24 December. From Jones et al. (2013b).

13. The Impact of Mesoscale Environmental Uncertainty on the Prediction of a Tornadic Supercell Storm using Ensemble Data Assimilation Approach

Nusrat Yussouf (CIMMS at NSSL), Jidong Gao and David Stensrud (both NSSL), and Guoqing Ge (OU CAPS)

Numerical experiments over the past few years indicate that incorporating environmental variability is crucial for successful very short-range (0-1 h) convective-scale ensemble forecasts. To explore the impact of model physics on the creation of mesoscale environmental variability and its uncertainty, combined mesoscale-convective scale ensemble data assimilation and forecast experiments are conducted for the 8 May 2003 Oklahoma City tornadic supercell storm. Two sets of 36-member WRF-ARW model mesoscale ensemble adjustment Kalman filter (EAKF) data assimilation systems with continuous cycling on a continental United States domain are conducted to provide background environmental conditions using either fixed physics or multiple physics parameterization schemes across the ensemble members. Two 36-member convective-scale ensembles are initialized at 3-km grid spacing, one using background fields from the fixed physics and the other using background fields from multiple physics mesoscale ensemble analyses. Reflectivity and radial velocity observations from four operational WSR-88D radars are assimilated into the convective-scale ensemble members using the ARPS model based three-dimensional variational (3DVAR) data assimilation system that is cycled for a 40-min period after which 1-hr ensemble forecasts are launched. Results show that the ensemble with background fields from the multiple physics mesoscale ensemble provides more realistic forecasts of significant tornado parameter, dryline structure, and near surface variables than the ensemble from fixed physics mesoscale background fields. The probabilities of a strong 0-3 km updraft helicity – a proxy for low-level rotation - from the multiphysics ensemble correlates better with the observed tornado and rotation tracks than probabilities from the fixed physics ensemble. This suggests that incorporating physics diversity across the ensemble can be important to successful probabilistic convective-scale forecast of supercell thunderstorms, which is the main goal of National Oceanic and Atmospheric Administration's (NOAA) Warn-on-Forecast initiative. This project is ongoing.

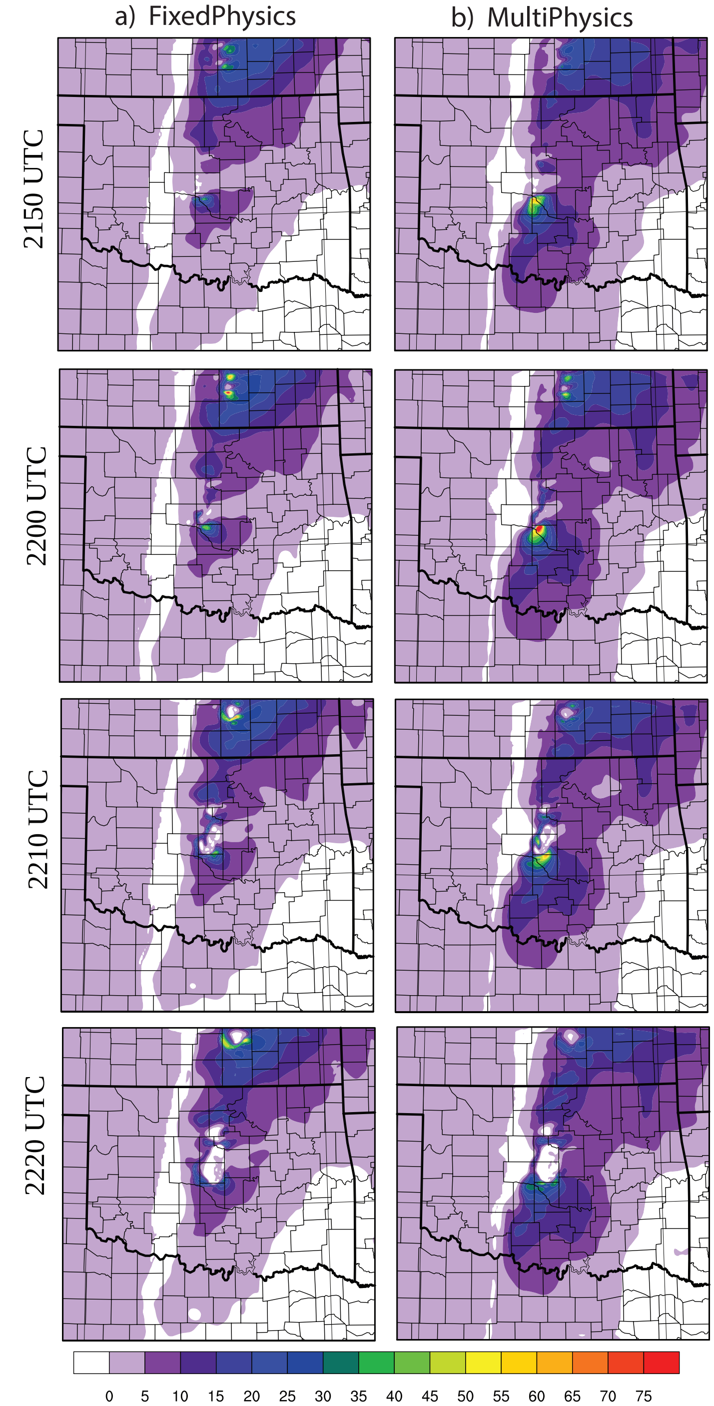
Publications

Yussouf, N., E. R. Mansell, L. J. Wicker, D. M. Wheatley, and D. J. Stensrud, 2013: The ensemble Kalman filter analyses and forecasts of the 8 May 2003 Oklahoma City tornadic supercell storm using single- and double-moment microphysics schemes. *Monthly Weather Review*, **141**, 3388-3412.

Yussouf, N., J. Gao, D. J. Stensrud, and G. Ge, 2013: The impact of mesoscale environmental uncertainty on the prediction of a tornadic supercell storm using ensemble data assimilation approach. *Advances in Meteorology*, in press. http://www.hindawi.com/journals/amet/aip/731647/

Awards

The Nusrat Yussouf et al. paper "The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes" was referred to NOAA/OAR Headquarters as a "Significant" contribution.



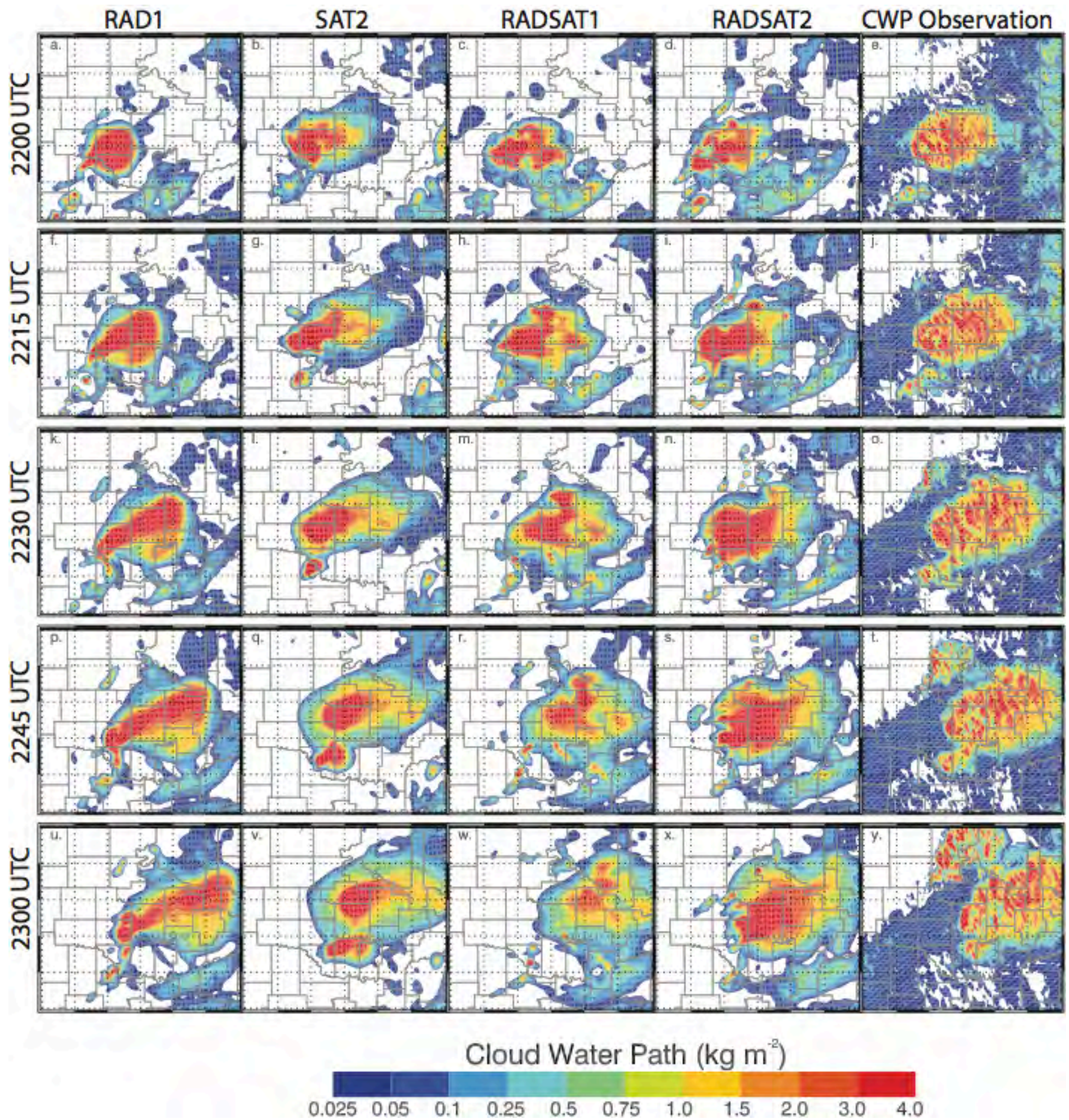
Ensemble-mean forecasts of significant tornado parameter (STP; colorfill, 5 increment) from FixedPhysics and MultiPhysics convective-scale experiments. The portion of the domain shown here is 306 x 363 km wide.

14. The Analyses and Prediction of a Supercell Storm from Assimilating Radar and Satellite Observations using Ensemble Kalman Filter Data Assimilation Technique

Matthew Vaughan (NOAA Hollings Scholar at NSSL), and Nusrat Yussouf and Thomas Jones (both CIMMS at NSSL)

A combined mesoscale and convective-scale WRF-ARW model based ensemble adjustment Kalman filter data assimilation system is used to explore the feasibility of assimilating GOES-East satellite-derived cloud water path (CWP) in addition to KTLX WSR-88D radar observations for short-range forecasts of the 8 May 2003 Oklahoma City tornadic supercell storm. The convective-scale ensemble is initialized from a mesoscale ensemble data assimilation system and four data assimilation and forecast experiments are conducted at convective-scale assimilating either only radar observations, only satellite observations, or both radar and satellite observations in two different combinations. All experiments initiate a supercell by the end of the assimilation period with unique reflectivity and near-storm environment characteristics. However, an experiment that assimilates both radar and satellite observations using initial conditions that have previous hour's satellite observations assimilated improves the near storm environment, reducing errors of downward shortwave flux and surface temperature when verified against Oklahoma Mesonet observations. In addition, this experiment produces the most realistic reflectivity structures and probability of updraft helicity track during the 1-h forecasts period. Overall results indicate that assimilating satellite observations in addition to radar into the convective-scale models may improve severe weather forecasting.

This project is completed.



Cloud water path (colorful) for the four experiments from the ensemble member that is closest to the ensemble mean at the 2200 UTC analyses. The last analyses at 2200 UTC are shown in the first row with 15 min forecasts valid at 2215, 2230, 2245, and 2300 UTC in the 2nd, 3rd, 4th, and 5th rows respectively. The last column is the GOES-12 CWP retrievals closest to the model output time.

15. Support NSSL Users on the Jet and Boomer HPC Environments

Gerald Creager (CIMMS at NSSL)

Various NSSL Forecasting Research and Development Division (FRDD) users have accounts on HPC resources within NSSL, at the Earth Systems Research Laboratory (NOAA/OAR/ESRL) in Boulder, Colorado, and on the University of Oklahoma's Boomer HPC installation, which as a part of the OU Supercomputing Center for Education and Research (OSCER) project. Working across various resources, with differing methods of operation, facilities, and software can often become a difficult task. Over the reporting period, local, in-house support has been implemented that allows NSSL FRDD users to request help from a single, local point of contact who is familiar with all of the systems, and can offer direct support on an immediate basis. In addition, a positive working relationship has been created where rapid technical-level information can be exchanged, allowing the local facilitator to obtain answers to problems and questions in a manner that is usually faster than the normal trouble-ticket system.

In addition, the close working relationship with technical management at the various centers has allowed access to additional resources that were not originally available to FRDD personnel, including additional disk allocations on the Jet HPC system at ESRL, and additional computing resources at OSCER.

Creager also assumed responsibility for requesting and managing the paperwork associated with computer allocations at ESRL (e.g., the Jet HPC cluster) and with determining requirements for Division computing thereon. An ongoing process of documentation of the scripts/workflow for the NSSL Mesoscale Ensemble remains a work-in-progress. The result will be a web site with documentation of each of the scripts, a set of definitions of functions, a list of all utilized data sets, and a flowchart of operations.

This project is ongoing.

16. Support the Development and Testing of Forecast Verification/Diagnostics for Warn-on-Forecast and Hazardous Weather Testbed Applications

Adam Clark (CIMMS at NSSL)

Verification, visualization, and new forecast diagnostic methods are being developed and tested for severe weather forecasting applications. These methods emphasize the attributes of explicitly forecast storms from high-resolution (i.e., 4 km grid-spacing or less) numerical weather prediction models. In addition, the sensitivity to model physics of pre-convective severe weather environments and larger scale features (e.g., drylines) important for convection is being examined. Much of this work is incorporated in the spring Hazardous Weather Testbed (HWT) Experimental Forecasting Program (EFP), as well as within the real-time, 4-km grid-spacing experimental version of the WRF

model knows as the NSSL-WRF, which is run locally and utilized by the SPC for operational severe weather forecasting.

To expand and accelerate the development of object-based time-domain diagnostics for verifying convection-allowing forecasts, Clark worked with the Developmental Testbed Center (DTC) through their visitors program to test/implement MODE-TD (Method for Object-based Diagnostic Evaluation – Time Domain) using HWT forecast data. Specifically, MODE-TD was using to evaluate characteristics of forecast rainfall systems such as translation speed, timing of initiation/dissipation, and diurnal cycle of system frequencies in 4-km grid-spacing configurations of the WRF model that differed only by their microphysics parameterizations.

As part of another DTC visitor's program project, Clark developed a method for identification, tracking, and visualization of simulated supercells in high-resolution models using MODE-TD. The method will be applied and tested during the EFP and within the real-time NSSL-WRF model. The method utilizes a newly developed technique for extracting updraft helicity from high-resolution models at 5-minute intervals.

A study was completed that focused on evaluating the 24 hour forecast position of drylines over a 5 year period in the NSSL-WRF model and the operational North American Mesoscale (NAM) model. A significant eastward bias in the forecast dryline position in the NSSL-WRF was documented, while the NAM model did not have any systematic biases. Additionally, in a related study, the sensitivity of the forecast dryline position to the boundary layer parameterization used in the WRF model is being examined.

For the 2013 EFP collaboration with the United Kingdom Met Office (UKMET) was established. This collaboration involved applying and evaluating 4.4- and 2.2-km grid-spacing nested versions of UKMET's Unified Model integrated over a domain encompassing most of the US. In subjective comparisons with the NSSL-WRF, it was found that in a majority of cases the high-resolution version of the Unified Model performed better than the NSSL-WRF.

As part of the 2013 EFP, a parallel or "hot-start" version of the NSSL-WRF that was initialized by a member of an Ensemble Kalman Filter-based 18-km grid-spacing mesoscale analysis system was compared to the regular NSSL-WRF. From subjective evaluations, it was found that neither model performed better. However, it was noted that there were often very large differences in the forecasts.

For improved visualization of high-resolution forecasts, an interactive web display utilizing Google-maps-like features and GIS was developed in collaboration with Chris Karstens. The web display allows zooming, overlaying of chosen fields, and side-by-side comparisons of model and observational fields, and was tested during the 2013 EFP. Several of the projects described above utilized this data explorer.

Much of the work behind these projects is ongoing.

Publications

Clark, A. J., J. Gao, P. T. Marsh, T. Smith, J. S. Kain, J. Correia, M. Xue, and F. Kong, 2013: Tornado pathlength forecasts from 2010 to 2011 using ensemble updraft helicity. *Weather and Forecasting*, **28**, 387-407.

Coffer, B. E., L. C. Maudlin, P. G. Veals, and A. J. Clark, 2013: Dryline position errors in experimental convection-allowing NSSL-WRF model forecasts and the operational NAM. *Weather and Forecasting*, **28**, 746-761.

Kain, J. S., M. C. Coniglio, J. Correia, A. J. Clark, P. T. Marsh, C. L. Ziegler, V. Lakshmanan, S. D. Miller, S. R. Dembek, S. J. Weiss, F. Kong, M. Xue, R. A. Sobash, A. R. Dean, I. L. Jirak, and C. J. Melick, 2013: A feasibility study for probabilistic convection initiation forecasts based on explicit numerical guidance. *Bulletin of the American Meteorological Society*, **8**, 1213-1225.

Lynn, B. H., Y. Yair, C. Price, G. Kelman, and A. J. Clark, 2012: Predicting cloud-to-ground and Intracloud lightning in weather forecast models. *Weather and Forecasting* **27**, 1470-1488.

Schumacher, R. S., A. J. Clark, M. Xue, F. Kong, 2013: Factors influencing the development and maintenance of nocturnal heavy-rain-producing convective systems in a storm-scale ensemble. *Monthly Weather Review*, **141**, 2778-2801.

Awards

The Adam Clark et al. paper “Tornado Pathlength Forecasts from 2010 – 2011 Using Ensemble Updraft Helicity” was referred to NOAA/OAR Headquarters as a “Significant” contribution. Subsequently, this paper was featured on the NOAA/OAR Research website.

Adam Clark was awarded the Mark and Kandi McCasland Award for Outstanding Undergraduate Research for his role as mentor to three undergraduate students that completed their Capstone course at OU.

17. Support Ensemble Verification using Object Based Approaches for Defining Storms and Storm Characteristics as Proxies for Severe Weather

James Correia Jr. (CIMMS at SPC)

Ensemble Verification of proxy severe storm reports: The Storm-Scale Ensemble of Opportunity (SSEO) was used to produce first guess severe storm probabilities similar to the Day 2 convective outlook. An object based approach utilizing updraft helicity tracks were used as proxies for severe storm reports and were verified with observed wind, hail and tornado reports. An analysis by month for all of 2012 was conducted to evaluate the proxy method and ensemble skill. Preliminary results suggest that springtime skill is much higher than late summer skill. Analyses were conducted with the help of a Research Experience for Undergraduates student and work is ongoing.

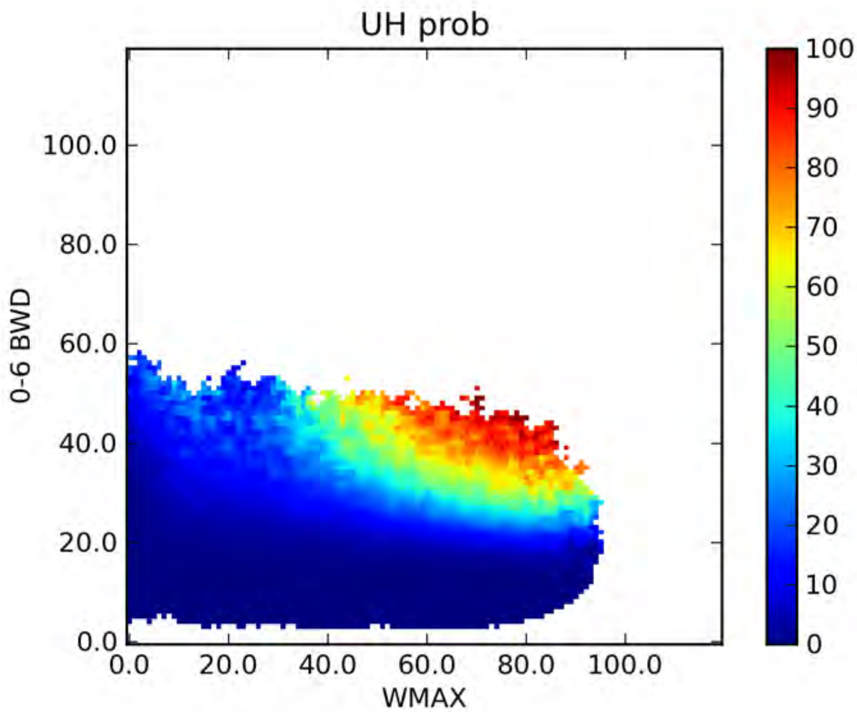
A four year climatology of simulated convective storms from NSSL WRF: A ~4 year (June 2009 thru April 2013, 1200 UTC-1200 UTC) climatology of simulated convective storms is constructed from the experimental NSSL ARW using an object based approach. A limited sensitivity analysis is conducted to test composite reflectivity (CREF) thresholds and storm areas. Choosing slightly higher thresholds (34 vs. 30 dBz) reduces storm size but increases the number of storms; however this has very little

effect on storm-size spectra for those storms containing hourly maximum updraft helicity values at or exceeding 25 m^2/s^{-2}. This is indicative of identifying more storm cores using higher thresholds.

Storm attributes are codified in terms of the maximum convective available potential energy (CAPE) and maximum 0-6 km shear in the hour preceding the storm. Two-dimensional histograms are constructed in the CAPE-shear parameter space to examine characteristics of the model environment relative to severe weather proxy variables used in the HWT Spring Experiment. The relationship between hourly maximum variables including updraft helicity (UH), 10-m wind speed, vertically integrated graupel (GR), and updraft speed (UP) are quantified.

Preliminary results indicate that updraft helicity ≥ 25 m^2s^{-2} in individual storms is present nearly fifty percent of the time when simulated storms have 10-m wind speeds >= 20 ms^{-1}, updraft speeds ≥ 26 ms^{-1}, GR ≥ 35 kg m^{-2}, and CREF ≥ 55 dBz. Additionally, storms meeting this UH threshold frequently occur in high deep-layer shear environments (>20 ms^{-1}) with relatively lower dependence on CAPE. This relationship is modified somewhat for GR and UP where there is more dependence on CAPE especially above 1800 J kg^{-1}.

This project is ongoing.



The smoothed probability that Updraft Helicity will exceed 25 m^2s^{-2} given a storm with maximum 0-6 km bulk wind difference (BWD) and maximum Wmax (derived from CAPE). The highest probabilities are confined in the upper right and have more dependence on BWD than Wmax.

18. Evaluation of Total Lightning Data Assimilation Algorithm Within the WRF Framework

Alexandre Fierro (CIMMS at NSSL), Don MacGorman, Ted Mansell, Conrad Ziegler, and Jack Kain (all NSSL), Scott Dembek (CIMMS Visiting Scientist), and Valliappa Lakshmanan (CIMMS at NSSL)

A new cloud-scale total lightning data assimilation algorithm was implemented within the WRF-ARW model as part of the GOES-R/JCSDA mission. Lightning data assimilation forces deep, moist precipitating convection to occur in the model using a nudging function for the total lightning data, which locally increases the water vapor mixing ratio (virtual potential temperature) via a computationally inexpensive smooth continuous function using gridded pseudo-GOES-R resolution (9 km) total flash rate (from EarthNetworks®) and simulated graupel mixing ratio as input variables.

The evaluation of this algorithm was conducted in two steps. The first step consisted in comparing the performance of the lightning data assimilation algorithm against a state-of-the-art cloud-scale variational assimilation technique (i.e., 3DVAR). The project employed the ARPS 3DVAR code which features a WRF interface to permits its use in WRF-ARW. Results for one particular high impact weather case study (29-30 June 2012 “super derecho”) demonstrated the value of the computationally inexpensive lightning data assimilation algorithm, which could easily be used in tandem with more sophisticated and CPU intensive variational codes. The second step of this work aimed at evaluating the performance of this lightning data assimilation algorithm over CONUS for a large sample of thunderstorms days using the WRF-NSSL framework. Real-time CONUS simulations were successfully completed for 60+ days during the spring and early summer. Daily summary of the performance of the lightning data assimilation algorithm were provided on a daily basis to the project collaborators/mentors as well as to the HWT program participants for their daily map discussions. The output of all the runs (as well as the control simulations) were archived for more detailed analysis, which will form as one of the milestones of an upcoming GEOS-R proposal call.

This research is ongoing.

Publications

Fierro, A. O., J. Gao, C. Ziegler, E.R. Mansell, D. R. MacGorman and S. Dembek 2013: Evaluation of a cloud scale lightning data assimilation technique and a 3DVAR method for the analysis and short term forecast of the 29 June 2012 derecho event. *Monthly Weather Review*, accepted.

Fierro, A. O., E.R. Mansell, C. Ziegler and D. R. MacGorman 2013: The implementation of an explicit charging and discharge lightning scheme within the WRF-ARW model: Benchmark simulations of a continental squall line, a tropical cyclone and a winter storm. *Monthly Weather Review,* **41**, 2390-2415.

Fierro A. O. and L. M. Leslie 2013: Links between Central Western Australian rainfall variability and large-scale climate drivers**.** *Journal of Climate,* **26***,* 2222-2246*.*

Fierro A. O. and L. M. Leslie 2013: Relationships between southeast Australian temperature anomalies and large-scale climate drivers. *Journal of Climate*, conditionally accepted.

Griffin E. M., T J Schuur, D. M MacGorman, M. R Kumjian and A. O Fierro, 2013: A polarimetric and electrical analysis of the overland reintensification of Tropical Storm Erin (2007), *Monthly Weather Review*, to be submitted.

Awards
Alexandre Fierro was awarded 2012 Editors' Citation for Excellence in Refereeing for *Geophysical Research Letters.*

NSSL Project 4 – Hydrologic Modeling Research

NOAA Technical Lead: J.J. Gourley (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives
Two subprojects, Flooded Locations and Simulated Hydrographs (FLASH) and Coastal, Inland FLood Observation and Warning (CI-FLOW) focus on inland flash flooding and tidal flooding, respectively. The FLASH subproject produces real-time flash flooding simulations at high temporal and spatial resolution for the entire coterminous United States. CI-FLOW yields water level predictions for watersheds influenced by tides. The objectives of this project are to improve scientific understanding of flash flooding events and to demonstrate the applicability of a modern hydrologic modeling framework to operational flash flood forecasting. This is achieved by first demonstrating that FLASH can run reliably in real-time and then by evaluating the skill of FLASH and CI-FLOW versus the skill of the operational tools currently used for flash flooding and water levels in tidal basins.

Accomplishments

1. Flooded Locations and Simulated Hydrographs (FLASH) Demonstration

J.J. Gourley (NSSL), and Humberto Vergara-Arrieta and Race Clark (OU School of Meteorology at CIMMS)

The FLASH system has been continually generating real-time flash flooding simulations over the conterminous United States at 1-km, 5-min resolution since October 2012 (with products archived starting in March 2013). These outputs are available at http://flash.ou.edu and have been experimentally demonstrated to forecasters at NCEP's Weather Prediction Center and other operational centers. During the project period, *a priori* parameters for the distributed hydrologic model were finalized. Additional products for display on the FLASH website have been developed and demonstrated, including direct streamflow simulations, modeled soil saturation, precipitable water analyses, precipitable water anomalies, Flash Flood Guidance to QPE ratios, precipitation recurrence intervals, and flood analyses from the MODIS satellite system. These products can all be compared with flash flooding observations and reports

including NWS Local Storm Reports, NWS Flash Flood Warnings, and public reports submitted to the Meteorological Phenomena Identification Near the Ground (mPING) system.

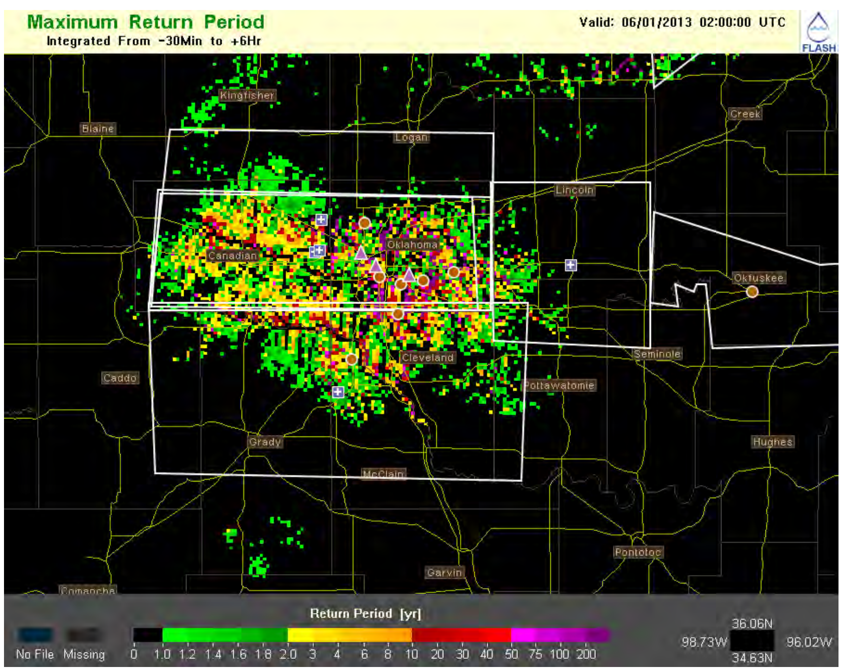
This project is ongoing.

2. Evaluation of FLASH Outputs

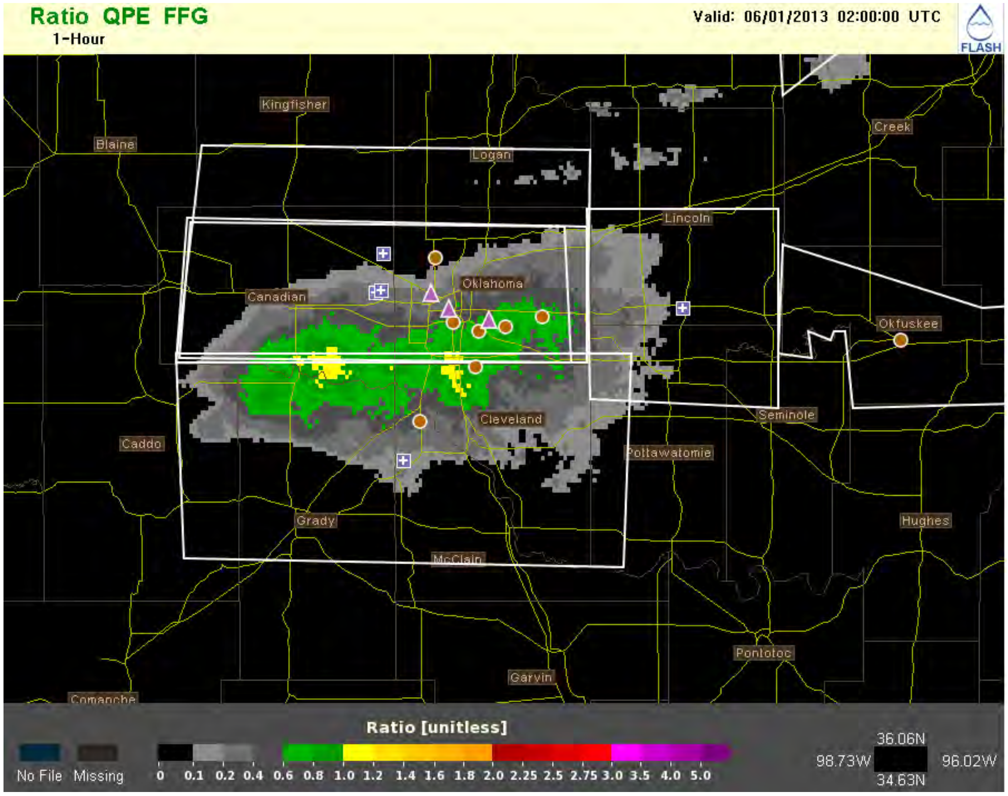
J.J. Gourley (NSSL), and Race Clark and Humberto Vergara-Arrieta (OU School of Meteorology at CIMMS)

The framework for subjective and objective evaluations of FLASH outputs has been developed. The subjective evaluation occurs via a survey of forecasters from the Weather Prediction Center, River Forecast Centers, and Weather Forecast Offices, and researchers from NSSL, ESRL, and the NWS Office of Hydrologic Development. This survey instrument was developed at NSSL and CIMMS in cooperation with the Weather Prediction Center. The objective evaluation for FLASH follows an identical procedure to the FFG evaluation performed under this project in FY2012.

This project is ongoing.



Example FLASH forecast (valid 1 June 2013, 0200 UTC) for the deadly 31 May 2013 flash flooding event in Oklahoma City, OK. FLASH correctly identifies the area of greatest concern for dangerous flash flooding impacts over southern Oklahoma County and extreme northern Cleveland County. White boxes represent valid Flash Flood Warnings from the Norman NWS with the centroid of each box marked by a plus sign. Local Storm Reports of flash flooding are marked with the red circles, and mPING flash flooding reports are marked with the purple triangles.



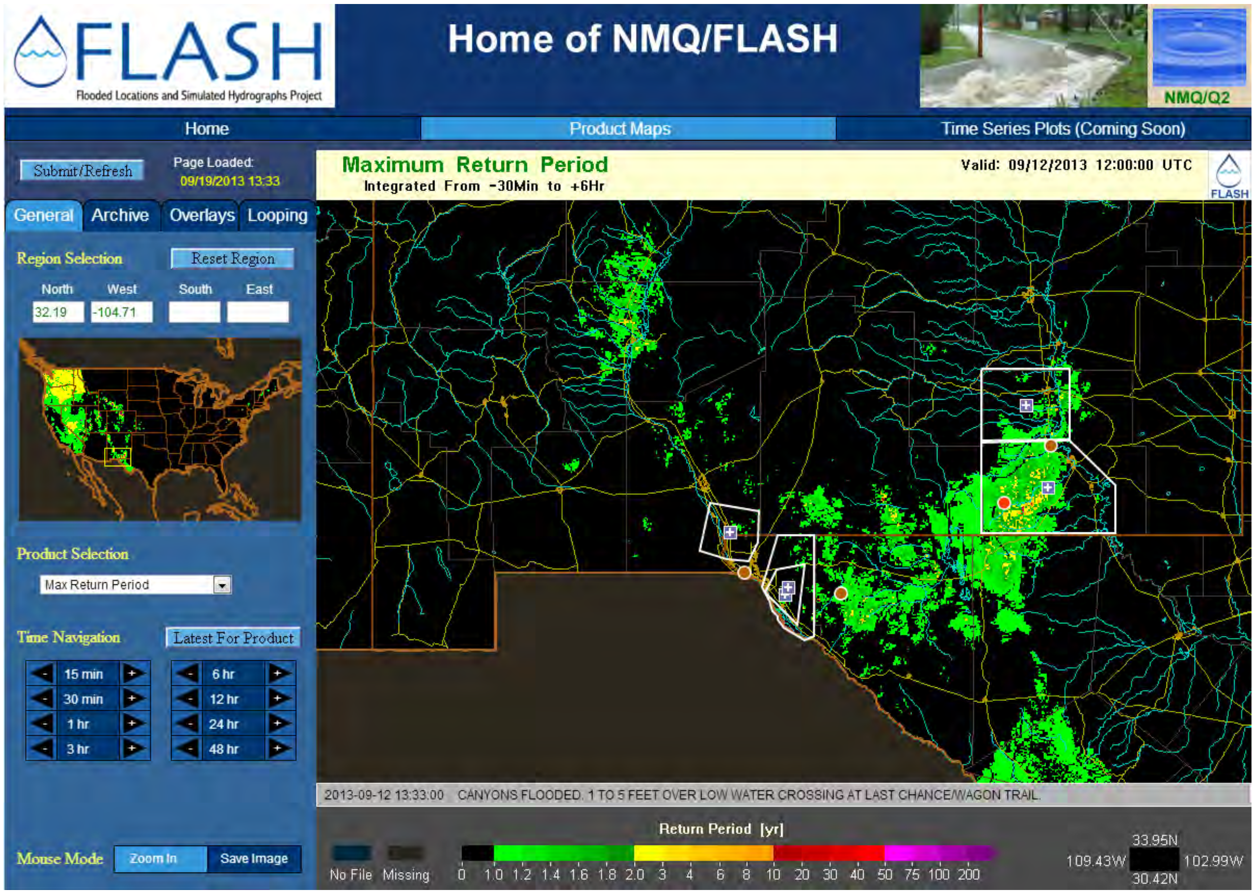
Example 1-hr QPE to Flash Flood Guidance ratio product valid on 1 June 2013 at 0200 UTC. There were 12 flood fatalities in southern Oklahoma County during this event, but FFG forecasts only minor flash flooding (the yellow pixels) and places it south of where the most extreme impacts were observed.

3. Creating Display Web Tools for the FLASH Project to Predict and Monitor Flooding

Brian Kaney (CIMMS at NSSL)

A set of display tools was created for the products of the FLASH product. Maps of the Hydrologic products of the system can be viewed with overlays flash flood warning polygonal regions, local storm reports and mPING flood reports. These were an important tool for rapid assessment and selection of events during the Flash Flood and Intense Rainfall (FFaIR) experiment in the summer of 2013. The figure below shows a screen shot of the display.

This project is ongoing.



Screen shot of the FLASH web page.

4. Evaluation of CI-FLOW Outputs

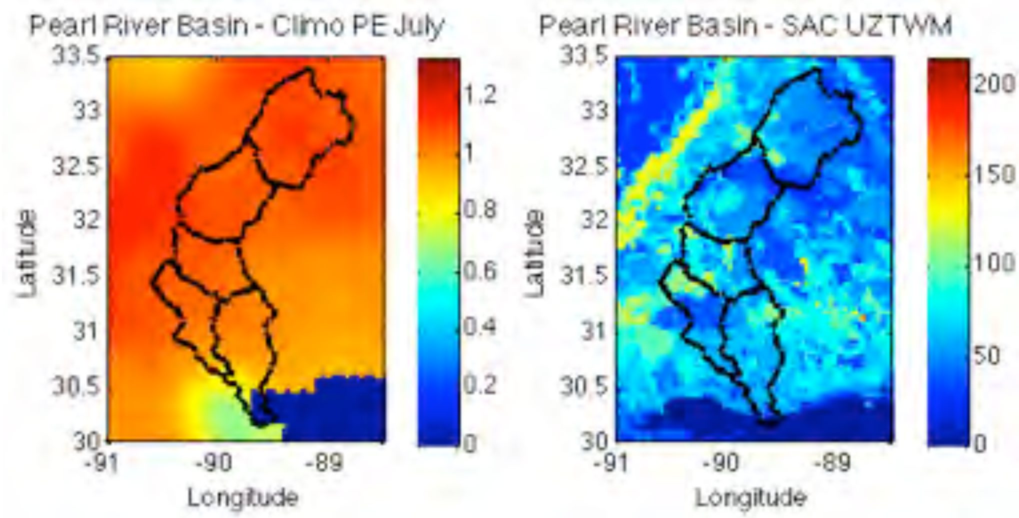
J.J. Gourley (NSSL) and Humberto Vergara-Arrieta (OU School of Meteorology at CIMMS)

a. Set-up and Configuration of the Hydrology Laboratory – Research Distributed Hydrologic Model (HL-RDHM) on Pearl River Basin in Mississippi

Server Hosting HL-RDHM. The previous set-up of HL-RDHM for research on the hydrologic modeling of Tar-Pamlico River and Neuse River basins was done in a server hosted by The University of Oklahoma's Supercomputing Center for Education and Research (OSCER). This server has recently been replaced, which required HL-RDHM to be moved to a new computing host. The new server hosting HL-RDHM is located in the NWC. It is part of the computer resources of the ARRC and the Hydrometeorology and Remote-Sensing (HyDROS) laboratory in The University of Oklahoma. HL-RDHM and required datasets have thus been transferred, re-compiled and tested for correct functioning.

Data Collection for Pearl River Basin Set-Up. Most of the datasets required by HL-RDHM are in place on the server, namely input data (i.e. potential evaporation and precipitation grids) and parameters of the water balance model (i.e. Sacramento Soil Moisture Accounting model - SAC-SMA; see figure below). Datasets related to the flow routing component of HL-RDHM were acquired through the Lower Mississippi River Forecast Center (LMRFC). 15-min streamflow observations were collected for verification and model adjustment purposes.

These projects are ongoing.

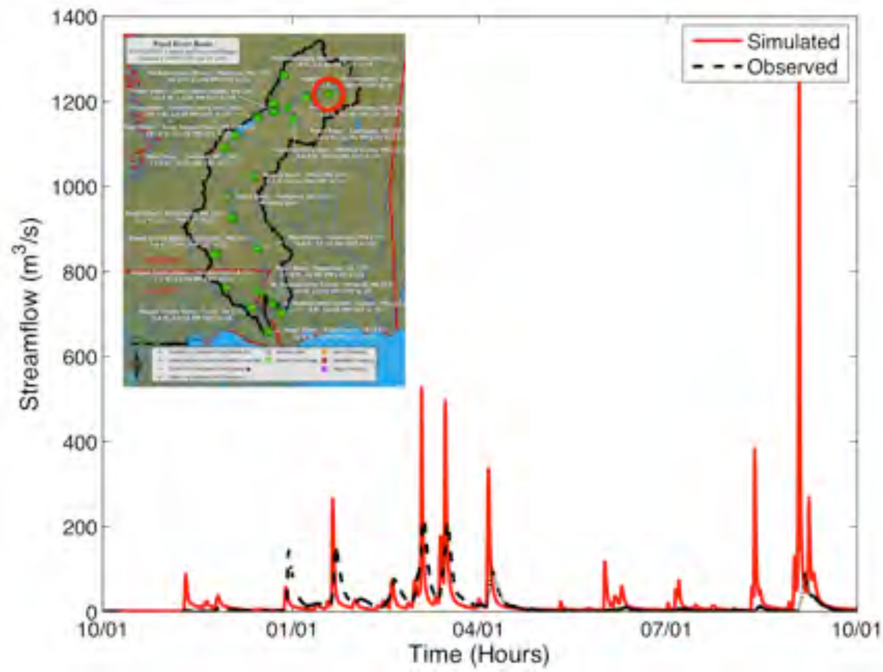


Sample of HL-RDHM data sets for Pear River basin set-up: Left Panel - Climatological Potential Evaporation (Climo PE, mm/day – monthly mean), Right Panel – The Upper Zone Tension Water Capacity (UZTWM) parameter of SAC-SMA model in HL-RDHM.

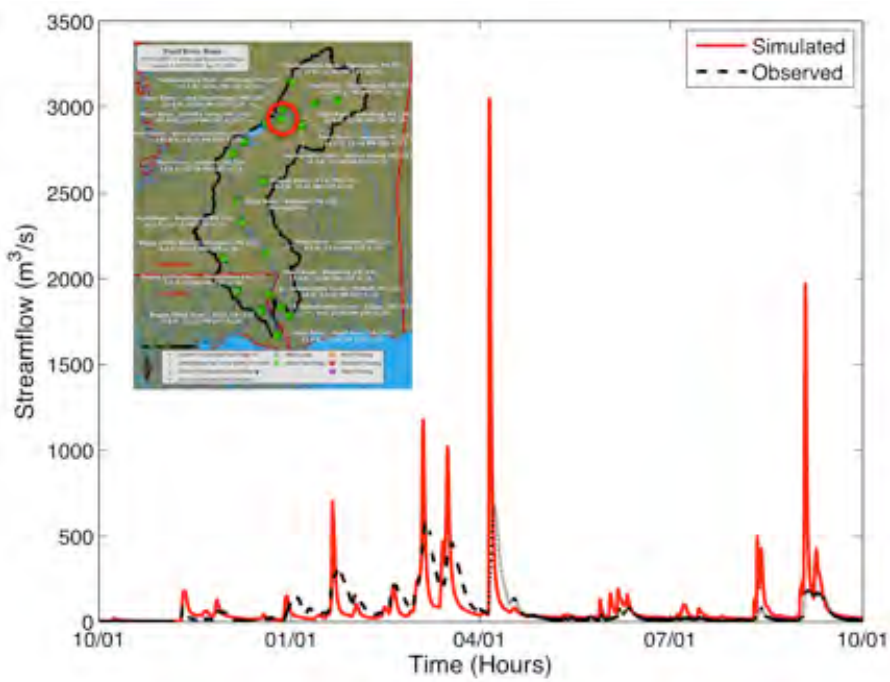
b. Testing and Benchmarking HL-RDHM on Pearl

The distributed hydrologic model HL-RDHM has been set-up on the Pearl River basin in Louisiana. Initial test runs indicate that the model has been successfully configured to generate streamflow at any location within the watershed. We have worked on benchmarking the skill of the baseline (uncalibrated) model at different gauged locations, primarily on the main stem (see three figures below). These preliminary results indicated that the baseline model performs reasonably well. Moreover, the skill appears to be consistent across spatial scales. Further evaluations will be performed at other stations on the main stem and on the different main tributaries of Pearl River.

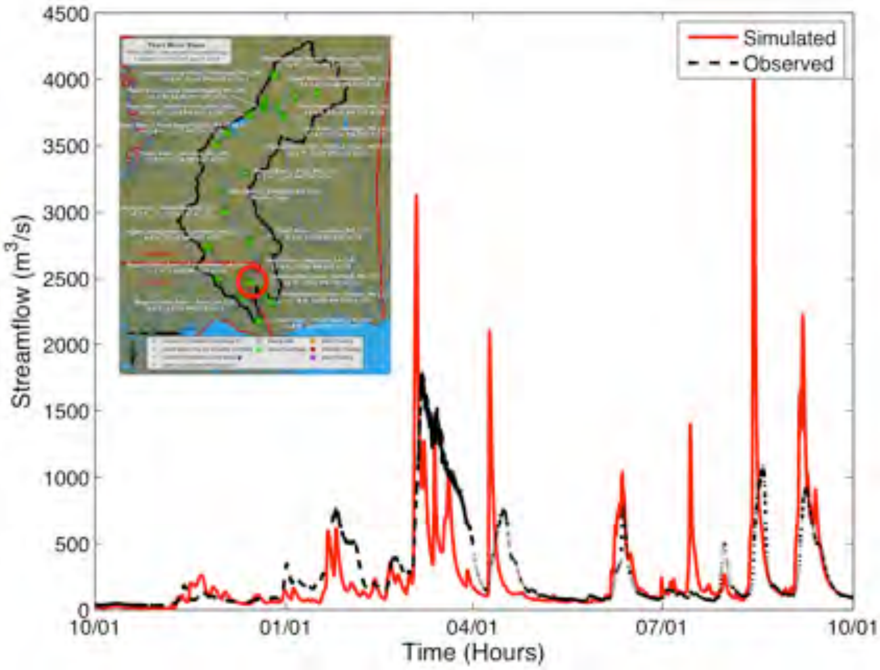
This project is ongoing.



Streamflow simulation for the water year 2000-2001 on Pearl River at Burnside (near Philadelphia; PLAM6 – USGS 02481880). The area draining to this location is ~ 1,347 km^2.



Streamflow simulation for the water year 2000-2001 on Pearl River at Lena (Good Hope; GDHM6 – USGS 02483500). The area draining to this location is ~ 5,131 km^2.



Streamflow simulation for the water year 2000-2001 on Pearl River near Bogalusa (BXAL1 – USGS 02489500). The area draining to this location is ~ 17,024 km^2.

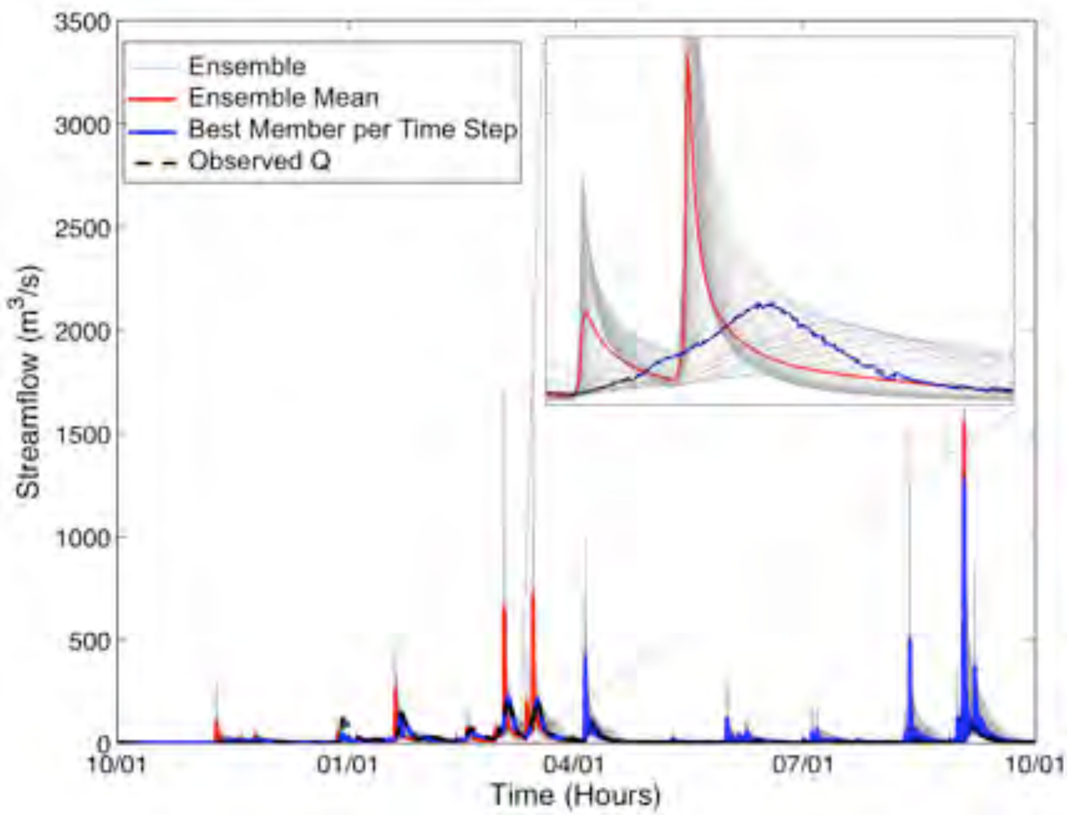
c. Ensemble-Based Predictions: Accounting for Parametric Uncertainty

Streamflow predictions at handoff locations and, in general, at any other locations will be done through ensembles. This strategy is one of the most important outcomes from the research performed over Tar River basin in North Carolina. Accounting for uncertainty in parameters through ensembles have proved to yield better results than those from deterministic modeling. Furthermore, this strategy will enable us to implement data assimilation techniques suitable for operational settings, such as the Ensemble Kalman Filter (EnKF).

Initial results from the benchmarking simulations indicate that the main source of uncertainty in the parameters of the model come from the routing. These results are consistent with what was observed over the Tar River basin in North Carolina. Therefore, we have started generating ensembles by perturbing the routing parameters (see figure below).

The subsequent steps in this research include experimentation on adding perturbations to different components of the modeling system (e.g. water balance parameters and/or quantitative precipitation estimates).

This project is ongoing.



Ensemble prediction for the water year 2000-2001 on Pearl River at Burnside (near Philadelphia; PLAM6 – USGS 02481880). The interior box shows a particular event between March and April 2001.

NSSL Project 7 – Synoptic, Mesoscale and Stormscale Processes Associated with Hazardous Weather

NOAA Technical Leads: Jack Kain, Don MacGorman, Ted Mansell, and Conrad Ziegler (all NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives

Contribute to a weather-ready nation by improving forecast ability/understanding for winter and springtime convective storms; complete the implementation of a new explicit, physics-based lightning prediction model within the WRF-ARW model as a significant step towards improving high impact weather forecasts within convection-resolving models.

Accomplishments

1. Explicit Forecast of Lightning Threats Within the WRF Framework

Alexandre Fierro (CIMMS at NSSL), and Don MacGorman, Ted Mansell, and Conrad Ziegler (all NSSL)

This implementation is motivated by the upcoming launch of the GOES-R in 2015, which will be equipped with the Geostationary Lightning Mapper (GLM) instrument capable of mapping total lightning (CG + intra-cloud) day and night, year-round with a nearly uniform resolution over the Americas ranging between 8 and 12 km. The simulated lightning flash density rates will be used in tandem with observed GLM lightning data within a statistical ensemble Kalman filter package to improve short term forecast of convection. The use of the lightning in the filter will allow to effectively improve the placement and evolution of the convection while suppressing spurious convection outside the lightning areas.

Lightning threats are currently diagnosed from model variables known to be well correlated with the occurrence of lightning (e.g., graupel mixing ratio, ice water content). To alleviate this need and provide a more physically sound approach to this problem, a new charging/discharge model has been successfully implemented into the WRF-ARW model with explicit solve for the ambient electric field via a computationally efficient MPI Multigrid elliptic solver developed at The Los Alamos National Laboratory. The lightning module features in-cloud inductive/polarization charging and non-inductive microscopic charging coupled with a bulk 2D and 3D discharge scheme. Cloud-scale (3-km) simulations of a wide variety of weather systems were conducted successfully and recently published.

This project is ongoing.

Publications

Fierro, A. O., E.R. Mansell, C. Ziegler, and D. R. MacGorman 2013: The implementation of an explicit charging and discharge lightning scheme within the WRF-ARW model: Benchmark simulations of a continental squall line, a tropical cyclone and a winter storm. *Monthly Weather Review,* **141**, 2390-2415.

Fierro, A. O., J. Gao, C. Ziegler, E.R. Mansell, D. R. MacGorman, and S. Dembek 2013: Evaluation of a cloud scale lightning data assimilation technique and a 3DVAR method for the analysis and short term forecast of the 29 June 2012 derecho event. *Monthly Weather Review*, accepted.

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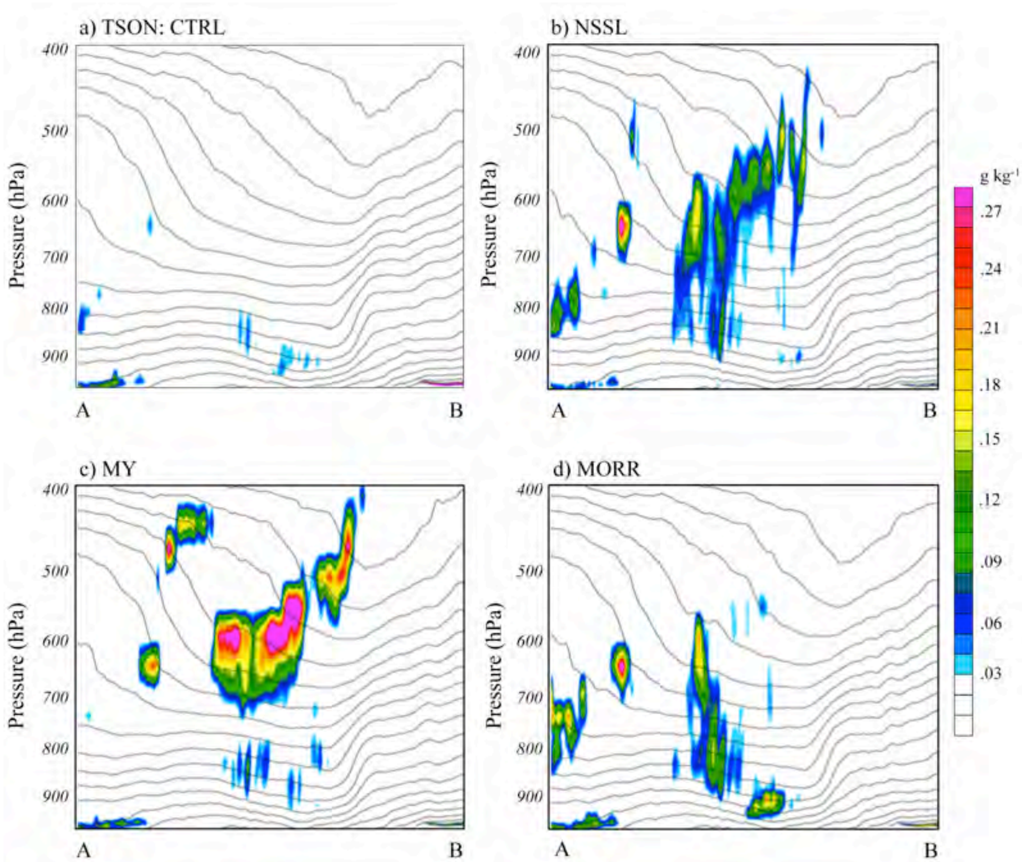
Griffin E. M., T. J. Schuur, D. M. MacGorman, M. R. Kumjian, and A. O. Fierro, 2013: A polarimetric and electrical analysis of the overland reintensification of Tropical Storm Erin (2007). *Monthly Weather Review*, to be submitted.

2. Effects of the Choice of Microphysical Parameterization on the Presence of Supercooled Liquid Water in Winter Storms

Heather Reeves (CIMMS at NSSL) and Kristen Cassady (OU School of Meteorology)

Different microphysics parameterization schemes are tested to assess how their distributions of supercooled liquid water (SLW) compare for several different winter storms. Particular interest was paid to the effects of increasing the number of moments. Results show that the Thompson scheme (which is used operationally by the FAA) has a low SLW bias. Increasing the number of moments does increase the amount of SLW via size sorting and its consequences on scavenging of SLW by snow.

This project is ongoing.



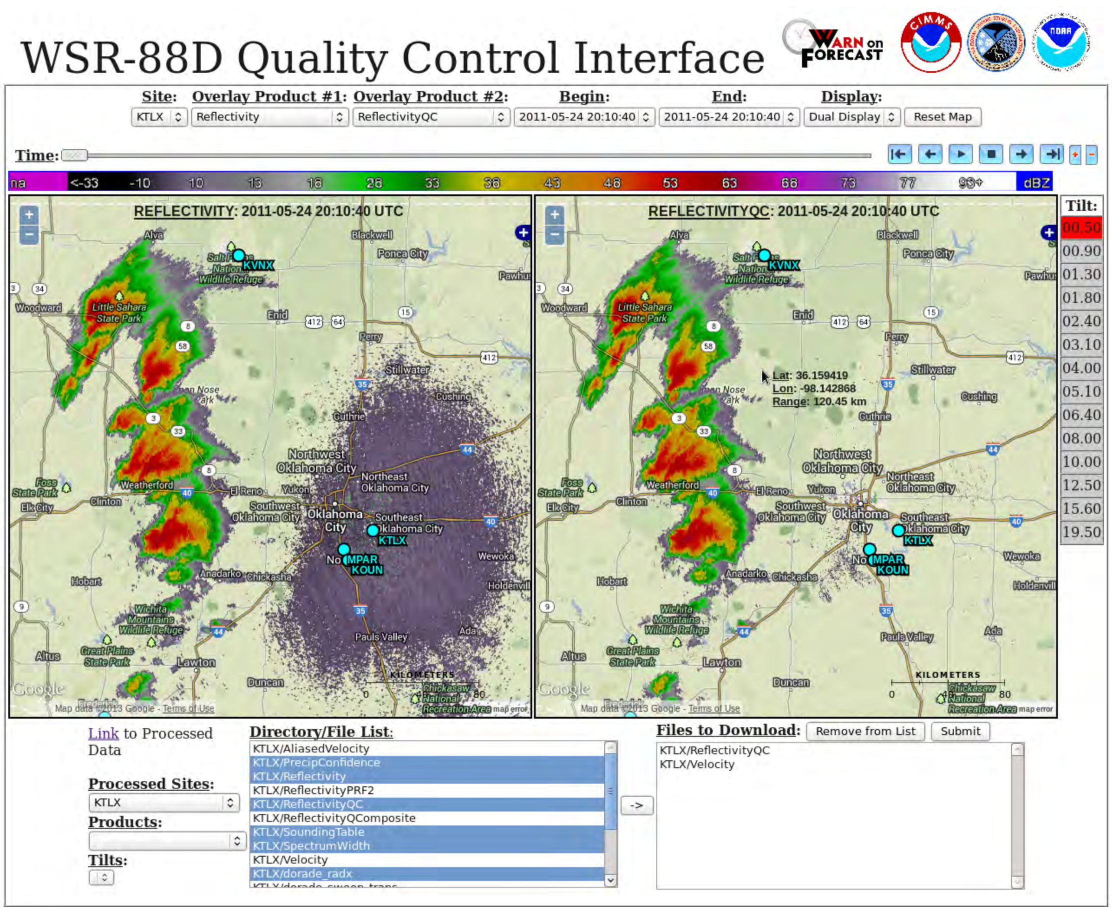
The 9-h forecast cloud water mixing ratio (shaded) and equivalent potential temperature (K; contoured) valid at 0300 UTC 26 Jan 2013. Cross sections are taken along the center axis of a comma-head snowstorm. Microphysical parameterization schemes included in this figure are the Thompson (a; TSON), National Severe Storms Laboratory Scheme (b; NSSL), Milbrandt-Yau (c; MY), and Morrison (d; MORR)

3. Radar Quality Control for Storm-Scale and Mesoscale Data Assimilation and Modeling

Chris Karstens (CIMMS at NSSL)

A major aspect of storm-scale and mesoscale modeling is the assimilation of quality-controlled observations (e.g., surface and upper-air data, radar data). During FY13, individual requests were fulfilled for quality-controlled radar data, including the following cases: 5 Dec. 2010, 19 May 2010, and 24 May 2011. Work began on manual quality control of radar data from the 24 May 2011 case (for use by participants in Warn-on-Forecast). In addition, a web-interface was developed that allows researchers to generate automated quality-controlled radar datasets at their leisure (see figure below). This interface makes available several algorithms, both operational and experimental (e.g., WDSS-II, AR-VAD), and numerous output formats (e.g., binary, netCDF, foray netCDF, dorade sweep, shapefile) for importing into data assimilation software.

This project is ongoing.



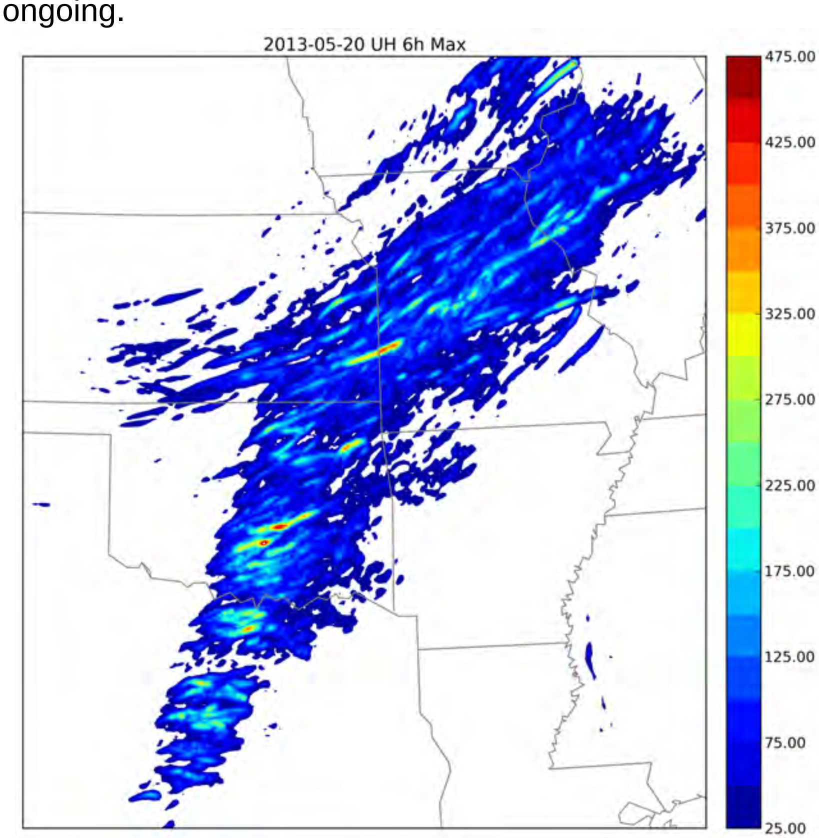
Screen capture of the web-interface for automated radar data quality control.

4. Hazardous Weather Testbed (HWT) Support

James Correia (CIMMS at SPC)

HWT support activities included preparing for ingest and plotting of convective initiation products generated by NSSL for use in N-AWIPS. Object based techniques were developed and applied to identify storm attributes in three distinct ensemble systems using the updraft helicity parameter. These were used during forecasting to assess ensemble skill in the timing of severe weather regimes. Refinement of updraft helicity parameters was added to cover mini supercells. Other parameters such as hail were explored using the same technique but were not as successful. Investigation continued on the utility of PBL vertical velocities for identification of boundaries aloft and other turbulent regimes thought to initiate convection.

This project is ongoing.



Forecast maximum updraft helicity (UH) from any CAPS ensemble member on 20 May 2013 from 18-00 UTC. The relatively rare values above 300 m2s-2 in multiple UH tracks supported the idea that a handful of storms (only a few ensemble members simulated tracks like these) would be capable of producing significant severe weather including tornadoes.

Publications

Clark, A. J., J. Gao, P. T. Marsh, T. Smith, J. S. Kain, J Correia Jr, M. Xue, and F. Kong, 2013: Tornado pathlength forecasts from 2010 to 2011 using ensemble updraft helicity. *Weather and Forecasting*, **28**, 387-407.

Coniglio, M. C., J. Correia Jr., P. T. Marsh, and F. Kong, 2013: Verification of convection allowing WRF model forecasts of the planetary boundary layer using sounding observations. *Weather and Forecasting*, **28**, 842-862.

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5. Storms, Forms, and Complexity of the Urban Canopy: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather

David Stensrud (NSSL), Kristin Calhoun (CIMMS at NSSL), and Larissa Reames, Bethany Hardinski, Jonathan King, and Paul Downes (all OU School of Meteorology at CIMMS)

The urbanization process and its manifold influences on weather have been understudied to date, particularly for small to mid-sized cities. Of particular societal concern are the vulnerabilities of human settlements to various forms of severe weather. This project explores the hypothesis that storms of a certain size and intensity respond to the various and variable biogeophysical imprints of the urbanized area, and depend on city size, shape, activity, and on the landscape matrix that embeds the urbanized area. The interdisciplinary research team from multiple organizations on this project spans multiple fields including terrestrial and atmospheric remote sensing, landscape ecology, urban and landscape planning, and meteorological modeling and radar analysis with the goal of synthesizing these results to develop an integrated assessment of the role of urban size and form on atmospheric phenomena in the US Great Plains. The primary focus of this project is the characterization of observed storms in urban areas and meteorological simulations.

To go beyond analyses of storm reports, which are inherently biased towards population centers, NEXRAD radar data is used to provide a nearly continuous evolution of storm severity, from convective initiation through storm dissipation. An initial exploration of radar data surrounding Oklahoma City was performed in year one to determine the best methodology for radar data quality control, storm tracking, and processing of multiple severe weather proxy algorithms (including hail size and rotational velocity estimation).

Following this initial processing to tune the methodology, three meteorology undergraduate students (Hardinski, King, and Downes) at OU were hired to complete NEXRAD radar data processing for 10 years of data over multiple cities in the southern plains. The students began full-time work on 28 May 2013 and are in the process of compiling a list of severe storm events for the following cities: Minneapolis-St. Paul, Dallas-Ft. Worth, Omaha, and Oklahoma City. For each of the events, the students examine WSR-88D reflectivity data from the radar in closest proximity to a given city (e.g., KTLX – Oklahoma City) to judge the suitability of the storm event. This

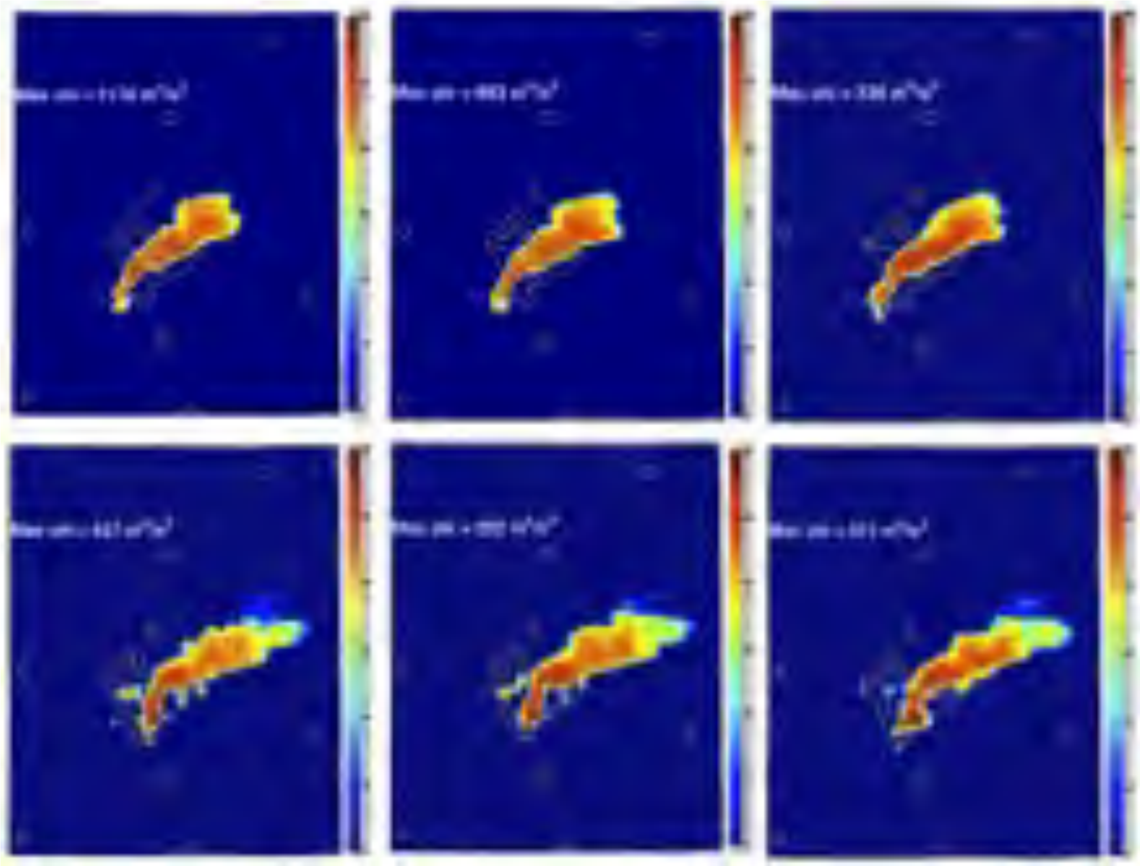
initial evaluation focuses on storm mode, interaction with the city, and complexity of the meteorological environment. If an event is deemed worthwhile (e.g., a storm crosses city boundaries and is relatively isolated), the student then requests and downloads the WSR-88D radar data from the NCDC for all surrounding radars in the region. WDSS-II is then used to complete all the radar data visualization and processing (Lakshmanan et al, 2007). Processing steps include: (1) radar merger (produces a three-dimensional grid of radar data incorporating the near storm environmental information and removes issues due to radar coverage holes and data artifacts due to storm movement to or away from an individual radar); (2) severe weather algorithms (including hail-size estimation, vertically integrated liquid, azimuthal shear and mesocyclone detection); (3) storm identification and tracking. The SegMotion algorithm within WDSS-II will be used to complete storm tracking and extraction of storm attributes in time (Lakshmanan and Smith 2009; 2010).

The numerical modeling portion of the project was focused upon basic model testing and evaluation during the first year. PhD student Larissa Reames was added to the project team starting 1 January 2013. The Advanced Research version of the Weather Research and Forecasting (ARW) model was selected for use. This model is suitable for studying thunderstorms, as well as having single layer urban models available for use to simulate urban effects within the model framework.

Tests were conducted for the 8 May 2003 tornadic supercell thunderstorm that passed across the southern portions of Oklahoma City, one of the urban areas selected for comparison. Initial testing found that the ARW is able to produce a supercell thunderstorm on this day, but the storm location was too far east, such that the simulated storm did not interact with the Oklahoma City urban environment as observed. To overcome this limitation, a modified initialization process was developed to force an updraft in the location of observed storm initiation along the dryline and to the southwest of Oklahoma City. After several tests, a robust initialization procedure was developed that leads to the simulated supercell thunderstorm developing and taking roughly the same path as the observed supercell thunderstorm.

Once the simulated storm path was in better agreement with observations, sensitivity tests with increasing values of surface roughness length were used to explore the influence of changes in roughness - due to building height and density - on storm behavior. Initial results indicated that the general storm location was not influenced by changes in surface roughness, but storm structure was influenced by changes in roughness (see figure below). This result gives us confidence that the urban environment has an influence on storm behavior as suggested in earlier studies.

This project is completed.



Simulated radar reflectivity (dBZ, color scale) for 1650 (top) and 1705 UTC (bottom) 8 May 2003 for an ARW simulation with no urban area (left), moderate urban (center) and high-density urban (right). The urban area is outlined by the gray isolines. Results indicate that the structure of the reflectivity field over the urban area differs among the simulations, indicating that the changes in surface roughness are influencing the simulated thunderstorm. "Max uhi" is the maximum updraft helicity intensity. It is an integrated vertical measure of the intensity of the rotating updraft. Larger values mean stronger updraft, stronger rotation, or both. In general, larger max uhi means a stronger storm.

Theme 3 – Forecast and Warning Improvements Research and Development

NSSL Project 5 – Hazardous Weather Testbed

NOAA Technical Leads: Lans Rothfusz (NSSL), David Andra (OUN), and Israel Jirak (SPC)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives

Experimental Forecast Program (EFP) objectives:

- Evaluate the utility of high-resolution ensemble forecast systems for severe storm guidance at both 24 and 3 hourly time scales;
- Continue improving information extraction from the ensembles and verify high-resolution forecasts.

Experimental Warning Program (EWP) objectives:

- Evaluate the accuracy and the operational utility of new science, technology, and products in a testbed setting to gain feedback for improvements prior to their potential transition into NWS severe convective weather warning operations;
- Foster collaboration between NSSL and GOES-R scientists and operational meteorologists.

Accomplishments

1. Experimental Forecast Program

James Correia Jr. (CIMMS at SPC)

a. Severe Weather for Use in 24-h and 3-h Convective Outlooks from Ensembles

Using object based algorithms, a method to extract simulated storm reports focusing on Hourly Maximum Updraft Helicity to construct full period Day 1 probabilities of severe weather was performed. In addition, we added three 3-hr period probabilities to test the ensembles ability to capture events at specific times. This method was applied to three ensembles (CAPS, AFWA, and NCEP SSEO) and verified daily during the experiment. All three ensembles use vastly different strategies (e.g. radar data assimilation with NAM input, multiple global model forecast input, NAM input and different WRF and NEMS based dynamic cores) and could be tested head to head. Real time verification occurred on both the 24- and 3-hr periods.

b. Severe Weather Variable Proxy Tests

Continued attempting to extract relevant information from the CAPS ensemble as it pertains to low-level rotation and hail directly from the model. New variables tested included 0-5 km vertically integrated graupel, 0-3 km updraft helicity, and variations of the updraft helicity parameter to allow for shallow and or elevated not simply just correlation through a deep layer. An evaluation of these diagnostics showed promise in different events during the experiment. For example during tropical storm Andrea numerous low level updraft helicity tracks were evident across Florida accompanying a risk of tornadoes, which matched well with convective storms but only coastal waterspouts were observed.

c. Incorporation of the NSSL Mesoscale Ensemble

As indicated elsewhere in this document, the NSSL mesoscale ensemble was incorporated into the N-AWIPS workflow. Support for the display of variables was accomplished for both east and west teams of the 2013 spring forecasting experiment.

d. Collaboration with the EWP

The EFP worked collaboratively with the EWP to deliver our experimental forecasts, usually the 3-h update forecasts, every 2 hours during the afternoon. A briefing was conducted and forecasts were delivered. A question and answer period was used to discuss the forecasts similar to a watch collaboration call conducted between SPC and the relevant WFOs. The EFP delivered our forecast grids via grib2 into the AWIPS-II system for display by EWP forecasters.

These projects are ongoing.

2. Experimental Warning Program

Kristin Calhoun and Darrel Kingfield (CIMMS at NSSL), William Line (CIMMS at SPC), Amanda Terborg (CIMSS-University of Wisconsin and NOAA/AWC), and Chad Gravelle (CIMSS-University of Wisconsin and NWSTC)

Kiel Ortega, Travis Smith, and Chris Karstens (CIMMS at NSSL), Greg Stumpf (CIMMS NWS/OST/MDL/DAB in Norman, OK), Clark Payne (CIMMS at WDTB), and Gabe Garfield (CIMMS at OUN)

The 2013 Experimental Warning Program spring real-time experiments were conducted over a period of three weeks in May and included approximately 40 participants split equally between operational forecasters and severe weather researchers. Each day, the forecasters participated in simulated nowcasting and warning operations using new software and data sources, listed below. They provided feedback to researchers through direct interaction as well as surveys. Finally, they provided a briefing on the

week's HWT activities via teleconference to about 70 forecast offices each Friday via a teleconference facilitated by CIMMS staff at the WDTB.

a. GOES-R Risk Reduction and Proving Ground Activities

The 2013 Spring Experiment, particularly the EWP activity in HWT, provides the GOES-R Program with a Proving Ground for demonstrating pre-operational data and algorithms associated with GOES-R. In 2013, the main focus of the experiment was demonstrating the GOES-R baseline and future capabilities products; however, it also included operational readiness trials of products transitioning from the GOES-R Risk Reduction program. The GOES-R products were generated from current satellite-based, land-based, and numerical model-based datasets and were demonstrated within a real-time AWIPS-II framework within the HWT. Products demonstrated in 2013 included cloud top cooling (CTC) observations, convective initiation (CI) nowcasting, total lightning detection and trends, 'airmass' Red-Green-Blue (RGB) imagery, and numerical model-simulated cloud and moisture imagery. Additionally, derived stability products including a 0-9 hour differential theta-e, precipitable water, and CAPE 'Nearcasts' were also available, demonstrating the utility of satellite data in combination with other datasets to provide unique fused decision aids.

NWS forecasters provided feedback to GOES-R scientists and developers in multiple ways: (1) real-time blog posts written by forecasters as an event transpired, available at http://goesrhwt.blogspot.com and https://secure.nssl.noaa.gov/projects/ewp/blog/, (2) daily and weekly debriefs, (3) daily post-event online surveys, (4) weekly webinars facilitated through the WDTB. Feedback was generally positive as NWS forecasters were eager to explore the new satellite products and capabilities that will be available come the launch of GOES-R. In the post event surveys, participants were asked how comfortable they felt with each product and subsequently, whether they believed those products would have an impact on their WFO operations and how much. Roughly 70% indicated they would use the Simulated Satellite imagery, most of which indicated they would utilize it most in the pre-storm period. Similarly, about 78% indicated the benefit of having the Nearcasting data available within the 1 to 3 hour forecast period, while 67% also reported that it was useful in the 3 to 6 hour period. 53% reported at least some to large impact of the CI on forecast operations, roughly 70% used and were comfortable with the CTC in their forecast operations, and nearly 80% were found the PGLM useful for situational awareness and warning operations. Lastly, only 40% reported that they would be comfortable using the RGB Airmass product in operations; this low percentage was likely to due to the less intuitive nature of the product and lack in training materials when compared to the other products available.

b. Hail Size Discrimination Algorithm

A Hail Size Discrimination Algorithm (HSDA) for the WSR-88D is being developed at CIMMS and NSSL. In order to gain feedback, beyond typical algorithm skill metrics, the HSDA was written into the ORPG so that data could be displayed within AWIPS-II. Forecasters provided feedback on the perceived skill of the algorithm during a day's

operations. This feedback is currently being used to help guide future algorithm modifications and development.

c. Multi-Radar/Multi-Sensor (MRMS) Severe Weather Algorithms

A major focus of the 2013 experiments involved capturing feedback from forecasters about the “best practices” for using MRMS severe weather data in the warning decision-making process. This project was conducted in collaboration with the WDTB to help create training materials for forecasters, as the MRMS system goes operational in the NWS in 2014/15. Forecasters integrated the MRMS data into their process using AWIPS-II software and provided valuable information related to the value of specific products. Analysis of these data is underway.

d. Experimental Model Guidance

Forecasters examined data from the Norman Forecast Office’s custom Weather Research and Forecast model (OUN WRF) as well as data from GSD’s Local Analysis Prediction System (LAPS) and Space and Time Multiscale Analysis System (STMAS). Goals included the evaluation of using 0-3 hour convective nowcasts to determine initiation, mode, and dissipation of severe convective storms. Analyses of the performance of these models are underway by their respective investigators.

These projects are ongoing.

3. Implemented Model with Radar Cycling in an Operational Warning Environment

Gabe Garfield (CIMMS at OUN) and Jidong Gao (NSSL)

Prior to Spring Experiment 2013, Garfield worked to improve the OUN WRF model. In particular, he worked with Jidong Gao (NSSL) to assist us in implementing a new data assimilation package for the OUN WRF.

Gao installed a modified ARPS 3DVAR code that employs model cycling. The new code works by interpolating NAM output and radar data to the ARPS model grid. After this, a 3DVAR analysis is performed using the background, radial velocity, and traditional data. This process is repeated seven times in 30 minutes. The final analysis is then interpolated back to the WRF grid, after which the model is allowed to run. The whole process takes two hours to complete (one hour longer than the previous version of the OUN WRF).

The updated model was used during the EWP portion of the 2013 HWT Spring Experiment. Visiting forecasters evaluated the model and recorded the results in daily surveys. Additionally, forecasters were interviewed directly to obtain subjective impressions of model performance with the new data assimilation package. These forecaster impressions will be evaluated in the upcoming months. Additionally, we

saved files necessary to re-run the old version of the OUN WRF in order to compare with the new version used during the experiment.

This project is completed.

4. Coordination for the 2013 HWT Spring Experiment

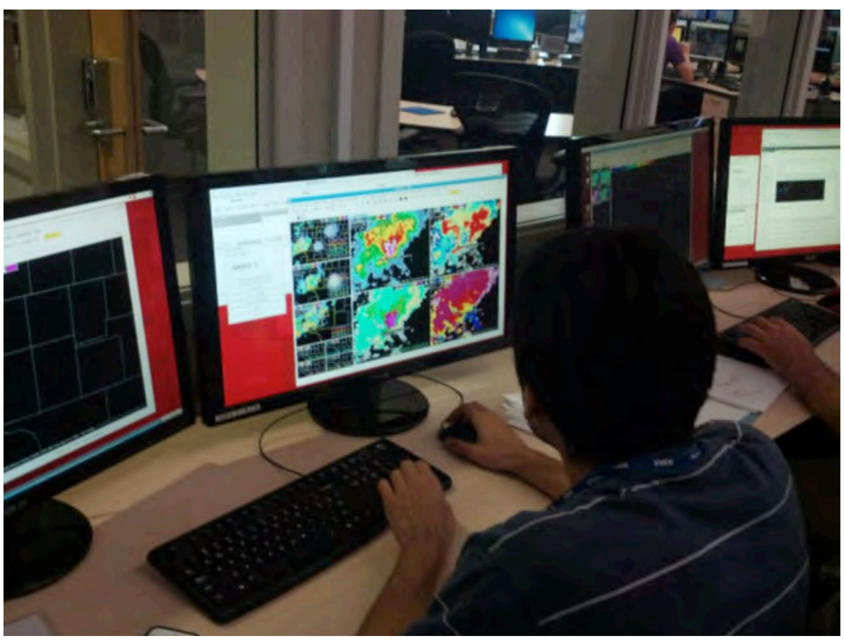
Gabe Garfield (CIMMS at OUN) and Chris Karstens (CIMMS at NSSL)

During the 2013 Spring Experiment, Garfield served as the Week One Coordinator for the EWP. Duties included providing daily forecast briefings, selecting operation areas, and answering questions from visiting forecasters. Additionally, he wrote daily forecast briefings and summaries, as well as a summary of the week's activities. Karstens served as Week One Backup Coordinator. He was responsible for helping to oversee daily operations and to address questions that would arise. He also helped facilitate collaboration between the EWP and the EFP by creating data mining techniques for visualizing the experimental products produced by each group.

This project is completed.

Publications

Kain, J. S. Kain, M. C. Coniglio, J. Correia Jr., A. J. Clark, P. T. Marsh, C. L. Ziegler, V. Lakshmanan, S. D. Miller Jr., S. R. Dembek, S. J. Weiss, F. Kong, M. Xue, R. A. Sobash, A. R. Dean, I. L. Jirak, and C. J. Melick, 2013: A feasibility study for probabilistic convection initiation forecasts based on explicit numerical guidance. *Bulletin of the American Meteorological Society*, **94**, 1213-1225.



A NWS forecaster uses AWIPS-II and dual-pol radar (with HCA/HSDA output in bottom left) to diagnose hail potential for a thunderstorm during 2013 HWT/EWP operations.

NSSL Project 6 – Development of Technologies and Techniques in Support of Warnings

NOAA Technical Lead: Lans Rothfusz (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives

The primary objects for this reporting period include:

1. Developing the capability to re-process and analyze 15 years worth of WSR-88D data for use in severe local storms, hydrological, and climatological research;
2. To conduct a real-time evaluation of data assimilation for the Warn-on-Forecast project;
3. Continue development of Multi-Radar Multi-Sensor (MRMS) algorithms for use in warning decision-making; and
4. Conduct enhanced verification of severe weather events.

Accomplishments

1. The Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS)

Kiel Ortega and Travis Smith (both CIMMS at NSSL)

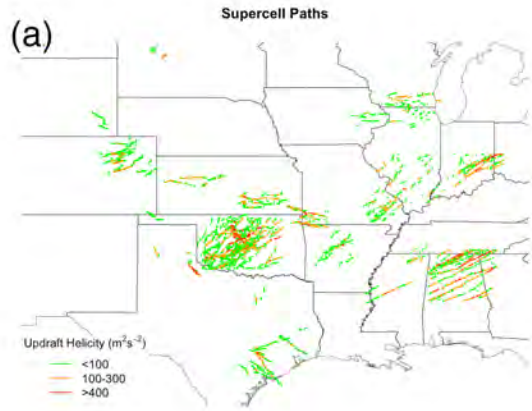
The MYRORSS dataset began processing just prior to the beginning of FY13. Thus far the years 2002, 2004, 2008 and 2010 have been completed by CIMMS at NSSL. The year 2006 has been completed by the NCDC, which is partnered in this effort. Currently, processing continues with the year 2012. Images of several fields are being produced so that quality-control can be conducted on the dataset, and will be followed by extensive data mining to produce radar-based storm information for warning, forecast, and climate scale analysis.

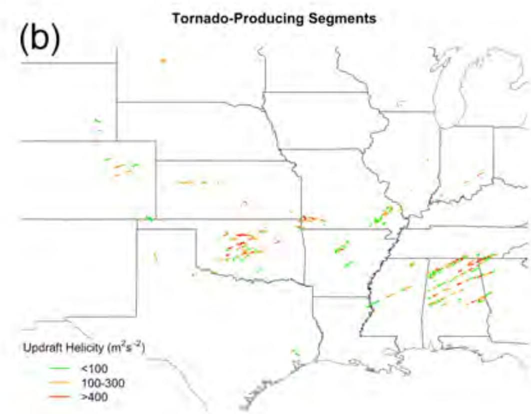
2. Warn-on-Forecast Real-Time Data Assimilation Experiment

Travis Smith, Kristin Calhoun, Kiel Ortega, Chris Karstens, and Darrel Kingfield (all CIMMS at NSSL)

Forecasters and research meteorologists tested a real-time three-dimensional variational data assimilation (3DVAR) system in the Hazardous Weather Testbed during the springs of 2010-12 to determine its capabilities to assist in the warning process for severe storms. This storm-scale system updates a dynamically consistent three-dimensional wind field every five minutes, with a horizontal and average vertical grid

spacing of 1 km and 400 m, respectively. The system analyzed the life cycles of 218 supercell thunderstorms on 27 event days during these experiments, producing multiple products such as vertical velocity, vertical vorticity, and updraft helicity. These data are compared to multi-radar / multi-sensor data from the WDSS-II to document the performance characteristics of the system, such as how vertical vorticity values compare to azimuthal shear fields calculated directly from Doppler radial velocity. Data are stratified by range from nearest radar as well as the number of radars entering into the analysis of a particular storm. The 3DVAR system shows physically realistic trends of updraft speed and vertical vorticity for a majority of cases. Improvements are needed to better estimate the near-surface winds when no radar is nearby and to improve the timeliness of the input data. However, the 3DVAR wind field information provides an integrated look at storm structure that may be of more use to forecasters than traditional radar-based proxies used to infer severe weather potential.





(a) Updraft Helicity for the entire life cycle of all storms analyzed during the HWT 3DVAR experiments. (b) Updraft Helicity for the tornado producing segments of tornadic storms in the analysis.

3. Multi-Radar/Multi-Sensor (MR/MS) Severe Weather Algorithm Development

Travis Smith, Kristin Calhoun, Kiel Ortega, Chris Karstens, Darrel Kingfield, and Valliappa Lakshmanan (all CIMMS at NSSL)

A major milestone in the MR/MS algorithm development has occurred, with the NWS agreeing to transfer the system into operations during 2014-15. In preparation for the initial research-to-operations transition, the severe weather products were evaluated in the Hazardous Weather Testbed in Spring 2013 (see NSSL Project 5).

a. Prototype Warning Generation Software

Work began on developing a prototype web-based interface that will allow forecasters to rapidly convert guidance information from projects like Warn-on-Forecast and MYRORSS into probabilistic hazard information. The goal is to create a tool that allows forecasters to more readily convey their uncertainty about the severity and evolution of severe convective phenomena, therefore allowing end-users to make more informed decisions. This tool aims to evolve current warnings from static polygons into polygons that move with identified threat(s) combined with embedded spatial uncertainty.

b. Geospatial Visualization for HWT Support

A web-based data visualization interface (NSSL Experimental Data Explorer) was developed for the 2013 Spring Experiment, which helped facilitate collaboration between the EWP and EFP. In addition to displaying experimental products produced within the HWT, the interface incorporated many other geospatial meteorological datasets, including SPC outlooks and watches, NWS warnings, local storm reports, and radar-derived products (i.e., MRMS). Further, a data-mining technique was developed to rapidly produce images of model fields from various high-resolution models, including the RAP, HRRR, NSSL WRF, and the UK-MET. This provided a means of subjectively verifying model- and human-generated forecasts in real-time.

c. Lightning Jump Algorithm

In severe storms, rapid increases in lightning flash rate, or “lightning jumps”, are coincident with pulses in the storm updraft and typically precede severe weather, such as tornadoes, hail and straight line winds, at the surface by tens of minutes. The GOES-R Geostationary Lightning Mapper (GLM) provides a general path to operations for the use of continuous total lightning observations and the lightning jump concept over a hemispheric domain. NOAA GOES-R Risk Reduction Research (R3) programs in support of future GLM capabilities have investigated the development of a total lightning jump algorithm (LJA) that can be used by NWS forecasters to enhance situational awareness, diagnose convective trends and potentially improve the short-term prediction of severe weather (Schultz et al. 2009,2011; S09/S11).

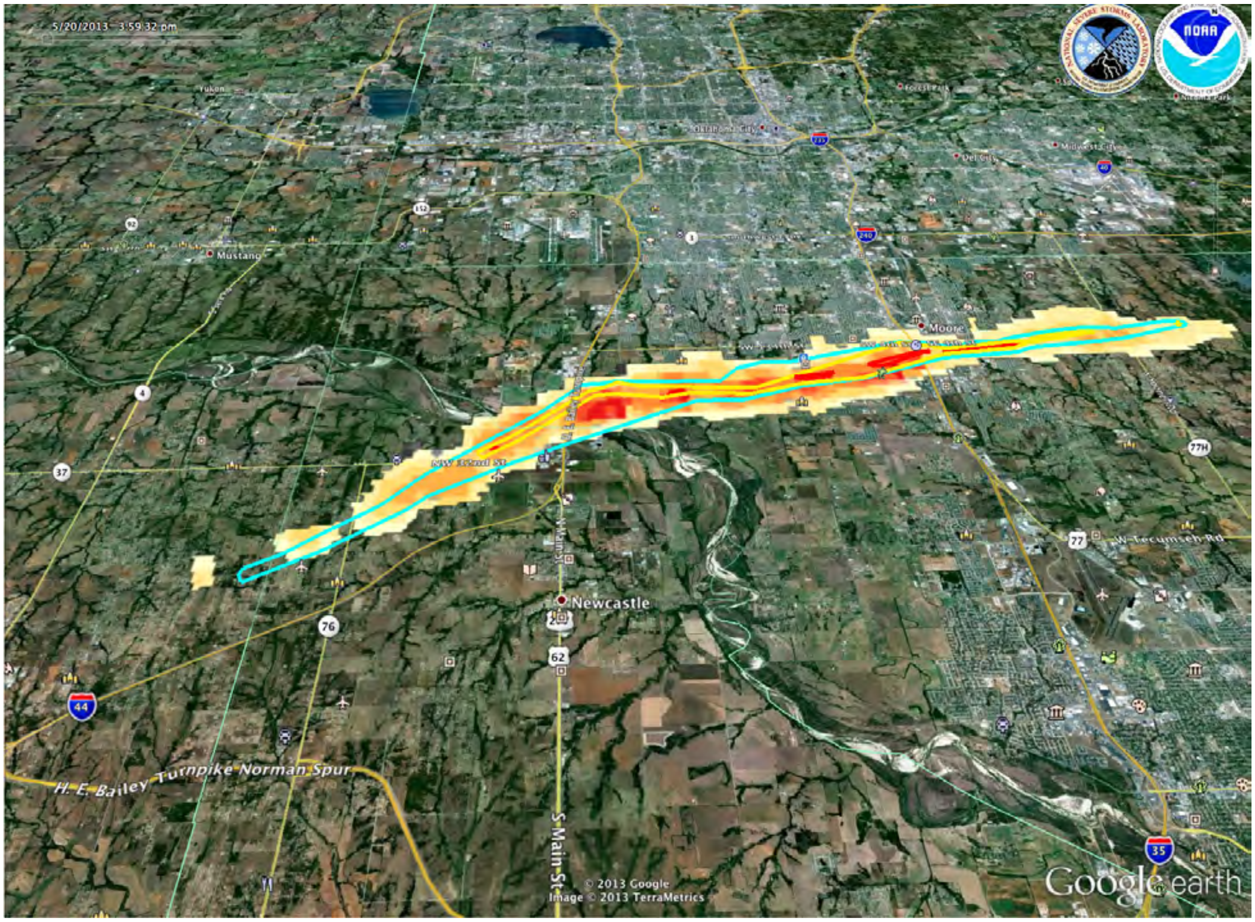
Based on the promising results of S09/S11, the NWS Office of Science and Technology (OST) deemed it a high priority to evaluate the LJA for operational implementation on an expanded lightning mapping array (LMA) and radar data set, using fully automated methods for storm cell identification and tracking and lightning jump detection, robust verification approaches, and new methodologies to assess the skill with and without the LJA in the forecasting process.

Implementation and preliminary evaluation of a fully automated, real-time LJA began in 2012 using the northern Alabama, Washington D.C, Oklahoma and west Texas LMAs. This real-time system integrates merged WSR-88D reflectivity data over LMA domains with the RUC/RAP model and LMA lightning flashes utilizing the WDSS-II framework. Automated tracking of storm objects is then completed at the -10 C isothermal level using the K-Means and SegMotion algorithms (Lakshmanan et al., 2003, 2009).

Based on results from the 2012 data, the flash rate, tracking and jump algorithms were revised and tuned to better account for differences between real-time data, research methodology, and results of S09/S11. Additionally in 2013, the operational domain was expanded to include the Colorado and Houston LMA domains as well as Earth Networks Total Lightning. Using a high degree of automation, verification of the algorithm is currently underway to produce key-statistics for the severe weather nowcasting based on the LJA employment in real time. In addition to these basic verification statistics replicating the S09/S11 methodology, enhanced verification techniques that employ radar proxies of severe weather and Severe Hazards Analysis and Verification Experiment (SHAVE) data are also being employed. The primary objective of this experiment is to evaluate the broader applicability of the LJA as a severe weather warning decision assistance tool.

d. Radar Velocity Data Quality, Rotation Tracks, and Tornado Debris Signature

Substantial improvements to warning guidance products the use Doppler velocity data as input were made. Two-dimensional velocity dealiasing routines were evaluated alongside the operational WSR-88D algorithm and showed substantial improvements in unfolding the aliased data, resulting in an improved algorithm being implemented on NSSL's real-time MR/MS system and for the Warn-on-Forecast data quality assurance for test/development cases. Additionally, temporally based quality controls were added to the Rotation Tracks processing using a multiple hypothesis tracking technique to filter out spurious circulation detections, resulting much cleaner data sets. Finally, a prototype technique to automate the detection of Tornado Debris Signatures that are identifiable with dual-polarization radar was implemented for the 2013 Spring Experiment and successfully tested on several events.



A Tornado Debris Signature track is colorized by the intensity of the circulation on radar (oranges/reds are higher values) for the 20 May 2013 Moore, OK, tornado event. In this event, the large amount of debris flying through the air coupled with the close proximity to the WSR-88D radar site 10 miles east of Moore allowed a very close match between the radar-estimated tornado path and the the path discovered by NWS/NSSL/CIMMS ground survey teams. (green = EF0; orange=EF2; red=EF4+).

4. The Severe Hazards Analysis and Verification Experiment (SHAVE)

Kiel Ortega (CIMMS at NSSL)

SHAVE continued both its usual severe storm verification during the spring and summer months and also conducted verification of winter storms. For calendar years 2012 and 2013, SHAVE operated a total of 162 days collecting 12,649 total reports. For the lightning jump verification, SHAVE, in total, has collected 5,857 hail reports within the LMA domains for use in lightning jump research activities. In total, SHAVE has collected 17,393 hail reports within 175 km of WSR-88D radars. Approximately 2,000 of these reports are currently being used to evaluate and modify a Hail Size Discrimination algorithm for the WSR-88D.

5. Prototype Development for Time-Ensemble Products

Gabe Garfield (CIMMS at OUN)

During spring 2013, Python was applied to develop new products for the OUN WRF model runs. In particular, prototypes were developed for time-ensemble updraft helicity and vertically integrated graupel (proxies for mesocyclones and hail, respectively). Development on these products will continue in anticipation of use in 2014 HWT Spring Experiment.

These projects are ongoing.

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ROC Project 10 – Analysis of Dual Polarized Weather Radar Observations of Severe Convective Storms to Understand Severe Storm Processes and Improve Warning Decision Support

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

1. ROC Applications Branch

NOAA Technical Leads: Bob Lee and Richard Murnan (both ROC Applications Branch)

Objectives

Our CIMMS student employees (Zachary Biggs and Corey Godine) provided important contributions to the validation and verification of new Dual-Polarization technology. A better understanding of Dual Polarization data is needed to improve input into algorithms. The ROC Applications Branch has the responsibility to collect and analyze radar data that will lead to improvements in the QPE algorithm. To do this, we need tools that can take raw data as input and quickly generate various statistics and graphics.

Accomplishments

The Branch is using two approaches to improving algorithm output, the QPE algorithm in particular. The first obvious approach is to examine the C programming language within the algorithms and make changes. The second approach examines the data going into the algorithms to ensure high quality. We have learned of several data quality concerns that need to be addressed. This is the approach that Zack and Corey have provided valuable contributions too.

NEXRAD produces a “log of events” that documents information such as VCP times, any alerts, and times for any event on the radar. This information is stored in a file called the “ASP” file and is quite useful when trying to analyze why a particular radar is not performing well. The issue with the file is there is so much information in it that it is impractical to find anything specific that you are looking for. Zack developed an Excel Add-In, programmed in Visual Basic that processes through the entire ASP file and makes the contents very easy to visually understand. The Add-In creates a worksheet with information about the volume scan times and alarms issued during each volume scan. Thus the user can see how long every volume scan took, and about how long it was supposed to take for its specific VCP. The user will also see information about RDA and RPG alarms consisting of MAR, MAM, or INOP and whether any of them were hit in a volume scan. In addition, users can see the Legacy and Dual Pol calibration information the radar calculated during every volume scan. These can then be plotted using a line chart to see how they are behaving over time from volume scan to volume scan.

The ROC Hotline has found the Add-In extremely useful as it allows them to diagnose radar problems by using nothing more than an ASP file containing several months' worth of data. They had a NWS Director task to identify all radars in the fleet that had experienced pedestal alarms and needed a tool to quickly help them sift through all of the ASP files to find the information they were looking for. Zack provided the tool and the training to the Hotline to answer this task. The tool continues to be a valuable asset for the ROC to use to ensure radar performance and high data quality into algorithms.

Zack also worked with the Matlab GUI and learned the basics of how it works. He was able to program a tool that the Applications Branch senior scientist had created into the GUI enabling other Application Branch scientists to use the tool at the click of a button.

As part of our data quality work Corey learned MATLAB to be proficient enough to write code that analyzes initial system differential phase (ISDP) from NEXRAD level II data. An ISDP assessment is essential to ensure high data quality for field forecasters and algorithm input. Corey successfully used his code to analyze ISDP data on 30 cases without any miscalculations. His results matched results that were manually conducted on a couple of cases. Corey's code will be incorporated into a larger script that tests various radar data on a monthly basis, including ISDP, to determine to what degree a radar is calibrated and what corrections need to be taken.

These projects are ongoing.

2. ROC Engineering Branch

NOAA Technical Leads: Russ Cook, Christina Horvat, and Bill Urell (all ROC Engineering Branch)

Objectives

Our CIMMS student employees (Jacob Bonsu, Jerry WongSickHong, Ankit Patel, DeShana Braxton, Mitchell Milligan, and Joshua Wakeam) provided important contributions to the validation and verification of new Dual-Polarization technology. The ROC Engineering Branch has the responsibility to provide the technical capability to collect and playback radar data that will lead to improvements in the QPE algorithm. To do this, the ROC needs secure systems collecting the data, information on the data links that collect the data and ability to playback data for analysis.

Accomplishments

Mr. Patel and Ms. Braxton collected and compiled information on the operational status and security posture of the WSR-88D network to perform Dual-Polarization quality analysis, troubleshoot site specific problems, and support monthly security logging and audit reporting. Ms. Braxton assisted with several Engineering Change Proposals for security updates. Mr. Bonsu and Mr. WongSickHong developed and populated data bases on all of the communications links that transmit radar data to central repositories and improved NWS contingency planning by developing a matrix to identify WSR-88D,

AWIPS and OPSnet capabilities. These improvements enabled the ROC to respond more quickly to communications outages that deprived ROC of critical operational and research data. Also, Messrs. Patel, Bonsu, and WongSickHong reclaimed valuable, reusable piece parts from end of life routers and switches. Mr. Milligan and Mr. Wakeam engineered valuable improvements to the hardware simulators that are used to emulate a normal radar environment in order for researchers to be able to play back radar data. Source scientists then used the resultant secure data and playback capabilities to optimize QPE algorithms to improve the timeliness and accuracy of future operational forecasts.

SPC Project 11 – Advancing Science to Improve Knowledge of Mesoscale Hazardous Weather

NOAA Technical Leads: Steven Weiss and Russell Schneider (both SPC)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Overall Objectives

Conduct activities to maximize the diagnostic and forecast value of geostationary satellite data and products, within the SPC, Hazardous Weather Testbed (HWT), and the GOES-R Proving Ground. A key component is to test and validate new satellite products associated with GOES-R, and to interact with NWS operational forecasters to prepare them for new satellite products. Emphasis will be on assessing the value of advanced satellite products for detection and short-term prediction of convective storms and associated hazards.

Support the HWT Spring Experimental Forecasting Program (EFP); collaborate with the Experimental Warning Program (EWP) group to deliver rapidly updating short period forecasts to warning forecasters, perform research into application of new tools, diagnostics, and techniques from convection allowing models and ensembles; and perform verification on severe weather proxy techniques such as the neighborhood probabilities.

Accomplishments

1. GOES-R Proving Ground

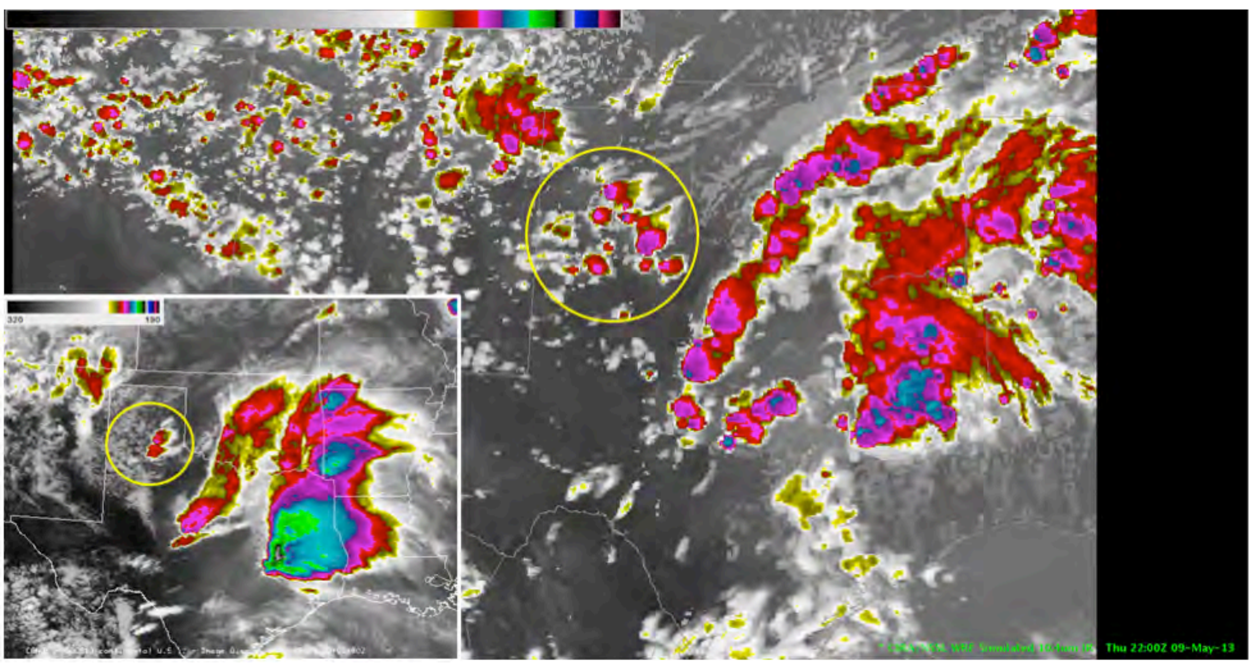
Chris Siewert and William Line (both CIMMS at SPC), and Kristin Calhoun (CIMMS at NSSL)

This was the fifth year of the GOES-R Proving Ground’s efforts at the SPC and HWT. Several conference and workshop presentations, including the AMS Annual Meeting,

NWA Annual Meeting, and NOAA Satellite Science Week, occurred between mid-2012 through early-2013 presenting the results from the fourth year of the Proving Ground's efforts, specifically focusing on the results from the HWT Spring Experiments. SPC forecasters were also provided familiarization and training on experimental GOES-R products that were evaluated during the 2012 HWT Spring Experiment.

The GOES-R Proving Ground Spring Experiment occurred from mid-May through early June 2013, with 18 NWS forecasters and 9 visiting scientists participating in evaluating a variety of proxy GOES-R products during real-time experimental forecasting and warning situations within a simulated operational environment. This year, the GOES-R products were provided for demonstration within primarily the NSSL/NWS EWP, although several products were also shown in the SPC/NSSL EFP. Demonstrated products included simulated satellite imagery and GOES-R unique band differences from the NSSL-WRF, object-based convective initiation nowcasts, cloud-top cooling rates, pseudo-Geostationary Lightning Mapper total lightning flash extent densities, 0-9 hour differential theta-e / precipitable water / CAPE "Nearcast", and GOES Sounder-derived RGB air mass imagery. Many of these products will continue to be delivered to SPC operations throughout the year for continuing forecaster familiarization and training.

This project is ongoing.



22-hr simulated satellite infrared (IR) imagery forecast from NSSL-WRF valid 2200 UTC 9 May 2013. Note the cluster of cells over Lubbock, just west of the main complex. Actual IR imagery (inset) valid at the same time showed that a similar situation occurred.

2. Hazardous Weather Testbed

James Correia Jr. and Chris Melick (both CIMMS at SPC)

Support activities by Correia included preparing for ingest and plotting of NSSL Mesoscale Ensemble products generated by NSSL for use in N-AWIPS. He developed and applied object based techniques to identify storm attributes in 3 distinct ensemble systems using the updraft helicity parameter. These were used during forecasting to assess ensemble skill in the timing of severe weather regimes. Refinement of updraft helicity parameters was added to cover mini supercells. Other parameters such as hail were explored using the same technique but were not as successful. Continued investigating the utility of PBL vertical velocities for identification of boundaries aloft and other turbulent regimes thought to initiate convection.

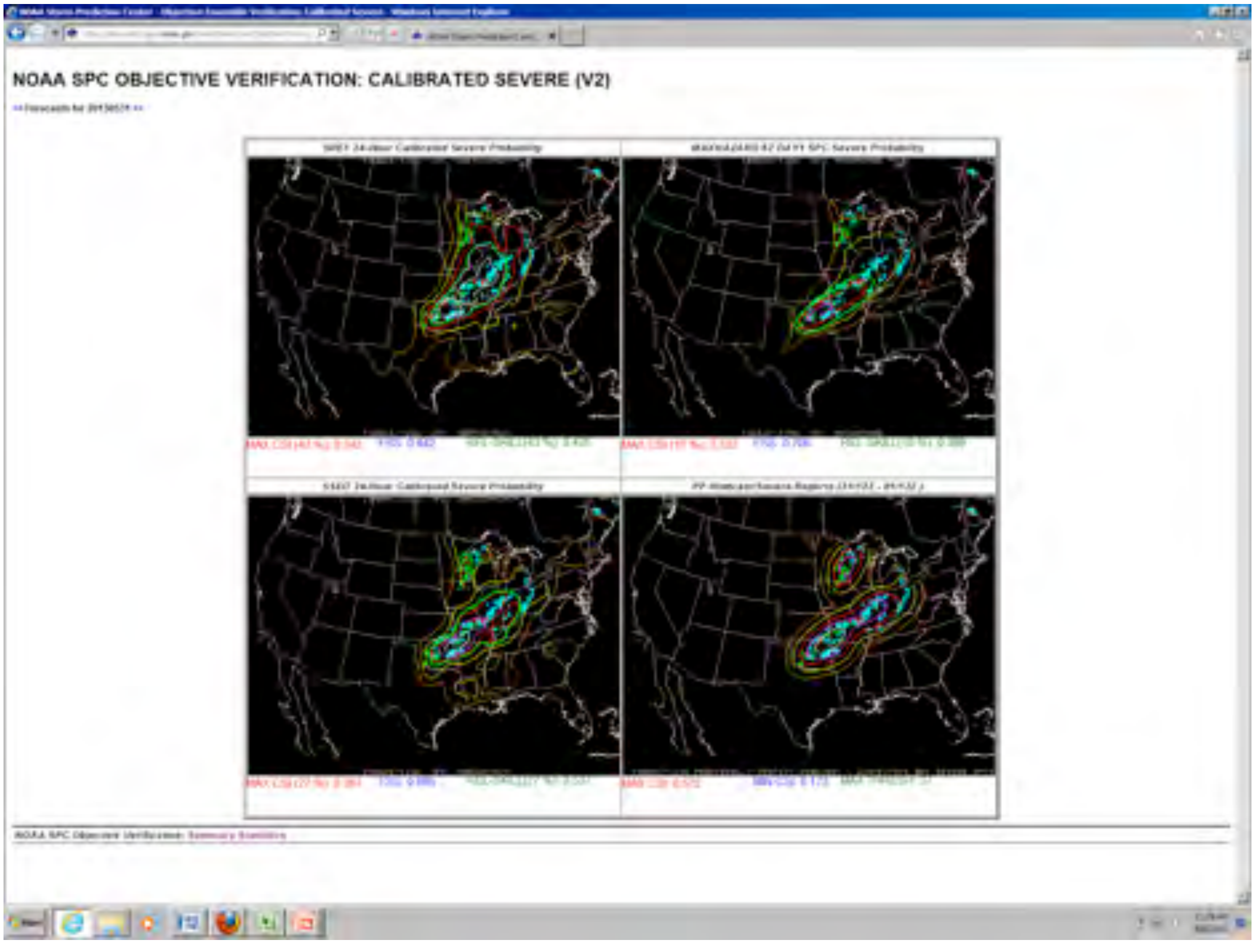
Support activities by Melick included conducting objective forecast verification for the second consecutive year in near real-time during the 2013 HWT EFP. The importance of incorporating verification metrics into the evaluation process was further explored for neighborhood probabilistic guidance of reflectivity from convection allowing ensembles and experimental forecasts of total severe thunderstorm probabilities. As with the 2012 EFP (Melick et al. 2012), the evaluation was facilitated via webpages (http://hwt.nssl.noaa.gov/Spring_2013/) using spatial plots for distinct time frames as well as a table that summarized statistical results. For some of the summary type analyses, time-series plots were also constructed for a more graphical representation of trends in the scores (e.g., the first figure below). This provided an effective means for the participants to quickly evaluate the forecast verification metrics and provide feedback on the comparison between the objective results and their own subjective impressions. Finally, EFP shared the human generated forecasts for severe convection for the first time with the EWP, which were used in preparation for their operations. Although both groups use different software applications, this initial collaboration was pursued by developing a process to convert the GEMPAK grid file format to GRIB2, which then would permit the display of the forecast team products within AWIPS-II.

Unlike the prior year, 1200 UTC initialized convection allowing ensembles were available for the first time to complement the traditional 0000 UTC initialized counterparts. This provided the opportunity to perform a formal comparison using Fractions Skill Score (FSS) and test whether the update provided any noticeable improvements in the ability of the models to predict storm placement and intensity. In addition, the relative skill score was introduced to gauge the performance of the experimental forecasts against a baseline reference, namely the practically perfect hindcasts. For completeness, both Critical Success Index (CSI) at various probabilistic thresholds and FSS were also computed with preliminary storm reports serving as the verification dataset. Additional investigation into the advantage of performing objective forecast verification routinely will further be addressed, with some of the analysis work presented at the 38th National Weather Association Annual meeting.

One of the direct outcomes from the 2012 EFP was the application of verification techniques developed and tested in the HWT for real-time daily objective verification of probabilistic ensemble guidance and operational SPC severe storm outlooks. This successful example of research to operations (R2O) transition was designed similarly with a few changes and improvements. Specifically, internal webpages were developed for the daily generated plots (e.g., second figure below) and computed statistics, where the image display sizes were increased, the domain expanded to include all of the contiguous United States, and the maximum hazard probabilities from the SPC 0600 UTC Day1 Convective Outlook substituted for one of the ensembles used in the EFP 2012. Furthermore, the number of forecast verification metrics was increased with the goal of getting a more complete picture of forecaster skill for the products issued at SPC and how they compare to locally generated model guidance.

This project is ongoing.

Summary table and time series plot of FSS created from the 2013 EFP website showcasing multiple day statistical overview. The daily accumulated scores from each day are presented, with the right most column representing the final outcome accumulated over the entire twenty five days of the 2013 EFP (5/6/2013 – 6/7/2013).



Sample spatial plots from SPC internal website illustrating the ability to display forecast verification metric scores for any user selected date. The forecasts represent the 24-hour total probabilities for severe thunderstorms valid for 12Z on 31 May 2013 to 12Z on 1 June 2013. The upper-left panel shows the SREF ensemble calibrated guidance, the upper-right represents the maximum hazard probabilities from the SPC 6Z Day1 Convective Outlook, the lower-left shows the SSEO ensemble calibrated guidance, with the "practically perfect" hindcast probabilities located in the lower right. Verification dataset comes from the NWS local storm reports, also plotted in each panel. Beneath each forecast, the corresponding Critical Success Index (CSI) at the maximum threshold, Fractions Skill Score (FSS), and relative skill score at the maximum threshold for CSI are displayed as well. The components needed to calculate the relative skill score from the practically perfect hindcast are given below the lower right panel.

3. Collaboration with the EWP

James Correia Jr. (CIMMS at SPC)

The EFP worked collaboratively with the EWP to deliver our experimental forecasts, usually the 3-hour update forecasts, every 2 hours during the afternoon. A briefing was conducted and forecasts were delivered. A question and answer period was used to

discuss the forecasts similar to a watch collaboration call conducted between SPC and the relevant forecast offices. The EFP delivered our forecast grids via grib2 into the AWIPS-II system for display by EWP forecasters.

This project is ongoing.

4. Ensemble Verification of Proxy Severe Storm Reports

James Correia Jr. (CIMMS at SPC)

The Storm-Scale Ensemble of Opportunity (SSEO) was used to produce first guess severe storm probabilities similar to the Day 2 convective outlook. An object based approach utilizing updraft helicity tracks were used as proxies for severe storm reports and were verified with observed wind, hail and tornado reports. An analysis by month for all of 2012 was conducted to evaluate the proxy method and ensemble skill. Preliminary results suggest that springtime skill is much higher than late summer skill. Analyses were conducted with the help of a Research Experience for Undergraduates student and work is ongoing.

This project is completed.

5. A Four-Year Climatology of Simulated Convective Storms from NSSL WRF

James Correia Jr. (CIMMS at SPC)

A ~4 year (June 2009 thru April 2013, 1200 UTC-12 UTC) climatology of simulated convective storms was constructed from the experimental National Severe Storms laboratory (NSSL) ARW using an object based approach. A limited sensitivity analysis is conducted to test composite reflectivity (CREF) thresholds and storm areas. Choosing slightly higher thresholds (34 vs. 30 dBZ) reduces storm size but increases the number of storms; however this has very little effect on storm-size spectra for those storms containing hourly maximum updraft helicity values at or exceeding 25 m^2s^{-2}. This is indicative of identifying more storm cores using higher thresholds.

Storm attributes are codified in terms of the maximum convective available potential energy (CAPE) and maximum 0-6 km shear in the hour preceding the storm. Two-dimensional histograms are constructed in the CAPE-shear parameter space to examine characteristics of the model environment relative to severe weather proxy variables used in the NOAA Hazardous Weather Testbed Spring Experiment. The relationship between hourly maximum variables including updraft helicity (UH), 10-m wind speed, vertically integrated graupel (GR), and updraft speed (UP) are quantified.

Preliminary results indicate that updraft helicity ≥ 25 m^2s^{-2} in individual storms is present nearly fifty percent of the time when simulated storms have 10-m wind speeds ≥ 20 ms^{-1}, updraft speeds ≥ 26 ms^{-1}, GR ≥ 35 kg m^{-2}, and CREF ≥ 55 dBz. Additionally, storms meeting this UH threshold frequently occur in high deep-layer shear environments (>20

ms^{-1}) with relatively lower dependence on CAPE. This relationship is modified somewhat for GR and UP where there is more dependence on CAPE especially above 1800 Jkg^{-1}.

This project is ongoing.

6. Special Projects in Effective Communication

James Correia Jr. (CIMMS at SPC)

Correia is serving as a liaison to many different groups within and concerning social science activities including the Weather and Water social science group within NOAA, a local social science group between NOAA, CIMMS, CASR, and CAPS, working with the SPC communications team including Dr. Susan Jasko (PR and communications specialty; University of California – Pennsylvania), and the NWS customer satisfaction survey team. In all of these efforts, I am gathering information on increasing the effectiveness of SPC products including watches and experimental convective outlooks. This includes surveying the NWS users/public about SPC Product use (NWS customer satisfaction survey 2012) and work towards clarifying the language used in the outlooks for the upcoming NWS survey in 2013. This also included questions related to social media that will be analyzed to see where the NWS stands in current practice and plot a course for the future. All of the groups mentioned above were critical in gathering feedback on the questions asked and thus served as an effective collaboration.

These projects are ongoing.

Publications

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Kain, J.S., M. Coniglio, J. Correia Jr., A. J. Clark, P. T. Marsh, C. L. Zeigler, V. Lakshmanan, S. D. Miller Jr., S. R. Dembek, S. J. Weiss, F. Kong, M. Xue, R. Sobash, A. Dean, I. L. Jirak, and C. J. Melick, 2013: A feasibility study for probabilistic convection initiation forecasts based on explicit numerical guidance. *Bulletin of the American Meteorological Society*, **8**, 1213-1225.

WDTB Project 12 – Warning Decision-Making Research and Training

NOAA Technical Leads: Ed Mahoney, Brad Grant, Liz Quoetone, James LaDue, Michael Magsig, Robert Prentice, Don Rinderknecht, and Jami Boettcher (all WDTB)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives
Increase expertise among NOAA/NWS personnel and their core partners on the integrated elements of the warning process. CIMMS scientists conduct applied research, develop and deliver training, and build applications to support the mission of meeting this goal. In doing so, we help NOAA/NWS warning forecasters and their core partners better serve the general public during warning operations and other hazardous weather events that require weather decision support services.

Accomplishments

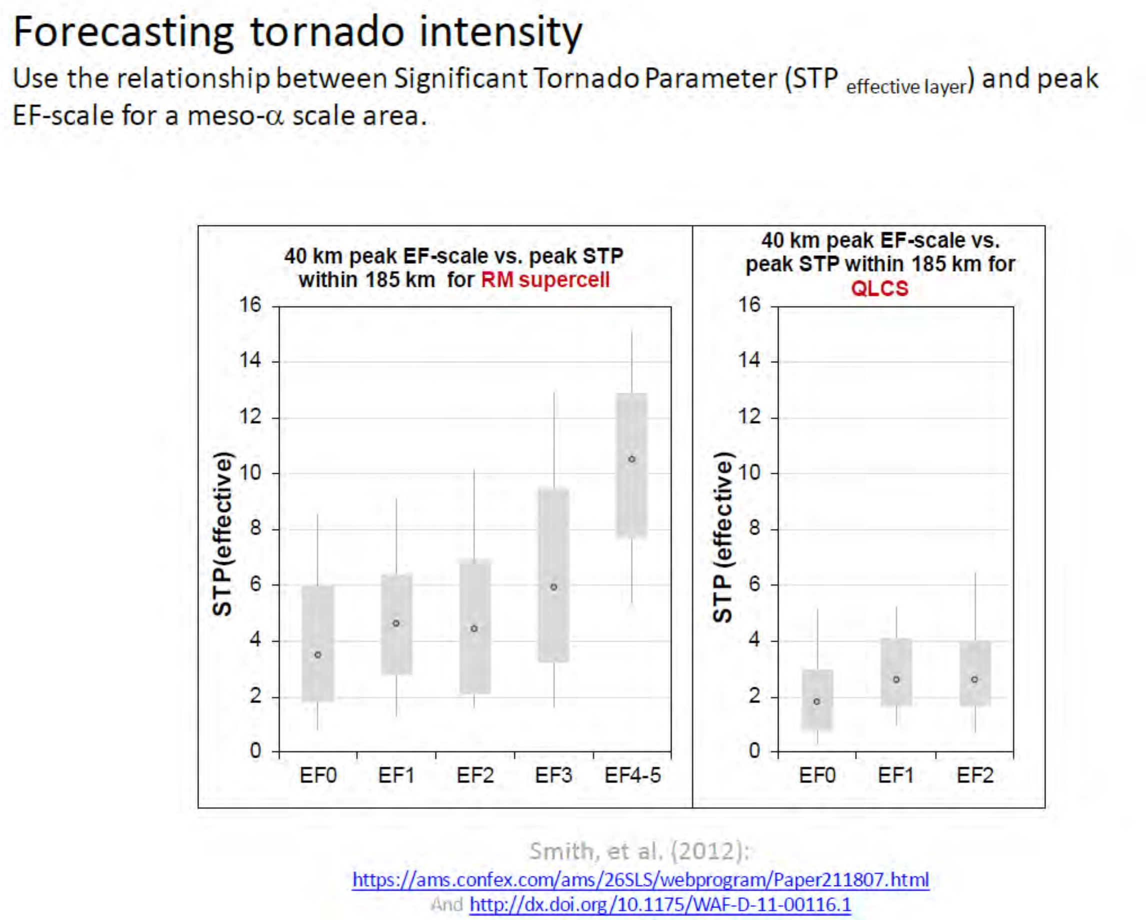
1. The Advanced Warning Operations Course (AWOC) – Core and Severe Tracks

Chris Spannagle, Veronica Holtz, Les Lemon, Steven Martinaitis, Dan McKemy, Tiffany Meyer, Mark Sessing, and Andrew Wood (all CIMMS at WDTB)

CIMMS scientists were heavily integrated into the development, delivery, and support of WDTB's Advanced Warning Operations Course (AWOC). AWOC is a blended learning course designed to provide training on advanced warning decision making techniques to every NWS forecaster with warning responsibility (Meteorologists and Hydrologists). AWOC was the first initiative to deliver warning decision-making training to all forecasters since the WSR-88D Operations Course of the 1990s, and it does so at a significantly reduced cost. WDTB was awarded the Department of Commerce Silver medal for the initial delivery of AWOC, and CIMMS personnel were critical to the success of AWOC.

In collaboration with WDTB instructors, CIMMS scientists made numerous changes to the AWOC from the previous versions of the course. Changes to the course included: (1) a new module on tornado warning guidance; (2) a new instructor-led training webinar on how to best issue warnings; (3) a new module on Social Science Aspects of Post Mortems (based on the Joplin, Missouri, Tornado Service Assessment); and (4) a new Weather Event Simulator simulation and simulation guide to address the updated training. CIMMS scientists also contributed logistical support for the AWOC, including answering forecasters' questions, assisting local facilitators, tracking student and forecast office progress using the NWS Learning Center (i.e., a Learning Management System), and providing completion certificates.

This project is ongoing.



Example from the Tornado Warning Guidance Quick Reference Guide developed as part of the Advanced Warning Operations Course (AWOC) Severe Track. This image compares the expected range of values for the Significant Tornado Parameter (STP) during right-moving supercells and quasi-linear convective systems (QLCS) tornadic events (based on work by Smith et al., 2012).

2. The Advanced Warning Operations Course (AWOC) – Flash Flood Track

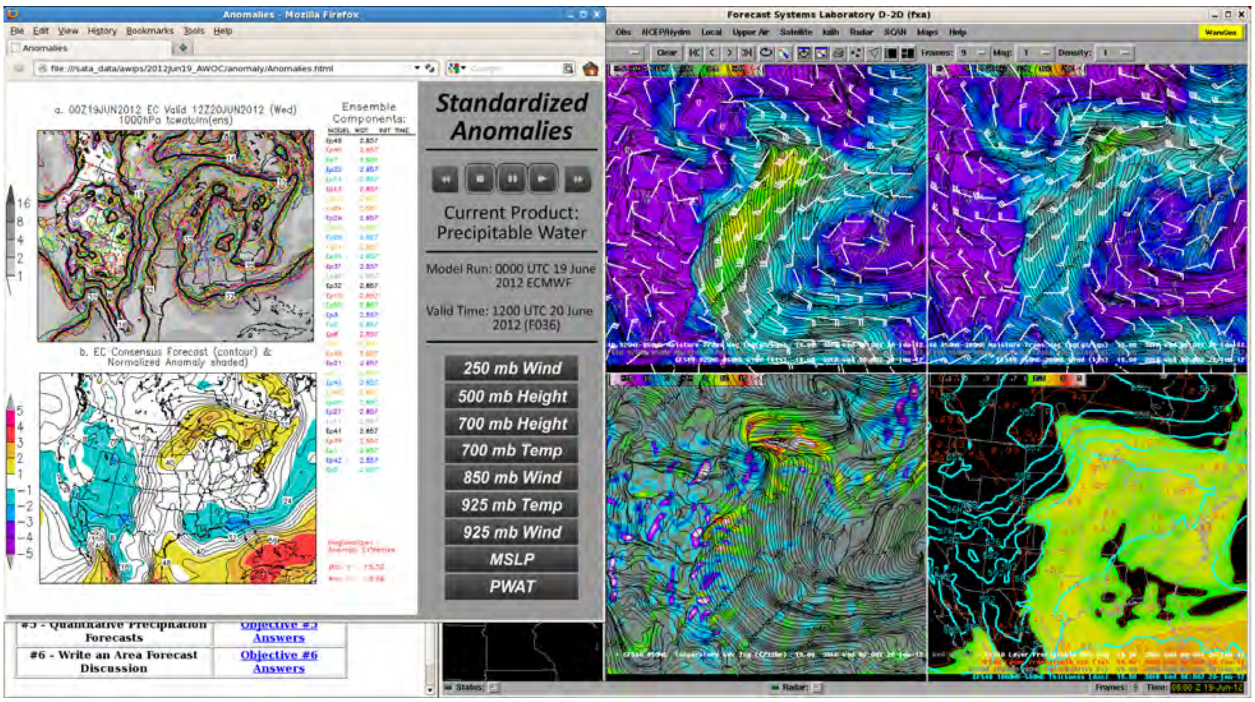
Steven Martinaitis and Mark Sessing (both CIMMS at WDTB)

CIMMS scientists were integral in developing a new track for AWOC specific to heavy rainfall and flash flooding (hereinafter referred to as the AWOC Flash Flood Track). The AWOC Flash Flood Track is a blended learning course designed to provide organized training to NWS forecasters (both meteorologists and hydrologists) on heavy rainfall and flash flood forecasting and warning decision making. The course employs a combination of updated material and pre-existing lessons that addressed findings and recommendations from recent NWS Service Assessments, such as the “Record Floods

of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010" and "Southeast United States Floods, September 18-23, 2009."

CIMMS staff and WDTB instructors delivered the course to NWS forecasters via a structured learning plan that contains a series of online modules and a two-part Weather Event Simulation (WES) component. Online course modules cover a variety of topics related to flash flood forecasting and warning responsibilities. The two-part WES simulation allows NWS forecasters to perform the two objectives. The first objective is to analyze forecast models, standardized anomalies, and quantitative precipitation forecasts (QPFs) to create a heavy rainfall and flash flood forecast. The second objective is to apply various observations and reports into the warning decision making process during a high-end flash flood event, including identifying situations that require enhanced wording and the "Flash Flood Emergency" statement.

This project is ongoing.



Screen capture of Application #1 of the Weather Event Simulator (WES) component of the AWOC Flash Flood Track, which focuses on the use of pattern recognition, meteorological ingredients, and standardized anomalies to forecast heavy rainfall events.

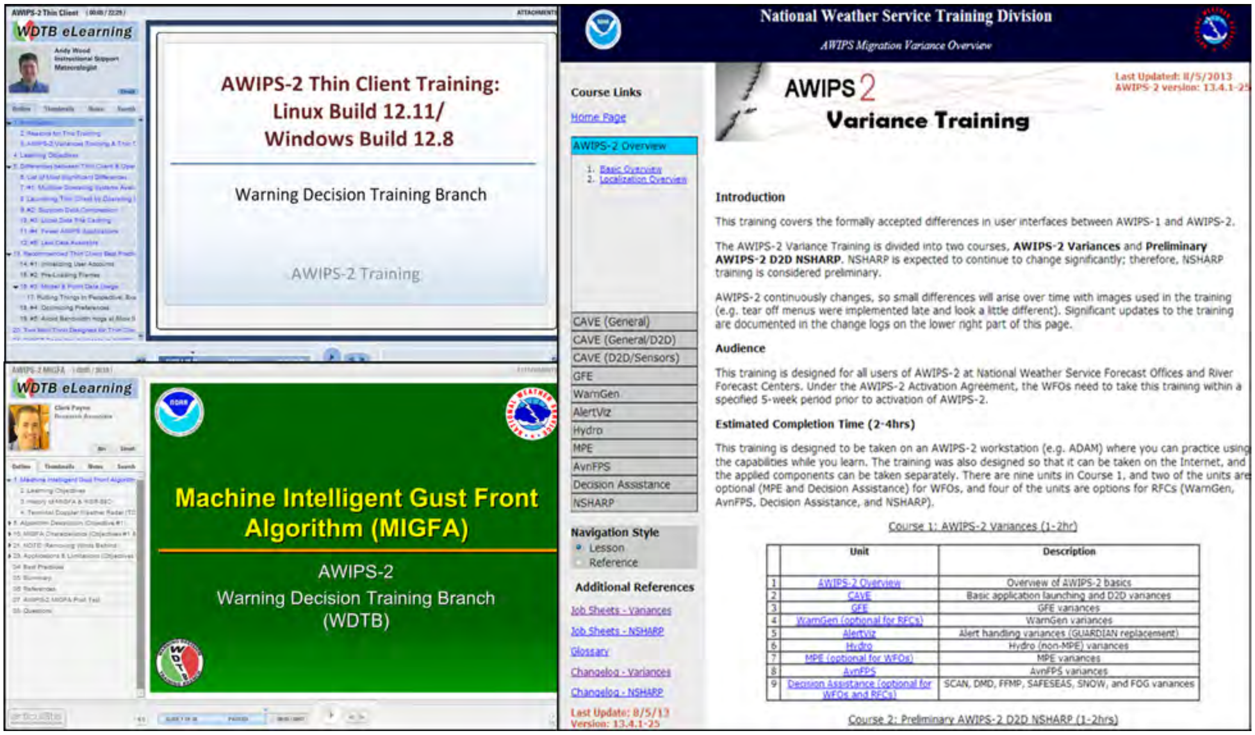
3. Advanced Weather Interactive Processing System (AWIPS) - II Training

Tiffany Meyer, Dale Morris, Dan McKemy, Chris Spannagle, Steven Martinaitis, Clark Payne, and Andrew Wood (all CIMMS at WDTB)

The NWS has embarked on a re-development of their AWIPS platform. The major focus of this AWIPS Technology Infusion project is the development by Raytheon Technology Services (the AWIPS prime contractor) of AWIPS-II, which initially consists of a conversion of the legacy AWIPS software into a modern services oriented architecture. Based in Java, this new software paradigm features a modular design with loosely-coupled components that communicate using an enterprise service bus and new data storage mechanisms, including the creation and usage of metadata. Two consequences of this new architecture include: (1) individual forecast offices must use new processes to localize and customize the software, and (2) a few hundred small functional changes introduced into the new platform. In support of this initiative, CIMMS staff at WDTB have developed a local real-time ingest of data into an AWIPS-II platform. All CIMMS at WDTB staff can learn the new software environment and discover any effects AWIPS-II may have on existing and new training and research initiatives. As a result of this initiative, CIMMS staff at WDTB have extensively tested the new platform and submitted trouble tickets on problems found, resulting in recommendations and improvements to the AWIPS-II software and documentation.

CIMMS staff at WDTB have designed, developed and released training materials for all forecasters and AWIPS Focal Points, in preparation for the migration to AWIPS-II. All forecasters are required to complete Variance training (on the differences between AWIPS-I and AWIPS-II) as part of their migration activities. This course is available in multiple locations including on the operational AWIPS-II workstations as a job reference. The Focal Point training consists of jobsheets, exercises, and asynchronous instructor-led presentations that contain many more technical details designed for those who need to configure and maintain AWIPS-II at each forecast office. In addition to these courses, CIMMS scientists at WDTB have created new training as updated applications in AWIPS-II have become available. MIGFA and Thin Client courses were created and published this year, as well as the installation and initial testing of Total Lightning, Tracking Meteogram, Hazard Services, and Data Delivery enhancements.

This project is ongoing.



This image shows examples of several different AWIPS-II related training: Thin Client (top left), MIGFA (bottom left), and Variance Training (right).

4. Distance Learning Operations Course (DLOC)

Mark Sessing, Les Lemon, Steven Martinaitis, Dale Morris, Mohamad Said, Clark Payne, Chris Spannagle, Veronica Holtz, Tiffany Meyer, Dan McKemy, and Andrew Wood (all CIMMS at WDTB)

The WSR-88D Distance Learning Operations Course (DLOC) continues to be an area of active collaboration between CIMMS and the WDTB. DLOC teaches recently hired NWS meteorologists a wide range of topics regarding the WSR-88D and severe weather, including: radar theory, operations of the radar, AWIPS D2D functionality, radar data interpretation, storm interrogation techniques, and severe storm threat assessment and forecasting. DLOC is a critical piece in the development of new NWS forecasters for warning operations. The NWS requires all forecasters who may be responsible for issuing warnings in the future to complete the course. This course is taught via a combination of teletraining, web-based instruction, on-station training, and residence training.

CIMMS staff members are closely involved with the development of DLOC. The collaborative work includes applied research on future radar improvements such as dual-polarization and current WSR-88D capabilities to assess severe weather and flash flooding threats. As part of this training, CIMMS personnel work closely with radar engineers and software developers to determine how recent updates to different components of the WSR-88D and AWIPS impact the system as a whole. This work

allows CIMMS staff to assist their WDTB collaborators in developing and updating significant portions of DLOC during the past year. Another area where CIMMS staff members play a critical role with DLOC is during the residence component of the course. The collaborative work with WDTB during these classes includes developing lecture materials, exercises, and simulations; delivering presentations, and providing expertise on warning-decision making issues to the class participants.

This project is ongoing.

National Weather Service interns participate in one of multiple severe weather warning simulations during the Distance Learning Operations Course workshop held in Norman, OK.

5. Dual-Polarization WSR-88D Operations Training

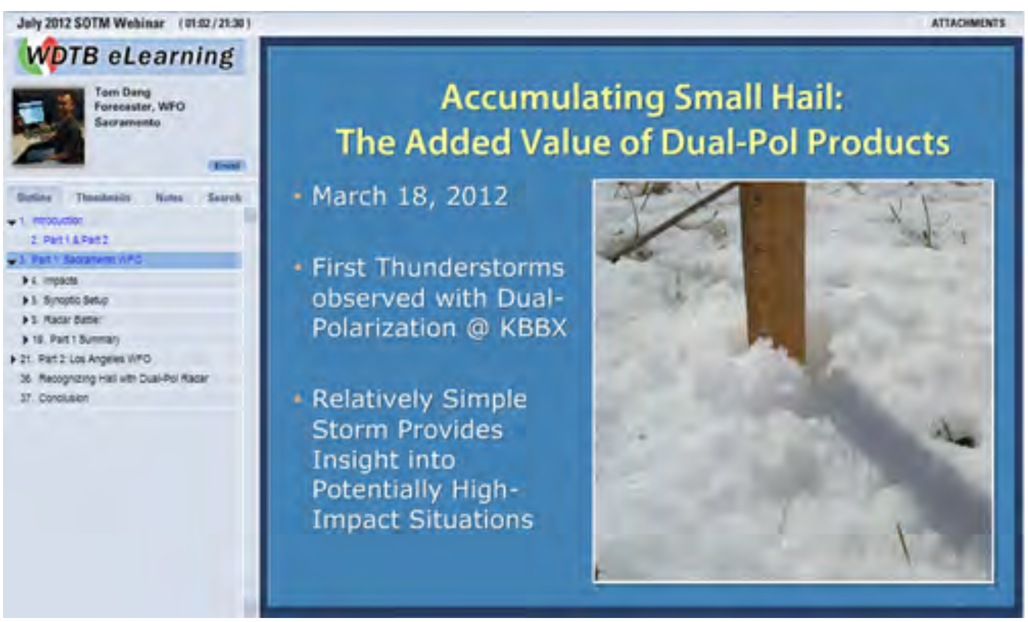
Clark Payne, Les Lemon, Mark Sessing, Chris Spannagle, Veronica Holtz, and Andrew Wood (all CIMMS at WDTB)

The upgrade to dual-polarization technology (dual-pol) on the WSR-88D network is comparable to the upgrade to the WSR-88D network itself back in the 1990s. As of the end of the fiscal year, all of the NWS radars in the network have been upgraded. With the upgrade come the new dual-pol base variables, in addition to the current base moments. These new variables have been shown to improve radar-derived precipitation

estimates, discriminate between hydrometeor types (i.e., rain, hail, snow, etc.), and identify new storm signatures (i.e., ZDR column) that can help a forecaster better interrogate storms for issuing warnings to the public. NWS forecasters were required to complete the Dual-Polarization Radar Operations Course developed by WDTB instructors and CIMMS personnel at WDTB previously. The training completions were tracked in the NWS Learning Center (i.e., a Learning Management System). CIMMS personnel at WDTB were integral to tracking completions of NWS employees required to complete the training. Because of these efforts of CIMMS personnel, the NWS forecasters as a group generally completed the dual-pol training well ahead of schedule and the WDTB received the National Weather Association, Operational Achievement Group Award for this sub-project. As of June 30, 2013, the dual-pol training courses were officially retired and rolled into the DLOC and AWOC tracks.

In addition to the continued support of the Dual-Polarization Radar Operations Course, CIMMS personnel were highly involved with the Storm of the Month facilitated by the WDTB. These webinars invited NWS forecasters to share one story of how the upgraded dual-pol WSR-88D impacted their operations. CIMMS personnel at WDTB have worked extensively with WDTB instructors to coordinate, implement, and archive these webinars on a monthly basis. These webinars were well received by NWS and non-NWS (who could only view the archived versions) forecasters, but were discontinued after May 2013 once the dual-polarization upgrade of the WSR-88D was complete.

This project is ongoing.



A "Storm of the Month" webinar slide presented by a forecaster from California. The forecaster showed the added value of dual-pol during a small hail event that resulted in accumulating hail which had direct impacts to their stakeholders.

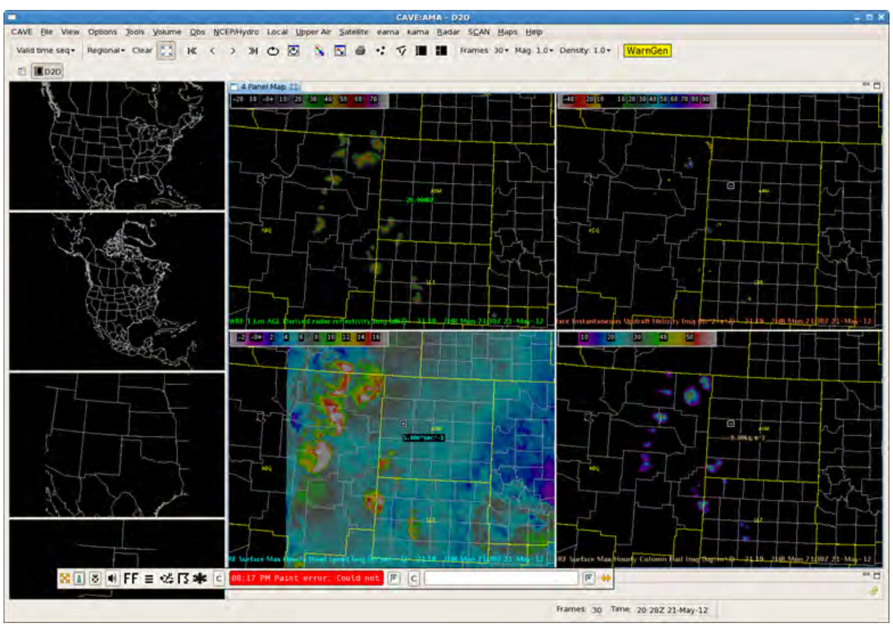
6. Experimental Warning Program/NOAA Hazardous Weather Testbed Support

Clark Payne (CIMMS at WDTB)

The 2013 Spring Experiment (EWP2013) occurred during 6-24 May 2013. The goal of this project was to test and evaluate new applications, techniques, and products to support NWS forecast office severe convective weather warning operations. Three primary projects were geared toward forecast applications this year: Evaluation of the Multiple Radar/Multiple Sensor (MRMS) gridded products, evaluation of multiple CONUS GOES-R convective applications (including pseudo-geostationary lightning mapper products when operations were expected within the Lightning Mapping Array domains [OK, western TX, AL, DC, FL]), and evaluation of model performance and forecast utility of the OUN WRF when operations were expected in the Southern Plains.

Forecasters participated in the experiment one week at a time. At the end of the week, they delivered a webinar, entitled "Tales from the Testbed," to other NWS forecasters detailing their experiences. CIMMS staff facilitated these weekly webinars with the weekly participants developing a short PowerPoint discussing the experiment and some examples of what they learned. Besides facilitating the webinar, CIMMS staff attended the daily weather briefings and stayed until the end of each day's shift to assist the participants with screen captures and write-ups for the webinar presentation.

This project is ongoing.



Example graphic included in the "Tales from the Testbed" webinar facilitated by CIMMS staff during the 2013 Spring Experiment. This graphic shows a forecast graphic from the OUNWRF model, displayed in AWIPS-II, including 1 km AGL Simulated Reflectivity (top left) and Maximum Surface Hourly Wind Speed (bottom left).

7. Weather Event Simulator (WES) – I

Dan McKemy and Mohamad Said (both CIMMS at WDTB)

Now in its twelfth year since the initial release, NOAA's NWS Weather Event Simulator (WES) continues to play an expanding role in NWS training. Every NWS forecaster with warning responsibility is required by NWS Directive 20-101 to take two simulations using the WES for each significant weather season per year. The WES is a key part of the WDTB's major training initiatives, allowing students to apply lessons in an operational context. In the past year, the WES was used in the development of training simulations for the AWOC, DLOC, and Dual-Polarization Radar Operations Course.

This work is ongoing as the WES architecture continues to remain in step with AWIPS-I releases. WES 9.10 was released in January 2013 to maintain this paradigm. This updated version of WES applied various fixes for AWIPS software components, including the Four-Dimensional Storm Interrogator (FSI), the Graphical Forecast Editor (GFE), and various D-2D display tools. Improvements were also made to optimize processing FSI data in WES, as well as making the WES more user friendly and compatible for NOAA staff. CIMMS staff provided extensive support to forecast offices in the installation and troubleshooting of this most recent software release, and responded to technical questions users had.

This project is ongoing.

A Distance Learning Operational Course (DLOC) student uses the Weather Event Simulator to develop warning decision process skills.

8. Weather Event Simulator (WES) – II

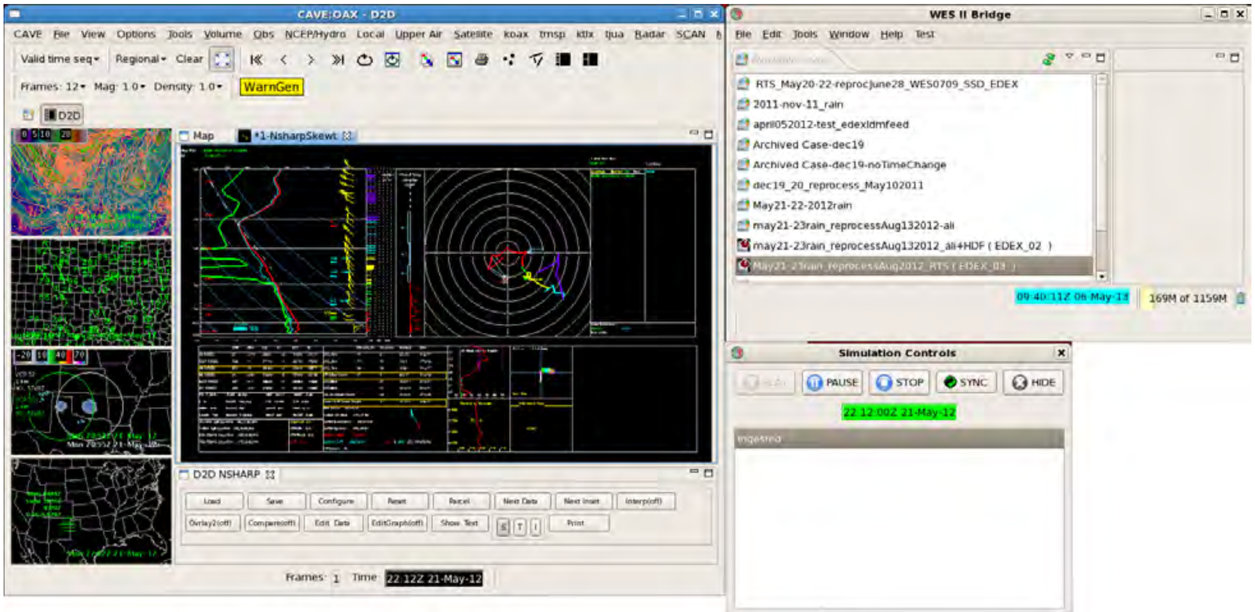
Dale Morris, Dan McKemy, Tiffany Meyer, and Mohamad Said (all CIMMS at WDTB)

The new AWIPS-II software being developed and deployed in all NWS forecast offices results in the obsolescence of the existing WES-I. A need therefore exists to preserve existing simulation functionality provided by WES-I and support the NWS Directive 20-101 requirement for every forecaster to complete two simulations prior to each significant weather season. As a result, the CIMMS staff and WDTB instructors have designed and are developing the WES-II Bridge based on the AWIPS-II platform. This design will also serve as a prototype method of incorporating training functionality into the "baseline" AWIPS-II system. To support this development and to ensure compatibility between AWIPS-II and WES-II Bridge, significant collaboration occurred between CIMMS personnel, WDTB instructors, the NWS Office of Science and Technology, and the AWIPS-II contractor.

CIMMS staff at WDTB collaborated with the NWS and the AWIPS-II contractor on the design and implementation of an updated archival solution, based on changes in both the AWIPS-II architecture and the playback requirements of WES-II Bridge. WES-II Bridge is the primary method that NWS forecasters as well as researchers and students at universities and other institutions will utilize to access archived case data in AWIPS-II. As a result, CIMMS at WDTB performed significant amounts of testing to verify the integrity of the archive, across most types of data available in AWIPS-II, including model, satellite, radar, surface and upper-air observations, derived products, and the like.

CIMMS staff at WDTB have tested and refined WES-II Bridge functionality, including: the ability to synchronize simulations for an emerging distributed simulation requirement. This ability to synchronize simulations will eventually span the NWS enterprise from national and regional centers down to individual forecast offices, and perhaps to eventually include partners. The WES-II Bridge also features a case converter so that existing AWIPS-I format case data will be viewable in the WES-II Bridge/AWIPS-II system; otherwise most previously collected AWIPS-II data would be unusable. The case converter will allow training and research activities based on the AWIPS-I storage paradigm to continue in the new system. The WES-II Bridge also features a streamlined method of presenting non-AWIPS information (spotter reports, video, briefings, etc.) during a simulation (formerly called WESSL – the WES Scripting Language). Exploiting messaging and geospatial capabilities of the AWIPS-II infrastructure, the updated WESSL provides a method to engage forecasters with feedback as they complete simulations. The initial release of WES-II Bridge to NWS WFOs is anticipated in 2013 or 2014, pending AWIPS-II development and deployment activities.

This project is ongoing.



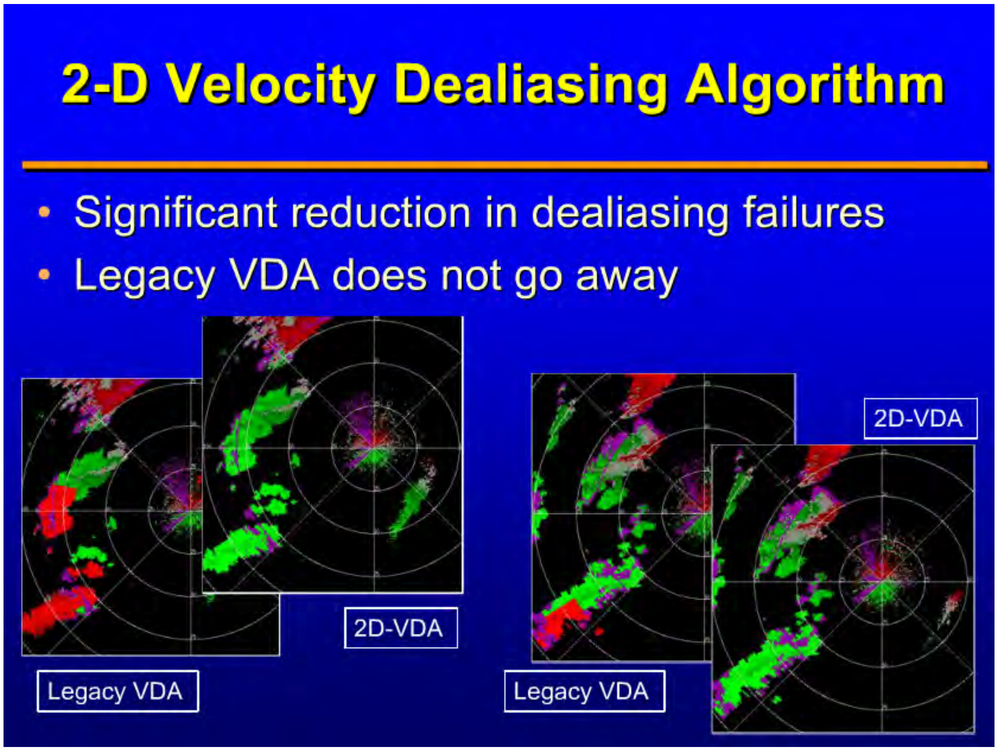
Sample displays shown from the WES-II Bridge software. Left: The AWIPS-II visualization software known as CAVE (Common AWIPS Visualization Environment) in its "D2D perspective". Top right: The WES-II Bridge main window allows cases to be loaded, unloaded, edited, simulated, and reviewed. Bottom right: The WES-II Bridge simulation control window controls the time of the simulation and its current state (play, paused, stopped). As the simulation progresses, the WES-II Bridge software ensures that the simulation window and the CAVE window are synchronized in time.

9. WSR-88D Build Improvement Training

Andrew Wood, Clark Payne, and Mark Sessing (all CIMMS at WDTB)

During the past year, outside of the ongoing dual-polarization technology upgrade, minor upgrades were made to the WSR-88D Radar Data Acquisition Unit (RDA) and Radar Product Generator (RPG) software. This latest software upgrades (Builds 13.1 & 13.2) restores some algorithms unavailable after the dual-polarization technology upgrade (e.g., Clutter Mitigation Detection and the Automated Volume Scan Evaluation and Termination algorithms) and adds other algorithms (e.g., 2-D Velocity Dealiasing Algorithm). CIMMS personnel have worked closely with WDTB instructors and partners at the ROC during training development for NWS staff (which is also available for NWS partners).

This project is ongoing as the WSR-88D continues to receive periodic software and hardware upgrades.



Example slide from on-line training developed by WDTB for WSR-88D Build 13.1. This slide discusses the 2-D Velocity Dealiasing Algorithm (new to Build 13.1) and how it improves upon the Legacy Velocity Dealiasing Algorithm.

CIMMS scientists help explain warning decision making to OU School of Meteorology students during a lab exercise using the Weather Event Simulator.

Publications

Lu, G., S.A. Cummer, J. Li, L. Zigoneanu, W.A. Lyons, M.A. Stanley, W. Rison, P.R. Krehbiel, H.E. Edens, R.J. Thomas, W.H. Beasley, S.A. Weiss, R.J. Blakeslee, E.C. Bruning, D.R. MacGorman, T.C. Meyer, K. Palivec, T. Ashcraft, and T. Samaras, 2013: Coordinated observations of sprites and in-cloud lightning flash structure. *Journal of Geophysical Research: Atmospheres* **118**:12, 6607-6632, doi:10.1002/jgrd.50459.

Meyer, T.C., T. J. Lang, S. A. Rutledge, W. A. Lyons, S. A. Cummer, G. Lu, and D. T. Lindsey, 2013: Radar and lightning analyses of gigantic jet-producing storms. *Journal of Geophysical Research: Atmospheres* **118**, 2872–2888. doi:10.1002/jgrd.50302.

Meyer, T.C., 2013: Radar and lightning analyses of gigantic jet-producing storms. Masters Thesis, Department of Atmospheric Science, Colorado State University, 59 pp.

Warning Decision Training Branch, 2012: The Advanced Warning Operations Course. Available at: http://www.wdtb.noaa.gov/courses/awoc/

Warning Decision Training Branch, 2013: The AWOC Flash Flood Track Course Page. Available at: http://www.wdtb.noaa.gov/courses/awoc/flashflood.html

Warning Decision Training Branch, 2012: The AWIPS-2 AlertViz Overview Course. Available at: https://doc.learn.com/login.asp?lcid=178419&requestedurl=courseredirect.asp?courseid=9804

Warning Decision Training Branch, 2012: Derived Parameters Course. Available at: https://doc.learn.com/login.asp?lcid=178419&requestedurl=courseredirect.asp?courseid=9803

Warning Decision Training Branch, 2013: The AWIPS-2 User Training. Available at: https://doc.learn.com/learncenter.asp?id=178419&page=141#User.

Warning Decision Training Branch, 2013: The AWIPS-2 Application Focal Point Transition Training. Available at: https://doc.learn.com/learncenter.asp?id=178419&page=141#FocalPoint.

Warning Decision Training Branch, 2013: The AWIPS-2 Machine Intelligent Gust Front Algorithm (MIGFA) Training. Available at: https://doc.learn.com/login.asp?lcid=178419&requestedurl=courseredirect.asp?courseid=11419

Warning Decision Training Branch, 2013: The AWIPS-2 Thin Client Training. Available at: http://web.wdtb.noaa.gov/secure/awips2/thinClient/player.html

Warning Decision Training Branch, 2012: The Distance Learning Operations Course (DLOC). Available at: http://www.wdtb.noaa.gov/courses/dloc/.

Warning Decision Training Branch, 2013: WSR-88D Build 13 Training. Available at: http://www.wdtb.noaa.gov/buildTraining/Build13-1/.

Warning Decision Training Branch, 2012: The Weather Event Simulator. Available at: http://www.wdtb.noaa.gov/tools/WES/.

Awards

The WDTB was awarded the National Weather Association's Operational Achievement Group Award "For delivering an innovative and highly effective training course, ahead of schedule, for NWS forecasters and partners as a critical element of the nation's dual polarization weather radar upgrade."

OST Project 13 – Research on Integration and Use of Multi-Sensor Information for Severe Weather Warning Operations

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB in Norman, OK)

NOAA Technical Lead: Stephen Smith (NWS/OST/MDL/DAB)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Objectives
Work with CIMMS/NSSL scientists in developing multiple-radar/multiple-sensor (MRMS) severe weather warning applications and advanced display systems and transferring that technology to NWS operational systems; collaborate with the NOAA Hazardous Weather Testbed - Experimental Warning Program at the National Weather Center in Norman.

Accomplishments

1. Operations Coordination for the Experimental Warning Program's 2013 Spring Experiment

The ninth full year of the CIMMS/NWS-Meteorological Development Laboratory (MDL) scientist position was completed during this review period. During this year, the scientist, Greg Stumpf, maintained his position as Operations Coordinator for the Experimental Warning Program's 2013 spring experiment (EWP2013) in the NOAA Hazardous Weather Testbed (HWT). The EWP is a proving ground for evaluating new applications, technology, and services designed to improve NWS short-fused (0-2 hour) hazardous convective weather warning decisions. He was responsible for the logistical coordination of a three-week real-time operational experiment in which eighteen (18) visiting forecasters from across the United States (and several from other countries) traveled to the NWC to evaluate these specific new innovations: 1) MRMS severe weather applications (more on this later); 2) the "OUN WRF", a version of the WRF numerical nowcast model developed by the NWS forecast office in Norman, OK; 3) an upgraded version of the NOAA Global System Division (GSD) Local Analysis and Prediction System (LAPS) which uses a variational analysis scheme; 4) a dual-polarization radar Hail Size Discrimination Algorithm (HSDA); 5) GOES-R Proving Ground convective nowcast and warning products; and 6) AWIPS-II. The results from these evaluations are being used to further develop these potential improvements to NWS warning services. Stumpf was responsible for creating and reformatting NSSL Web content describing activities in the EWP spring programs since 2008, and authored an extended manuscript and presentation on EWP2011 and EWP2012 for the 26th AMS Severe Local Storms Conference. He collaborated with other CIMMS, NSSL, WDTB, and university scientists, in a number of planning retreats and meetings for the HWT,

and to help consult and develop content related to the new Forecasting A Continuum of Environmental Threats (FACETs) initiative at NSSL. Stumpf traveled to Weiner-Neustadt, Austria, for 1.5 weeks, to participate in the European Severe Storms Laboratory (ESSL) convective weather forecast/nowcast testbed experiment. This trip included the delivery of a presentation on the EWP and FACETs activities, as well as consultation to improve their testbed operations. *This project is also reported in NSSL Project 5.*

2. Severe Weather Warning R&D

Stumpf continues to collaborate with the severe weather warning R&D activities at CIMMS and NSSL and served as the co-principal investigator for the MRMS severe weather warning algorithm experiment in the testbed. *This project is also reported in NSSL Project 6.* During FY13, he continued to support a limited capability to import and display several popular MRMS products to all NWS forecast offices in Southern, Central and Eastern Region. More importantly, during FY13, the MRMS implementation project charter was officially signed, and the process to transfer the technology to operations began. The initial operating condition for the MRMS implementation will be ready during FY14. Stumpf was involved in the following activities related to the MRMS tech transfer: 1) Conducted an experiment during the EWP2013 Hazardous Weather Testbed spring program to gather MRMS-Severe “best practice” information as the initial basis for the development of warning decision training materials with the WDTB; 2) acted as the main subject matter expert (SME) for the MRMS severe weather product suite and AWIPS-II issues related to MRMS; 3) developed a new Vertically-Integrated Ice (VII) algorithm within WDSSII (C++) for MRMS based on request from WFO FWD and SPC; and 4) began the development of a collaborative MRMS “community” on the NWS Virtual Laboratory (VLab). In addition, he served on the VLab Support Team, to help design, develop, and implement the NWS VLab as a whole.

3. Lightning Jump Algorithm Evaluation

Stumpf continued collaboration with other CIMMS and external scientists to evaluate a Lightning Jump Algorithm (LJA; Schultz et al. 2009) for the NWS. He developed an enhanced algorithm verification plan, and may carry out this evaluation during FY14. *This project also is reported in NSSL Project 6.*

4. Development of Innovative Methods to Quantitatively Evaluate Severe Weather Warnings

A project to develop innovative methods to quantitatively evaluate severe weather warnings continued in FY13. The technique includes geospatial (gridded) verification methods that can be used to better determine the “goodness” of severe weather warnings. The verification system is a major aspect of the Forecasting A Continuum of Environmental Threats (FACETs) initiative at NSSL, and will be used to evaluate new hazardous weather warning concepts such as a continuous hazard system (“threat-in-motion” or TIM). Stumpf participated in a collaborative study with four NWS forecast

offices to evaluate the TIM concept from an operational workload standpoint. This study looked at the entire 27 April 2011 severe weather outbreak. In addition, work began to extend the evaluation of automated threats-in-motion for the 27 April 2011 event beyond just the Tuscaloosa-Birmingham storm to all of the afternoon supercell storms that were tornado warned. Results will be reported in FY14.

5. AWIPS-II

Stumpf spent some time enhancing development skills in AWIPS-II, attended several developer training workshops, participated on the AWIPS-II Enhanced Product Development Team training sessions, built more programming expertise in Java. He continues to serve as the project lead for the Four-Dimensional Stormcell Investigator (FSI), the project which adapted the NSSL WDSSII 3D/4D base radar display application into AWIPS. Work included consultation on modifications for FSI for new elevation scan angle coverage patterns.

Stumpf continued to be involved with the AWIPS-II Hazard Services software project, in collaboration with the NOAA Global Systems Division (GSD). This included the completion of an AWIPS-II Statement Of Work on the concept of Probabilistic Hazard Information (PHI) implementation in AWIPS-II.

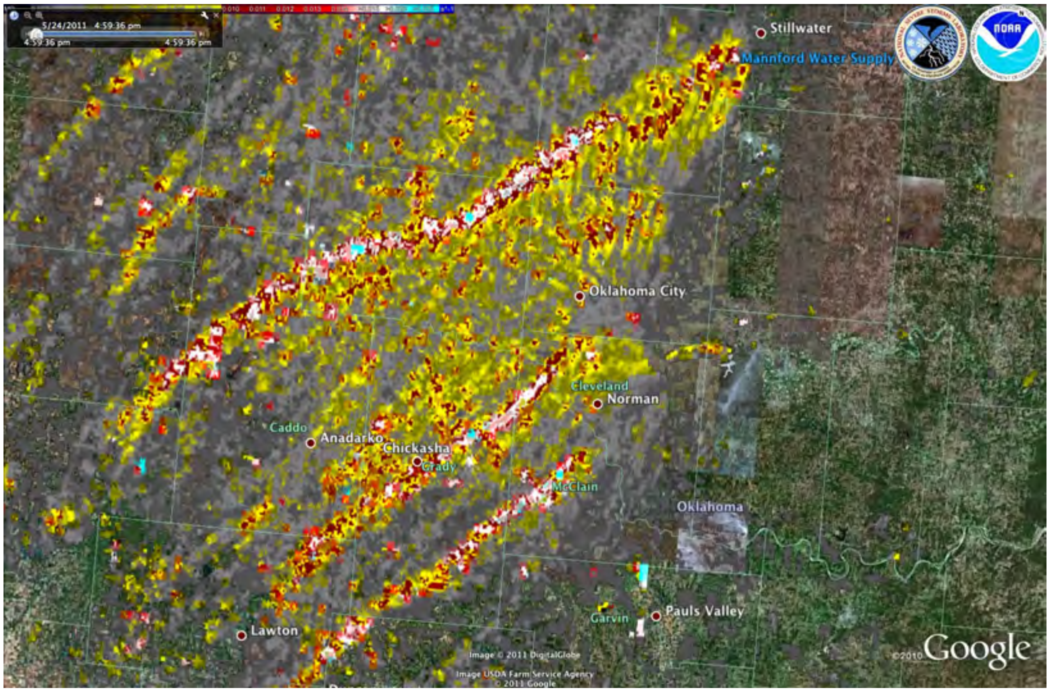
6. Central Weather Bureau (Taiwan) Activities

Stumpf conducted a customer service visit to the Central Weather Bureau in Taipei, Taiwan. This included the development and delivery of PowerPoint and hands-on training for WSR-88D storm algorithms, the System for Convective Analysis and Nowcasting (SCAN), and the FSI. In addition, informational briefings on MRMS and the EWP in general were provided.

These projects are ongoing.

Awards

Greg Stumpf is part of the team that won the NOAA Technology Transfer Award for leading the development of an on-demand, near real-time, web-based tool for tracking severe weather, tornadoes, and hail swaths across the continental US (see figure below). This tool is based on the MRMS severe weather algorithms.



On-Demand "rotation tracks" from the 24 May 2011 tornado outbreak in central Oklahoma.

NWSTC Project 14 – Forecast Systems Optimization and Decision Support Services Research Simulation and Training

NOAA Technical Leads: John Ogren (NWSTC), Jeffrey Zeltwanger (NWSTC), Teresa Murphy (NWSTC), Jerry Griffin (NWSTC), Jim Jones (NWSTC), Hattie Wiley (NWSTC), Dave Cokely (NWSTC), Dave Cokely (NWSTC), Randy Rieman (NWS/OCWWS/HSD/HSUPB, Mark Glaudemans (NWS/OCWWS/HSD/HSUPB), Yelena Platt (NWS/OOS/OD/FMB), Scott Burgoon (NWS Headquarters), Jim Poole (NWSTC), Cathy Burgdorf (NWSTC), Kim Runk (NWS/OPG)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

All projects are ongoing.

Objectives
The objective of the NWSTC is to train those in the NWS to achieve the overall mission of protecting lives and property. CIMMS projects help achieve this objective.

Accomplishments

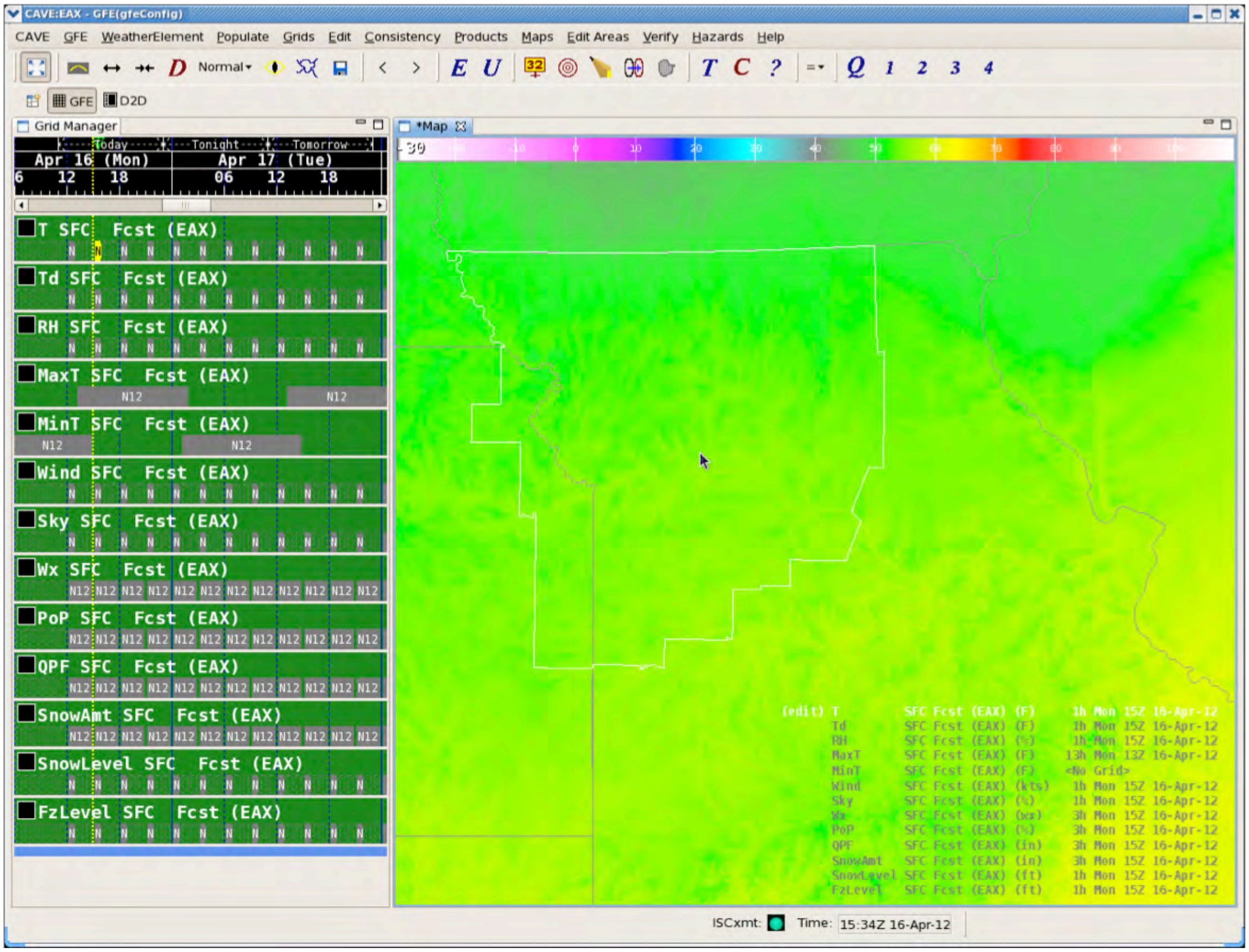
1. Using Graphical Forecast Editor (GFE) in the Forecast Process

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC), Hattie Wiley (NWSTC), Teresa Murphy (NWSTC), Kevin Freeman (EPP)

NWS forecasters use Graphical Forecast Editor (GFE) software to produce weather element forecast grids for the dissemination to the public. Our goal was to create a new LMS distance-learning course for the AWIPS-II version of GFE. The reason for creating this course is because there does not exist a nationally adopted basic GFE user training. We sought to develop a nationally relevant GFE basic user course, which adapts existing materials created by the NWSTC and appends new materials.

Our team desired to use an innovative technique for the GFE training, which was to create interactive distance learning. Using Adobe Captivate software, we were able to create simulation training, where we can take screen captures of the GFE software interface and place it into Captivate. Captivate is a program similar to Power Point, except it provides functions like click boxes to advance slides, as well as highlight boxes, text captions, and even recorded audio. Generally, we would place our GFE screen captures into Captivate, and play audio we recorded to give directions and to explain certain aspects, tools, and procedures of GFE. Each video also was given closed captioning capabilities to ensure 508 Compliance. Along with the simulations, we developed job sheets for some of the more complicated procedures in GFE.

An example of a completed simulation can be found at http://www.nwstc.noaa.gov/GFE/GFEBasicUser/sims/Analyze_grid_in_SE_using_sample_contour_tools.swf. This simulation shows a student how to analyze modeled forecast grids using the Sample and Contour Tools. There are 36 simulations total throughout the Using GFE in the Forecast Process course. These simulations were produced from June 2012 to September 2012. The course was released on 13 September 2012.



GFE interface populated with forecast grids.

2. Introduction to GFE

Justin Schultz (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC)

Originally, there was a plan to include a lesson in the Using GFE in the Forecast Process course that provided introductory knowledge about GFE. However, we felt it would be better to take this particular lesson and make it its own distance-learning module, which was called Introduction to GFE. The reasoning was that most NWS personnel have experience in GFE already, and hence, do not need an introduction to the software. If someone needed an introduction to GFE, he or she could go through the Introduction to GFE module, which describes the purposes of GFE, who uses it, how to launch it, and its basic components.

Development of the course began in late August 2012. It took only a few weeks to develop the material and the HTML since most of the material had already been written into Using GFE in the Forecast Process. We simply took the lesson out of the GFE User training and adapted it into its own HTML shell. Introduction to GFE was released on 13 September 2012.

3. GFE Focal Point Training

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC), Hattie Wiley (NWSTC), Teresa Murphy (NWSTC)

With the advent of AWIPS-II, up-to-date training for GFE Focal Points needed to be developed. The format of this course is different than other GFE courses since this one was built as an entire curriculum, broken up into seven individual courses, consisting of information on (1) basic GFE concepts; (2) GFE Perspective information; (3) server configuration; (4) intersite coordination grids; (5) GFE command line scripts; (6) BOIVerify configuration; and (7) service packup practices.

Review and updates of the course content began 7 November 2012, and Schultz wrote the LMS and Training Portal announcements for this course, as well as updated the quiz questions for each course. The GFE Focal Point course was officially released 13 March 2013.

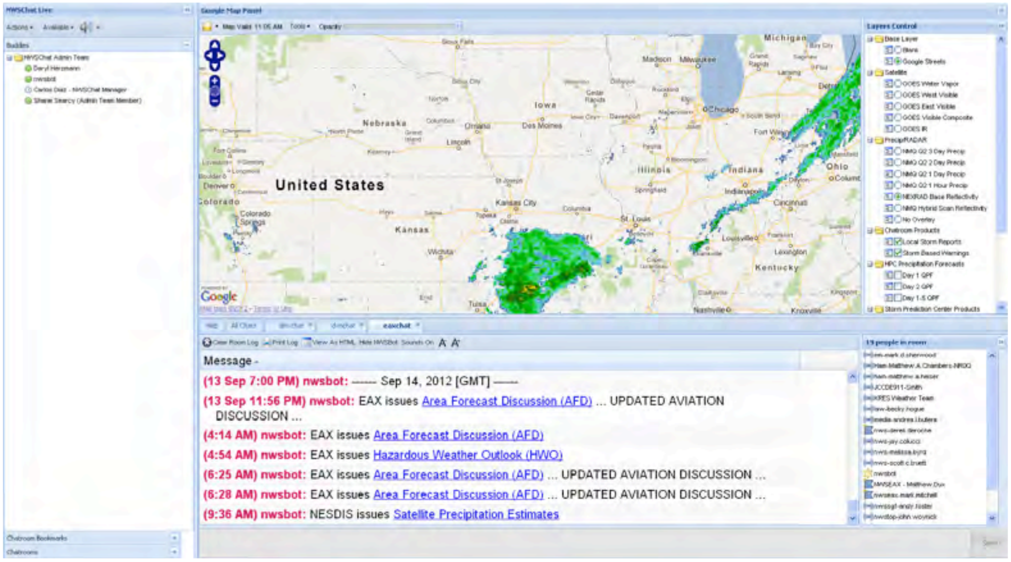
4. Using NWSChat

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC), Hattie Wiley (NWSTC), Teresa Murphy (NWSTC), John Ogren (NWSTC), Daryl Herzmann (NOAA Configuration Branch), Bradley Small (NWS Forecast Office, Des Moines, IA), Carlos Diaz (NOAA Operations and Requirements Division), Shane Searcy (NWS Forecast Office, Des Moines, IA), Karl Jungbluth (NWS Forecast Office, Des Moines, IA)

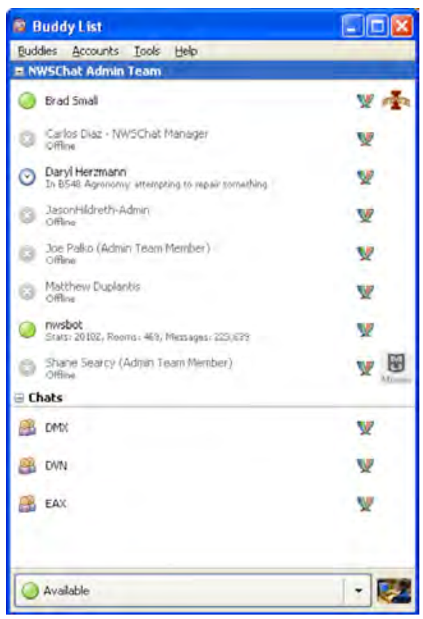
NWSChat is an instant messaging program used by NWS operational personnel and NWS partners (i.e., members of the emergency management community, government partners of the NWS, and electronic and television media) to share critical warning decision expertise and other types of significant weather information essential to the NWS's mission of saving lives and property. NWSChat has been used in the NWS for several years, but no formal training existed. This distance-learning course provides the knowledge and skills required by a NWS user to utilize NWSChat.

Development of training was somewhat difficult due to NWSChat's binary nature. It can be accessed either through an instant messaging client (e.g., Pidgin) or online (NWSChat Live). Therefore, we produced two lessons where each interface is described independently of the other. This way, the student would not get the two interfaces confused. We also developed Articulate presentation pieces, which are interactive presentations that show images and point out specific portions of program interfaces.

After internal and external reviews, the course was released 31 October 2012.



NWSChat Live interface (accessed online).



NWSChat interface (accessed through Pidgin).

5. Community Hydrologic Prediction System (CHPS)

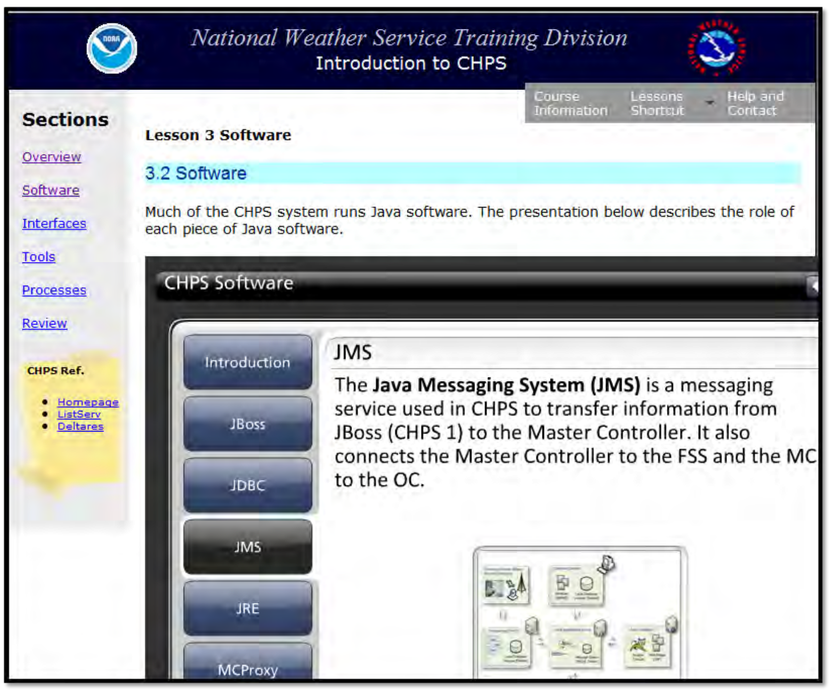
Megan Taylor (CIMMS at NWSTC), Justin Schultz (CIMMS at NWSTC), Teresa Murphy (NWSTC), Hattie Wiley (NWSTC), Dave Cokely (NWSTC), Randy Rieman (NWS/HSUPB), Mark Glaudemans (NWS/HSUPB)

CHPS is the software that replaced the National Weather Service River Forecast System. CHPS was designed to (1) provide more efficient operations at River Forecast Centers (RFCs); (2) incorporate external models; and (3) provide an infrastructure for

coordinating with external partners. Overall this training fits into the NOAA Strategic Goal 2 as it would prepare RFC forecasters for their positions and allow them to make more accurate decisions in the forecasting process.

During the fiscal year, significant progress was made in the development of CHPS training. First was the release of Introduction to CHPS. This was followed by a course modification of CHPS Basic Configuration, creation of CHPS Display Configuration Training (see project 6 below), and creation of CHPS Advanced Configuration Training (see 7 below). Taylor was both a writer/developer in CHPS and also an instructional designer – in this capacity, she reviewed training and provided ideas on media and images to enhance the training. With this model, CHPS RFC User Training was released. Schultz's role in CHPS is described more fully in projects 6, 7, and 8 below.

The future of CHPS will be continued training development as needed in the field. The type of training also will depend on modifications made to the software.



Screenshot of Introduction to CHPS – to see all CHPS courses, go to www.nwstc.noaa.gov/CHPS.

6. CHPS Display Configuration Training

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Teresa Murphy (NWSTC)

Schultz coded the job sheet PDF files into the HTML of the appropriate lesson pages for the Display Configuration course. In November 2012, he developed the quiz files used

to produce review material, and a Facebook note was written about this course. ***Display*** The course was released 11 December 2012.

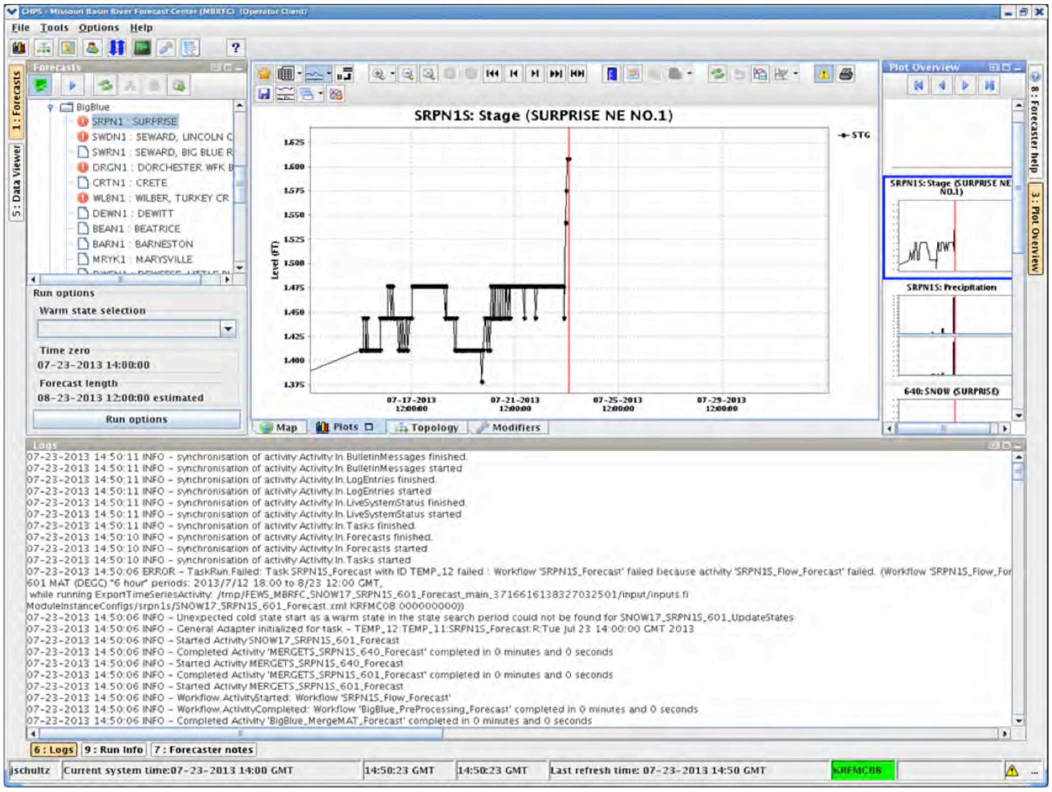


Image of the CHPS interface on NWSTC servers.

7. CHPS Advanced Configuration Training

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Teresa Murphy (NWSTC)

The purpose of this course is to provide descriptions and examples for modifying CHPS configuration files in order to add functionality and improve performance. Schultz reviewed the course and mapped out media pieces (visual media, such as videos or Captivate presentations) for the course. Course HTML development began late in 2012 and after writing LMS and Training Portal blurbs for Advanced Configuration, as well as a Facebook note, to link the course from the NWSTC Facebook page, the course was published on 15 January 2013.

8. CHPS User Training

Justin Schultz (CIMMS at NWSTC), Teresa Murphy (NWSTC), Hattie Wiley (NWSTC)

Work began on CHPS User Training. This training provides detailed instruction on how to produce hydrologic forecast products for RFCs and Weather Forecast Offices (WFO).

WFOs have only recently been granted access to CHPS, while RFCs have had CHPS capabilities for some time. Since WFOs and RFCs use CHPS for different purposes, we decided it would be best to produce separate user training module. Our first priority was RFC CHPS training since RFCs use CHPS more often.

Development for the RFC course began in February 2013. The HTML shell was completed 6 March 2013. In the meantime, images were selected for our HTML shell, and Schultz developed a dialogue script for a video media piece and also developed a simulation piece for the training to act as a review for CHPS user operations. The simulation piece can be found at http://www.nwstc.noaa.gov/CHPS/rfc_user/media/chps_sim/chps_sim.swf.

Development for the WFO course began in April 2013. Special trips were made in May 2013 to the Missouri Basin RFC (MBRFC) to obtain pictures and to capture video of CHPS user operations to input into both courses, and in June 2013 to the North Central RFC (NCRFC) and NWS Forecast Office MPX (Chanhassen, MN) to gain feedback on both CHPS RFC and WFO user training. As of the end of FY13, the CHPS RFC user training is a work in progress, as well as the CHPS WFO User training course. A tentative release date for the CHPS RFC User training is sometime in mid-August 2013. No tentative release date for the CHPS WFO User training has been set.

9. NWS Observational Programs Overview

Justin Schultz (CIMMS at NWSTC), Megan Taylor (CIMMS at NWSTC), Jerry Griffin (NWSTC), Jim Jones (NWSTC), Hattie Wiley (NWSTC), Teresa Murphy (NWSTC), Dave Cokely (NWSTC)

The NWS Observing Program distance-learning course has been updated. The goal of this course is to espouse two previous courses and update information contained therein, Data Acquisition for Managers and Quality Control.

The topics of this consolidated course include (1) Observing Programs Customers and Partners; (2) Quality Assurance/Quality Control Practices; (3) Surface Observing Programs; (4) Upper Air Support; (5) Cooperative Observer (COOP) Program; and (6) Observing Equipment Maintenance.

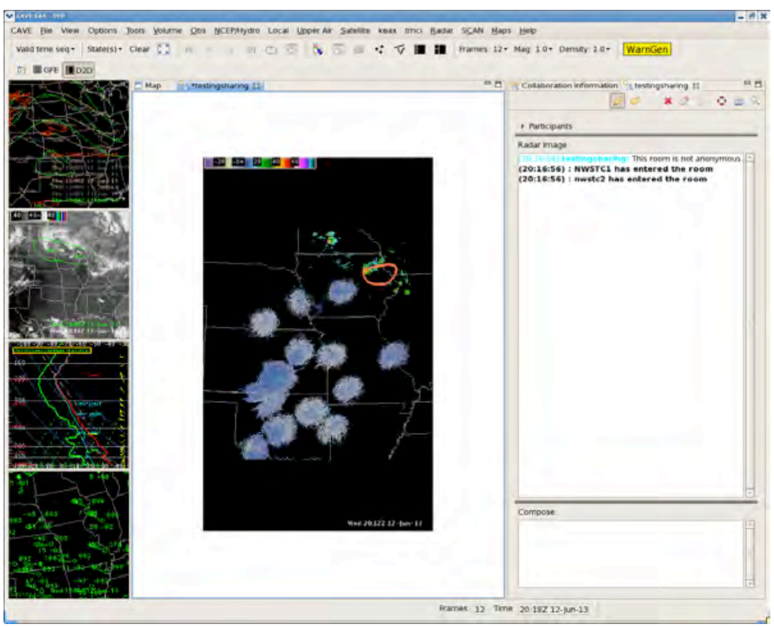
During January 2013, Schultz developed a basic outline for this course that was reviewed. Program subject matter experts were consulted for course content, and as of the end of FY13, this is a work in progress.

10. AWIPS-II Collaboration Tool

Justin Schultz (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC), Hattie Wiley (NWSTC)

The AWIPS-II Collaboration Tool was built into AWIPS-II Operational Build (OB) 13.2.1 in late March 2013. This innovative tool allows NWS personnel to communicate directly through AWIPS with other NWS offices. The two primary functions of the Collaboration Tool are chatting (similar to 12Planet) and the ability to share an AWIPS display with other offices in real-time. This tool was developed as a replacement for 12Planet. Since this is a new tool, training was developed for the LMS.

Training was developed in the form of a distance-learning module, which began in April 2013. A course outline was reviewed and feedback provide. A finished course content document was sent for review on 13 June 2013, and on 14 June 2013 the CIMMS scientist developed Articulate presentation components for the course. As of the end of FY13, the training development is still in progress. Reformatting of course material, per awaited feedback, will take place in July 2013.



AWIPS-II Collaboration Tool interface.

11. Safety and Environmental Focal Point Training

Megan Taylor (CIMMS at NWSTC), Hattie Wiley (NWSTC), Yelena Platt (NWS/FMB), Scott Burgoon (NWS Headquarters), Jim Poole (NWSTC)

Safety and Environmental Focal Point Training began as a project to convert the several weeklong resident courses into more cost efficient online courses. Since safety and environmental requirements are federally mandated, these courses would not only be

for the protection of the employees, but the agency as well. Progress has not been optimal due to slow turnaround times during the review process. However, this will be the first time that focal points nation-wide will be able to get all of their training resources in one place. The estimated time for completion of this project is mid-to-late fall 2013. Thereafter our involvement would be to update the online training as regulations change and additions to the courses are needed.

Screenshot of Safety Focal Point Training — see the Safety and Environmental courses at www.nwstc.noaa.gov/safety.

12. Social Media Outreach

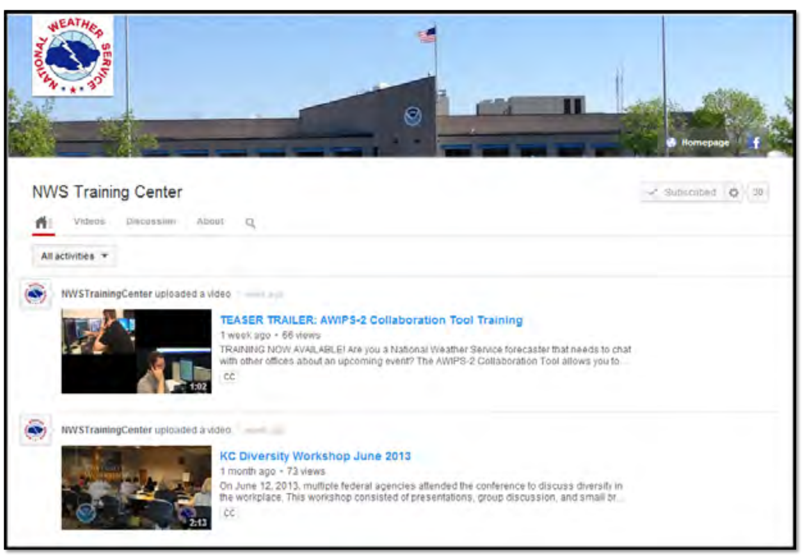
Megan Taylor (CIMMS at NWSTC), Jeff Zeltwanger (NWSTC), John Ogren (NWSTC), Cathy Burgdorf (NWSTC)

The Social Media project was an idea that Taylor initiated when NWSTC was trying to figure out how to spread the word about some of its training that was not getting much attention. Skill issues within the NWS likely are due to lack of training, although the training may already exist and no one knows about it due to a breakdown in communication (a point mentioned in the Weather-Ready Nation Roadmap). This project began with a very successful launch of a Facebook fan page in October 2012. There, we list course announcements, news about the training center, and in general connect with other parts of the NWS.

The second part of the project involved launching a YouTube channel, which went live in May 2013. This channel is used to publish training course teaser trailers, marketing videos, and most importantly video training aides. This also humanizes our instructors who are oftentimes only names on HTML pages for a distance-learning course.

The future of the Social Media project is to increase our reach on both platforms in an effort to expand the visibility of the NWSTC and the training it produces. We also started a campaign to publish images with general facts about weather and the NWS for field offices to share with their constituents. This is in hopes of sharing our weather knowledge with the general public.

Screenshot of NWSTC Facebook Fan Page.



Screenshot of NWSTC YouTube Channel.

13. Training Within the NWSTC

Megan Taylor (CIMMS at NWSTC), Hattie Wiley (NWSTC)

Taylor took on a role as a NWSTC trainer as part of her duties. She has become a Google Sites subject matter expert, as well as skilled in video editing and performance as it relates to instruction, and has become skilled in webpage development. She trains other staff members on various software and skills that are used in the office. By extension, this helps the NOAA Strategic Goal in that the staff is becoming better trainers so that it can instruct properly for preparing the nation for weather events.

One of Megan Taylor's presentations given to NWSTC staff, and also to an instructional design and technology conference.

14. Decision Support Service Deployment Boot Camp

Somer Erickson (CIMMS at NWSTC), Kim Runk (NOAA/NWS OPG), Chad Gravelle (CIMSS-University of Wisconsin), Mike Hudson (NWS/CRH/ROC), Jennifer Zeltwanger (NWS/CRH/ROC), Kelsey Angle (NWS/CRH/ROC), Wendy Pearson (NWS/CRH/ISD), Jim Keeney (NWS/CRH/ISD), John Ogren (NWSTC), Jeffrey Zeltwanger (NWSTC), Shea Lane (Springfield, MO Emergency Manager), Kevin Brown (Jefferson City, MO Emergency Manager)

Decision Support Service (DSS) Deployment Boot Camp is a basic training session, directly connected to the Weather-Ready Nation initiative. It is designed to position the

NWS for growth in providing first-class decision support at Emergency Operations Centers and on-scene at disaster sites where response teams are formed under the Incident Command System (ICS) structure.

The overarching goal of the workshop is to increase understanding of partner requirements and build capacity for effective DSS provision by offering practical, interactive training in ICS structure, risk communication, building and delivering effective presentations, and successful media interviewing techniques. The weeklong workshop culminates in a full day incident simulation exercise during which participants replicate incident support activities in a safe, but realistic environment. The CIMMS scientist led a session on Risk Communication, acted as facilitator for one of the incident simulation groups, and provided her emergency management experience perspective on a partners' panel discussion. Feedback from student surveys was unanimously positive regarding the practical value of the course.

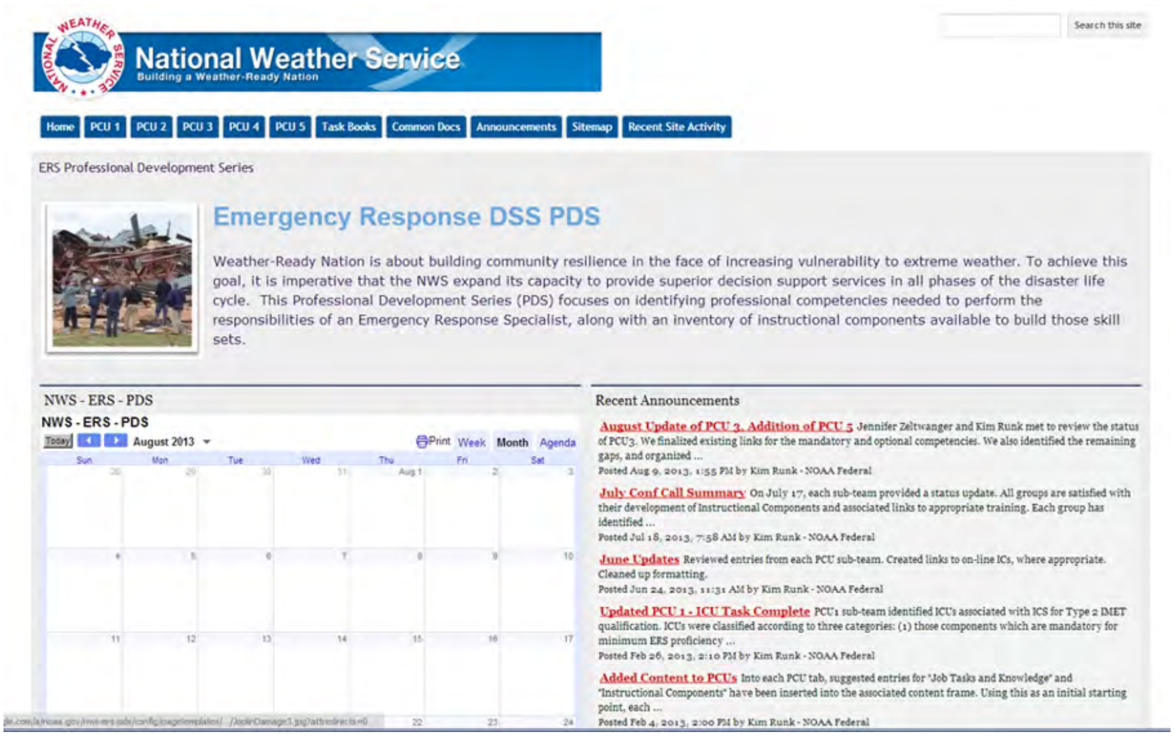
Emergency Manager Kevin Brown, serving as Incident Commander for the DSS Deployment Boot Camp incident simulation, provides instructions concerning safety plan protocols and priority objectives for the day.

15. Emergency Response Specialist (ERS) Professional Development Series (PDS)

Somer Erickson (CIMMS at NWSTC), Kim Runk (NWS/OPG), Jennifer Zeltwanger (NWS/CRH/ROC), Roger Lamoni (NWS/WRH), Aimee Fish (NWS/ARH), Timothy Oram (NWS/SRH), Larry Van Bussum (NWS Liaison to National Interagency Fire Center), Kevin Scharfenberg (NWS Weather-Ready Nation Program), David Manning (NWS/ERH), Brad Grant (WDTB), Rick Davis (NWS TBW and NWSEO representative)

The extreme end of decision support services involves the deployment of personnel trained in skill sets needed to provide quality support services on-site at a disaster event

or at a planned, large-venue event for which an Emergency Operations Center is activated. Inasmuch as one of the key Weather-Ready Nation goals is to integrate weather more seamlessly into the National Response Framework, building capacity for the fulfillment of these deployments needs is critical. The purpose of this professional development series is to create a unified set of professional competencies and associated training resources that will establish qualification standards for Emergency Response Specialists, the cadre of personnel designated for incident dispatch. The CIMMS scientist was one of ten team members identified to contribute to the process of creating the initial version of this plan. Four primary Professional Competency Units have been identified and articulated, and sub-teams have been formed to identify instructional components for each unit. After that, a gap analysis will be conducted to identify areas for which additional training must be developed.



Home page of Google Site hosting professional competency requirements for training to become certified as an Emergency Response Specialist in the NWS. Version 1 will be transferred to the NWS Training Portal upon completion.

16. Weather and Climate Analysis for FEMA Watchstanders

Somer Erickson (CIMMS at NWSTC), Andrew Ansorge (CIMMS at NWSTC), Julie Adolphson (NWS Forecast Office, Pleasant Hill, MO), Kelsey Angle (NWS/CRH), Brian Barjenbruch (NWS Forecast Office, Topeka, KS), Evan Bookbinder (NWS Forecast Office, Pleasant Hill, MO), John Cangialosi (NWS/NHC), Mike Hudson (NWS CRH), Jim Keeney (NWS CRH), John Ogren (NWS NWSTC), Wendy Pearson (NWS/CRH), Kim Runk (NWS/OPG), Jennifer Zeltwanger (NWS/CRH), Jeff Smith (FEMA Region VII), Russell Washington (Director, FEMA HQ National Watch Center)

FEMA Watchstanders maintain 24/7/365 situational awareness of manmade and weather events to provide information in support of senior leadership decision-making on how FEMA may need to respond to regional or national events. Since nearly all disaster events are weather related and weather affects all phases of the disaster lifecycle (mitigate, prepare, respond, recover), weather is mission critical to FEMA. However, Watchstanders often do not have adequate background or training in monitoring, analyzing and interpreting weather information to meet the operational needs of FEMA or fulfill professional qualification standards (PQS). Ensuring that FEMA, a core federal partner of the NWS, is able to meet its PQS will benefit it in assisting the American public before, during, and after a disaster, and also will help the NWS towards its goal of building a Weather-Ready Nation.

To address the weather needs of Watchstanders, FEMA Region VII and the NWS Operations Proving Ground (OPG), both located in Kansas City, collaborated to pilot the development of a “Weather and Climate Analysis for FEMA Watchstanders” training course. CIMMS scientists and OPG staff led the course development and were assisted by subject-matter experts from the NWS Central Region Headquarters, including two Emergency Response Specialists, the National Hurricane Center and NWS Weather Forecast Offices Pleasant Hill, MO and Topeka, KS. Two Watchstanders from each of the ten FEMA regions, two Watchstanders from FEMA Headquarters, and three additional Watchstanders from Region VII were sent to the NWS Training Center in Kansas City for in-residence training held 26-28 February 2013.

The course addressed the following topics: overview of the NWS, basic weather terms and symbols, space weather, severe weather, tropical weather, winter weather, fire, drought, heat, and dust storms, flooding, climate, weather radar, NWS web navigation and resources, and Decision Support Services. Training consisted of a lecture style discussion of each topic. Other activities were incorporated throughout the training to synthesize course concepts. The 3-day course culminated with a tabletop exercise that tested the understanding, analysis, and interpretation skills of the Watchstanders (see figure below).

CIMMS scientists and NWS staff used a custom-designed NWS/FEMA/Weather-Ready Nation template to create the Microsoft PowerPoint slides and the accompanying training manual/workbook pages for each course unit. Each page of the training manual/workbook included an image of a slide, key points, websites or takeaways from

that slide and space for the Watchstanders to take notes. Additionally, CIMMS scientists provided a web resource guide of important weather websites with plain English descriptions of these websites.

CIMMS scientists also worked with NWS personnel to develop interactive, hands-on activities to reinforce core course concepts. A “Weather Jeopardy” game tested the Watchstanders knowledge of common meteorological terms, frequently used NWS watch, warning and advisory products, and identification of weather symbols. A web scavenger hunt covered the range of course topics by asking the Watchstanders to find real-time atmospheric and geophysical information from current drought conditions to the latest earthquake magnitude to quantitative precipitation forecasts for the next five days. CIMMS scientists and NWS personnel were available to provide assistance throughout these activities.

Pre- and post-tests were administered to assess the understanding of Watchstanders before and after the course. In the FEMA After Action Report, it was stated, “On average, the participants improved their [pre-test to post-test] score by 20%...” Daily evaluations and a cumulative course evaluation were administered to the Watchstanders to elicit feedback that will enhance future course offerings. Responses from the first course were overwhelmingly positive, with almost all Watchstanders stating they would recommend this course to their FEMA colleagues.

This first course succeeded in providing useful training to help FEMA Watchstanders in better monitoring, analyzing and interpreting weather information. The course also further strengthened the NWS-FEMA relationship and the collaboration between CIMMS scientists and the NWS. Future courses are planned for late in FY13 pending FEMA travel funds, with additional courses possible in FY14.

Andrew Ansorge (CIMMS at NWSTC/NOAA/NWS Operations Proving Ground), Kelsey Angle (NOAA/NWS CRH) and Jim Keeney (NOAA/NWS CRH) facilitate discussion and answer questions with FEMA Watchstanders during the tabletop exercise.

17. Social Science Integration – Assessing Effectiveness of Hazard and Impact Messaging in the Context of NWS Products and Services

Andrew Ansorge (CIMMS at NWSTC), Somer Erickson (CIMMS at NWSTC*),* Elliott Jacks (NWS/OCWWS), Andy Horvitz (NWS/OCWWS), Kim Runk (NWS/OPG), Vankita Brown (NWS/OCWWS), Jennifer Sprague (NWS/SPP), Ken Galluppi (Arizona State University), Jessica Losego (University of North Carolina), Burrell Montz (East Carolina University), Susan Jasko (California University of Pennsylvania)

Two CIMMS scientists have been working on projects aimed at more effective communication of hazard and risk in the context of NWS products. They have been developing ideas for next steps in the NWS Office of Climate, Weather, and Water Services (OCWWS) Winter Hazard Simplification Demonstration (see project below), which was coordinated with Eli Jacks (OCWWS) and the NOAA Social Science Group. The CIMMS scientists also have assisted in partner meetings aimed at evaluating usability and usefulness of NWS information: two meetings were focused on Fire Weather customers, another with local area emergency managers (see projects below).

Erickson also was actively engaged with the NOAA Social Science Group, led by Jennifer Sprague and Vankita Brown; and with the Weather for Emergency Managers cooperative, led by Ken Galluppi, Jessica Losego, and Burrell Montz. These groups are dedicated to assisting the NWS with improving clarity in its messaging, and the effectiveness of its risk communication to better serve decision makers.

18. NWS Winter Hazards Simplification Demonstration

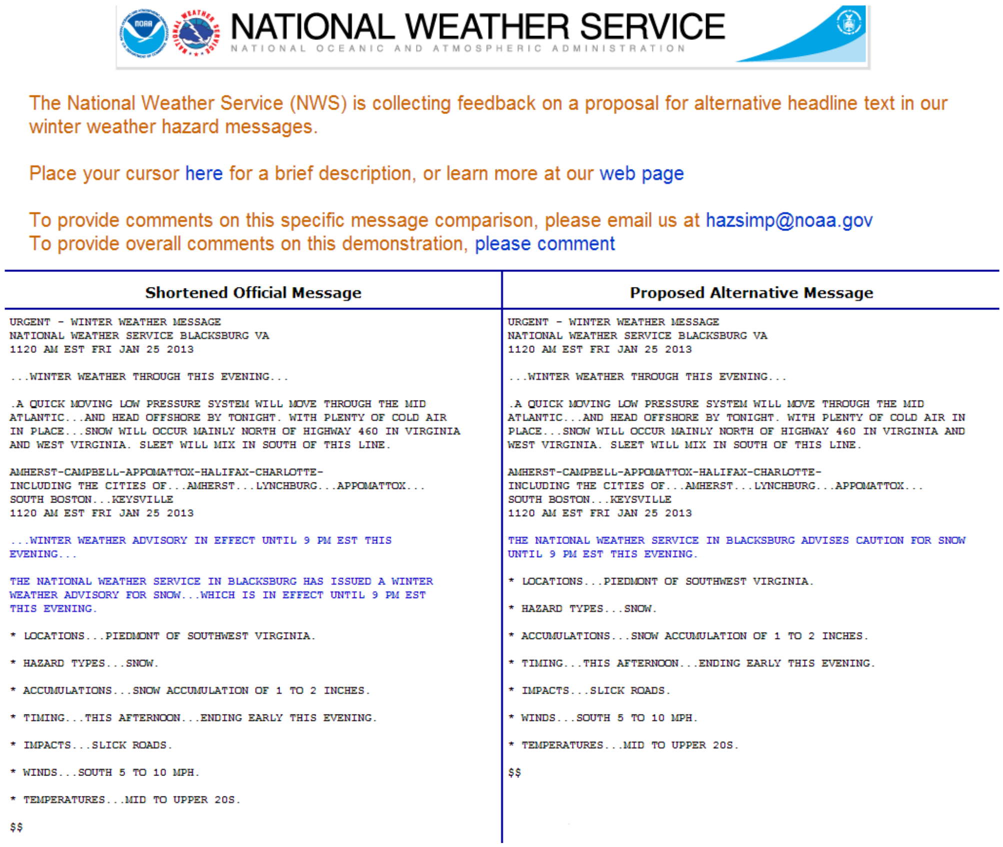
Andrew Ansorge (CIMMS at NWSTC), Somer Erickson (CIMMS at NWSTC*),* Eli Jacks (NWS/OCWWS), Andy Horvitz (NWS/OCWWS), Kim Runk (NWS Operations Proving Ground), John Keyes (NWS Forecast Office, Pocatello, ID), Greg Schoor (NWS Forecast Office, Baltimore/Washington D.C.), John Margraf (NWS Forecast Office, Twin Cities, MN), Melody Magnus (NWS/OCWWS), Vankita Brown (NWS/OCWWS), Craig Schmidt (NWS/WRH), John Ferree (NWS/OCWWS), Kolly Mars (NOAA/NIDS), Dan Arnold (NOAA/NIDS)

A key component of the NWS mission is issuing watches, warnings and advisories (WWAs) to protect life and property. However, feedback from NWS customers collected using surveys and service assessments, has shown that some customers do not fully understand or know how to respond to WWAs. OCWWS, with assistance from regional and local NWS personnel and also computer programming and social science subject-matter experts from CIMMS in the NWS Operations Proving Ground (OPG) ran the Winter Hazards Simplification Demonstration during the winter of 2012-2013. The objective of this demonstration was to clarify and simplify winter weather hazard messages by using alternative wording to improve communication, which is in support of the NWS' Weather-Ready Nation initiative and the Plain Writing Act of 2010.

OCWWS staff requested that the alternative wording be produced in real-time to minimize the workload impact on staff at local weather forecast offices. To accommodate this request, a computer program was developed by a CIMMS scientist within the NWS OPG to translate official winter weather hazard messages to an alternative hazard wording for NWS partner and public comment. Utilizing Python on a Linux system that ran the Local Data Manager, real-time official winter weather hazard messages were automatically ingested and translated to the alternative hazard wording for 26 participating forecast offices representing every NWS region. The official and alternative winter weather hazard messages were then securely transmitted to a NOAA NWS Internet Dissemination System (NIDS) server where the messages were then displayed side-by-side on a webpage for easy comparison by NWS partners and the public to provide comments (see figure below). This process of automatically translating official messages to the alternative wording kept the forecast office workload impact minimal while performing this research to operations demonstration.

From 11 December 2012 to 31 March 2013, over 5,000 surveys were collected and nearly 1,000 emails were received on this demonstration. NWS and CIMMS social scientists provided guidance on how to analyze the two types of feedback and approved the methodology to analyze the feedback. CIMMS scientists, and volunteers from the NWS at national and regional headquarters and from local forecast offices, helped analyze the feedback. The main findings are that NWS partners and the public are in support of change, with the top three suggestions being to (1) use a color scale, (2) shorten the message length, and (3) keep the current WWA terms while utilizing alternative words. A CIMMS scientist presented these results at a joint session of the American Meteorological Society's 41st Conference on Broadcast Meteorology/2nd Conference on Weather Warnings and Communication in June 2013.

Next steps for this project are being identified for the 2013-2014 winter. The core OCWWS/CIMMS/OPG team, along with other interested staff from forecast offices and regional headquarters, plan to develop more customer-focused prototypes based on the feedback from the 2012-2013 demonstration, as part of the operations-to-research process. These new prototypes will be evaluated using an improved web survey focused specifically on this demonstration. The core OCWWS/CIMMS/OPG team also is looking to increase social science support for this demonstration. Early indications are that NOAA's Coastal Services Center may be able to assist or join the core team through refinements to the prototypes, conducting on-site focus groups with NWS partners and the public, and developing a web-based survey.


NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

The National Weather Service (NWS) is collecting feedback on a proposal for alternative headline text in our winter weather hazard messages.

Place your cursor here for a brief description, or learn more at our web page

To provide comments on this specific message comparison, please email us at hazsimp@noaa.gov
To provide overall comments on this demonstration, please comment

Shortened Official Message

URGENT - WINTER WEATHER MESSAGE
NATIONAL WEATHER SERVICE BLACKSBURG VA
1120 AM EST FRI JAN 25 2013

...WINTER WEATHER THROUGH THIS EVENING...

.A QUICK MOVING LOW PRESSURE SYSTEM WILL MOVE THROUGH THE MID ATLANTIC...AND HEAD OFFSHORE BY TONIGHT. WITH PLENTY OF COLD AIR IN PLACE...SNOW WILL OCCUR MAINLY NORTH OF HIGHWAY 460 IN VIRGINIA AND WEST VIRGINIA. SLEET WILL MIX IN SOUTH OF THIS LINE.

AMHERST-CAMPBELL-APPOMATTOX-HALIFAX-CHARLOTTE-
INCLUDING THE CITIES OF...AMHERST...LYNCHBURG...APPOMATTOX...
SOUTH BOSTON...KEYSVILLE
1120 AM EST FRI JAN 25 2013

...WINTER WEATHER ADVISORY IN EFFECT UNTIL 9 PM EST THIS EVENING...

THE NATIONAL WEATHER SERVICE IN BLACKSBURG HAS ISSUED A WINTER WEATHER ADVISORY FOR SNOW...WHICH IS IN EFFECT UNTIL 9 PM EST THIS EVENING.

* LOCATIONS...PIEDMONT OF SOUTHWEST VIRGINIA.

* HAZARD TYPES...SNOW.

* ACCUMULATIONS...SNOW ACCUMULATION OF 1 TO 2 INCHES.

* TIMING...THIS AFTERNOON...ENDING EARLY THIS EVENING.

* IMPACTS...SLICK ROADS.

* WINDS...SOUTH 5 TO 10 MPH.

* TEMPERATURES...MID TO UPPER 20S.

$$

Proposed Alternative Message

URGENT - WINTER WEATHER MESSAGE
NATIONAL WEATHER SERVICE BLACKSBURG VA
1120 AM EST FRI JAN 25 2013

...WINTER WEATHER THROUGH THIS EVENING...

.A QUICK MOVING LOW PRESSURE SYSTEM WILL MOVE THROUGH THE MID ATLANTIC...AND HEAD OFFSHORE BY TONIGHT. WITH PLENTY OF COLD AIR IN PLACE...SNOW WILL OCCUR MAINLY NORTH OF HIGHWAY 460 IN VIRGINIA AND WEST VIRGINIA. SLEET WILL MIX IN SOUTH OF THIS LINE.

AMHERST-CAMPBELL-APPOMATTOX-HALIFAX-CHARLOTTE-
INCLUDING THE CITIES OF...AMHERST...LYNCHBURG...APPOMATTOX...
SOUTH BOSTON...KEYSVILLE
1120 AM EST FRI JAN 25 2013

THE NATIONAL WEATHER SERVICE IN BLACKSBURG ADVISES CAUTION FOR SNOW UNTIL 9 PM EST THIS EVENING.

* LOCATIONS...PIEDMONT OF SOUTHWEST VIRGINIA.

* HAZARD TYPES...SNOW.

* ACCUMULATIONS...SNOW ACCUMULATION OF 1 TO 2 INCHES.

* TIMING...THIS AFTERNOON...ENDING EARLY THIS EVENING.

* IMPACTS...SLICK ROADS.

* WINDS...SOUTH 5 TO 10 MPH.

* TEMPERATURES...MID TO UPPER 20S.

$$

Screen capture of a side-by-side Winter Weather Advisory from NWS Blacksburg, VA. The official message is on the left hand side and the automatically generated alternative message is on the right hand side. The blue text highlights the text that was changed from the official message to the alternative message. Certain parts of the official message (e.g. Valid Time Event Code (VTEC)) were omitted for this demonstration only. NWS partners and the public could provide feedback using either the survey link or demonstration's dedicated email address found above the side-by-side messages.

19. Operations Proving Ground Operational Readiness Evaluations (OREs)

Andrew Ansorge (CIMMS at NWSTC), Somer Erickson (CIMMS at NWSTC), Kim Runk (NWS/OPG), Chad Gravelle (UW-CIMSS/SSEC and NWS/OPG), Jack Richardson (QuTech/NWS/OPG)

A key component of the NWS Operations Proving Ground – an initiative of the NWS Weather-Ready Nation – are Operational Readiness Evaluations (OREs). The purpose of OREs is to test new tools, techniques and applications (herein, candidate capabilities) from NOAA testbeds and labs in a realistic operational setting, as part of the research-to-operations and operations-to-research processes. Since real-time weather may not provide suitable examples to test these candidate capabilities, weather events are archived to create simulation-training scenarios for AWIPS-II. Currently, CIMMS scientists and OPG staff are using a prototype 2-rack AWIPS-II system to

experiment and develop this archived data playback functionality to provide simulation-training scenarios.

Several proposals were accepted as ORE sessions for FY13 and FY14: (1) a lightning tool from NASA's Short-term Prediction Research and Transition Center (SPoRT), which provides a graphical display of lightning count along a user-defined track; and (2) Integrated Hazard Information Services, which will combine WarnGen, Graphical Hazards Generator, and River Pro to enable two-way communication among decision makers. This is an official NWS sanctioned Operations and Services Improvement Process (OSIP) project.

These proposals and the corresponding simulation training scenarios will be evaluated in the ORE room, which has an 'X' configuration with three of the four sections of the 'X' equipped with an AWIPS-II workstation and a standard PC computer (see first figure below). This configuration is similar to the operational configuration of the NWS Weather Forecast Office Pleasant Hill, Missouri. This 'X' configuration also can foster collaboration among forecasters and/or core partners during a simulation-training scenario while also providing a view of the situational awareness display (see second figure below). A table in the back of the room supports small group training or discussion about the scientific integrity and interoperability of the candidate capabilities being tested within the ORE.

In addition, CIMMS scientists were involved in two outreach opportunities for the OPG. First, Deputy NWS Director Laura Furgione visited CIMMS scientists and OPG staff while touring the ORE room on 22 February 2013. Discussion with the deputy director focused on the configuration of the ORE room, collaboration plans with other testbeds and labs, and the OPG's plans for streamlining the research to operations and operations to research process. Second, a CIMMS scientist and the OPG interim director were featured in a three-minute video on the OPG that was published as part of the NWS Training Center's outreach for the 2013 Severe Weather Awareness Week. The OPG interim director discussed the role of the OPG in validating new forecast science and providing effective communication to NWS' core partners during severe weather. The CIMMS scientist and OPG staff are shown demonstrating the ORE room's capabilities through a hydrologic briefing.

Configuration of the NOAA/NWS Operations Proving Ground's Operational Readiness Evaluation Room.

Andrew Ansorge uses the situational awareness display's SMART Board to annotate an image in the Operations Proving Ground's Operational Readiness Evaluation Room.

20. South Dakota Fire Weather Partner Meeting

Somer Erickson (CIMMS at NWSTC), Andrew Ansorge (CIMMS at NWSTC), Kim Runk (NWS/OPG), Jennifer Zeltwanger (NWS/CRH), Sally Pavlow (NWS Forecast Office, Sioux Falls, SD), Michael Fuhs (NWS Forecast Office, Sioux Falls, SD), Travis Tarver (NWS Forecast Office, Aberdeen, SD), James Scarlett (NWS Forecast Office, Aberdeen, SD), Dave Carpenter (NWS Forecast Office, Rapid City, SD), Jeffery Schild (NWS Forecast Office, Rapid City, SD)

Fire weather information and services from the NWS have become inconsistent between forecast offices, which can create confusion among fire weather partners and hinder decisive decision-making. As part of the Weather-Ready Nation initiative to provide superior decision support services, NWS Central Region Headquarters (CRH), with specialized assistance from CIMMS scientists, led a research effort to understand how fire weather partners utilize NWS fire weather information to make decisions about their fire management plans, staffing levels, and resources. The NWS was interested to learn from fire weather partners how to enhance the effectiveness and consistency of fire weather information and services.

To facilitate this research, CIMMS scientists travelled to Pierre, SD to meet with South Dakota fire weather partners and discuss how they use NWS fire weather information, identify gaps in NWS products and/or services, and understand their needs. One CIMMS scientist focused on fostering the discussion while the other CIMMS scientist typed notes about the discussion for later. After returning to the NWS Training Center, the CIMMS scientists provided a briefing to NWS CRH staff and South Dakota Weather Forecast Offices on initial takeaways. The CIMMS scientists then completed a transcript of the discussion for internal review by NWS CRH staff. Finally, an eight-page report discussing the key findings was compiled and provided to NWS CRH staff, South Dakota Forecast Offices, and South Dakota fire weather partners. This preliminary and any future research may change how the NWS provides fire weather information to their partners, in order to provide a more consistent level of service as part of the research-to-operations process.

CIMMS Task III Project – Development of Short-Range Realtime Analysis and Forecasting System based on the ARPS for Taiwan Region – Year 3

Ming Xue (OU CAPS and School of Meteorology), Fanyou Kong (OU CAPS), Keith Brewster (OU CAPS), Chong-Chi Tong (OU CAPS and School of Meteorology), and Rong Kong (OU CAPS and School of Meteorology)

NOAA Technical Lead: Fanthune Moeng (NOAA/GSD)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (Taiwan Central Weather Bureau; NSSL; and NOAA/GSD)

Objectives

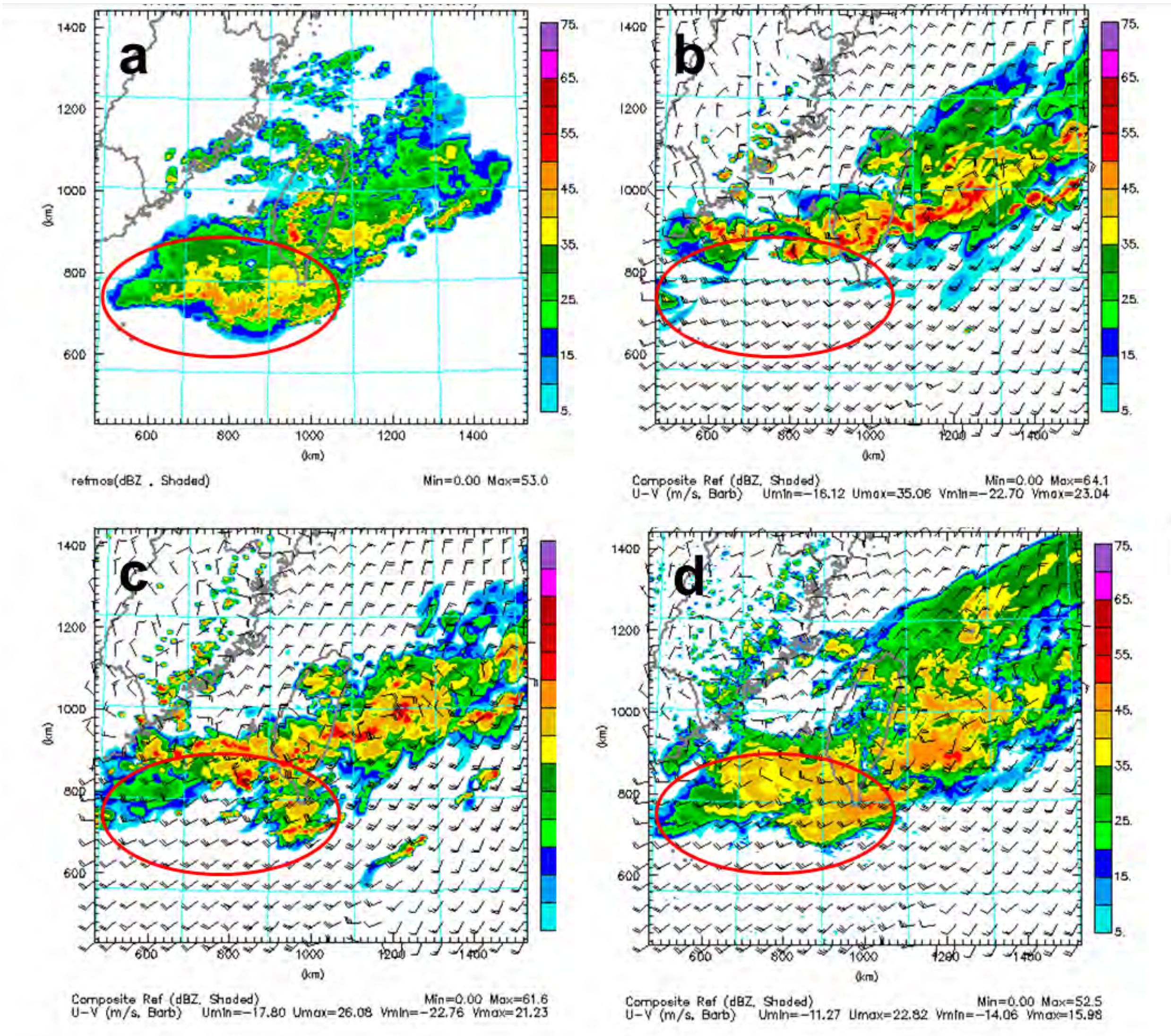
Configure, demonstrate, and deploy a real-time forecasting system at convection-allowing resolution (2.5 km), based on ARPS modeling system, for the Central Weather Bureau (CWB) of Taiwan, and to obtain accurate 0-4-h heavy precipitation forecasts.

Accomplishments

During the reporting period, CAPS had developed, tested, and provided pre-processing programs (data convertors) to analyzing auto-meteorological observation data (AWS) and multi-functional transport satellite (MTSAT) infrared and visible channel data to CWB to be implemented; performed case studies on one Meiyu case (28 May 2010) and on Typhoon Morakot case (7-8 August 2009) to investigate the impact of adding AWS and MTSAT data assimilation, and the impact and effectiveness of various DA cycling strategies; investigated through a new Meiyu case of 12 June 2012 the effectiveness of partial cycling assimilations (with different cycling time durations of 0, 1, 2, and 3 hours) of AWS, GTS, and radar data in improving simulated radar echo pattern. A two-moment microphysics scheme (Milbrandt-Yau scheme) has also been tested and showed improved performance for delaying early radar echo decaying compared to single-moment microphysics (see figure below). Sensitivity experiments were performed by modifying cloud analysis procedure by humidity reduction in echo free region, and showed positive impact on inhibiting spurious precipitation associated with partial cycling data assimilation.

CAPS met all deliverable requirements for the reporting period, including three code deliveries including verification package update and new data convertors for AWS and MTSAT with instructions, one annual report due October 2012, one PowerPoint presentation for the semi-annual review. CAPS performance during this reporting period has been accepted in the annual review meeting held in CWB in November 2012 and the semi-annual review meeting held in May 2013 in Boulder, CO.

This project is completed.



Observed composite reflectivity (a) valid at 0700 UTC 12 June 2012, and one hour simulations valid at the same time, by using (b) one time 3DVAR analysis with single moment Lin microphysics scheme, (c) one hour cycling window with Lin scheme, and (d) one hour cycling window with Milbrandt-Yao two-moment microphysics.

CIMMS Task III Project – Ensemble Simulation of GOES-R Proxy Radiance Data from CONUS Storm-Scale Ensemble Forecasts, Product Demonstration and Assessment at the Hazardous Weather Testbed GOES-R Proving Ground

Ming Xue, Keith Brewster, Fanyou Kong, and Youngsun Jung (all OU CAPS)

NOAA Technical Leads: Mark DeMaria and Ingrid Guch (NESDIS/STAR)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/NESDIS)

Objectives
Through collaborations, a better understanding of the interaction between cloud microphysics and radiative transfer modeling will be sought so as to provide insights for improving the Community Radiative Transfer Model (CRTM) system, which is part of the operational data assimilation systems at NCEP.

Accomplishments
This project represents collaboration between three institutions: CAPS, CIMSS-Wisconsin, and CIRA-Colorado State. The proposed project employs 4-km storm-scale ensemble forecasts (SSEFs) produced by CAPS for the Hazardous Weather Testbed (HWT) Spring Experiments. Utilizing national supercomputing resources, synthetic imagery is generated in real-time, for several infrared channels from selected ensemble members, at hourly intervals. Three radiative transfer (RTM) model packages will be employed in the project. They include the Community Radiative Transfer Model (CRTM) package from NESDIS, the package based on the Successive Order of Interaction (SOI) RTM from CIMSS-University of Wisconsin, and an RTM package from CIRA-Colorado State University. They will be used to generate synthetic brightness temperatures for selected Advanced Baseline Imager (ABI) and current GOES infrared channels. In addition, EnKF-based data assimilation capabilities will be developed that combine brightness temperature assimilation with radar data, at convection-allowing resolutions (~4 km). The synthetic imagery will be made available in near real-time to the HWT as part of the GOES-R Proving Ground. The project will help familiarize operational forecasters, numerical modelers and physical scientists with the capabilities of GOES-R.

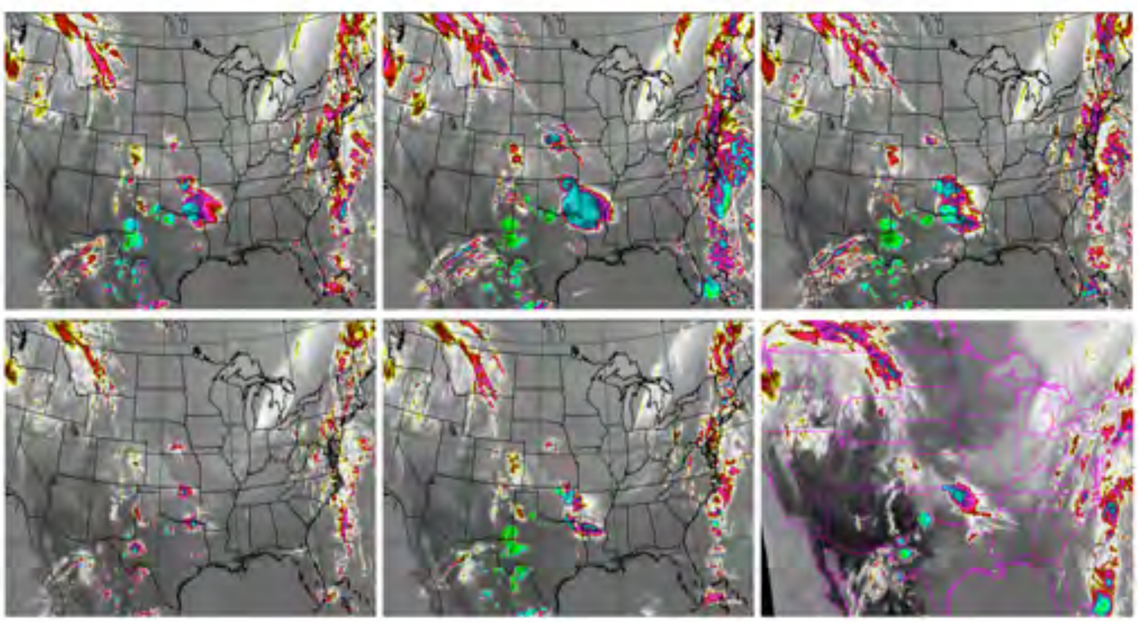
The CRTM were run during the 2013 HWT Spring Experiment, generating realtime synthetic brightness temperature (BT) of 6.48 and 10.7 µm for GOES-13 for a microphysics ensemble that comprises Thompson, Milbrandt and Yau, Morrison, WDM6, and NSSL schemes, all partial or full two-moment schemes. Ensemble probability products from a core fifteen-member CAPS SSEF for 10.7 µm BT were also produced and demonstrated on CAPS real-time forecast website (http://www.caps.ou.edu/~fkong/sub_atm/spring13.html). All products were made available to HWT participants for evaluation as part of the GOES-R Proving Ground. Feedback from the participants was positive. The first figure below shows example products generated in real-time during 2013 NOAA HWT Spring Experiment along with observed 10.7 µm GOES-13 imagery valid at 2000 UTC on 23 May 2013.

The CIMSS team, by applying the Successive Order of Interaction (SOI) forward radiative transfer model to CAPS 2012 season SSEF dataset, investigated the ability of several two-moment cloud microphysical and planetary boundary layer parameterization schemes to accurately simulate cloud characteristics over the contiguous U.S. (CONUS) through comparison of real and synthetic infrared BT. The results revealed that the microphysics schemes that were double moment in all five cloud species

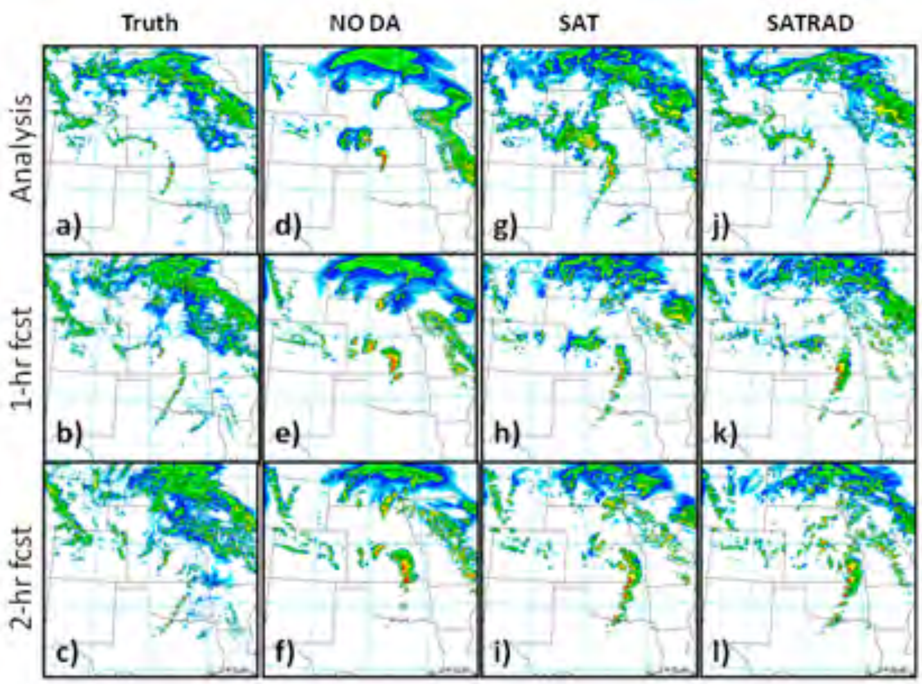
tended to produce too much upper level cloud cover, whereas simpler schemes did not contain enough high clouds. Smaller differences occurred in the cloud field when comparing the PBL schemes, with the greatest spread in the statistics occurring during and after peak heating. Results varied somewhat depending upon the verification method employed, which indicates the importance of using a suite of verification tools when evaluating high-resolution model performance. The large differences between the various cloud and PBL schemes indicate that there remains large uncertainty in how these schemes represent subgrid-scale processes affecting the cloud field.

CAPS team developed EnKF-based data assimilation capabilities that combine satellite BT assimilation with radar data at convection-allowing resolutions (~4 km). Potential impact of radiance data from the future GOES-R satellite on analysis and forecasting was investigated with and without radar data using an EnKF through realistic observing system simulation experiments (OSSEs). Simulated 10 May 2010 case was used in this research where the truth was the CAPS realtime forecast employing the Weather Research and Forecasting (WRF) model while the DA was performed with Advanced Regional Prediction System (ARPS) and its EnKF system. The preliminary results show that simulated satellite radiance significantly improved forecasts of a line of storms with supercell characteristics and the performance was improved further when both simulated radiance and simulated radar observations were assimilated (second figure below).

This project is ongoing.



Synthetic 10.7 µm GOES BT imageries for 5 members of the CAPS 2013HWT Spring Experiment ensemble forecasts, running at convection-permitting resolutions (~4 km) on the CONUS domain, using 5 different microphysics schemes (Thompson, Milbrandt and Yau, Morrison, WDM6, NSSL from top left to lower middle) along with observed GOES-13 imagery at the lower right. Images are valid at 2000 UTC on 23 May 2013, 20 hours of forecast time.



Simulated reflectivity for (a-c) truth simulation, and experiments that assimilated (d-f) no observations (NO DA), (g-i) synthetic satellite radiance at 6.95 and 10.35 µm (SAT), and (j-l) satellite radiance in SAT along with synthetic radar reflectivity and radial velocity data (SATRAD) for one hour from 2000 UTC to 2100 UTC at ten minute intervals. Images are valid at 2100, 2200, and 2300 UTC (top to bottom) on 10 May 2010.

CIMMS Task III Project – Contribution to Model Development and Enhancement Research Team by the Center for Analysis and Prediction of Storms

Ming Xue, Kefeng Zhu, and Yujie Pan (all OU CAPS), Xuguang Wang (OU School of Meteorology and CAPS)

NOAA Technical Lead: Stan Benjamin (NOAA/ESRL/GSD)

NOAA Strategic Goal 2 – *Weather-Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/ESRL/GSD – FAA Aviation Weather Research Program)

Objectives

Develop and test an ensemble Kalman filter (EnKF) and GSI-based EnKF/3DVAR hybrid data assimilation system suitable for operational implementation for the Rapid Refresh (RAP) forecasting system; establish radar DA capabilities in the EnKF and hybrid systems and eventually apply the systems to the High Resolution Rapid Refresh (HRRR) system.

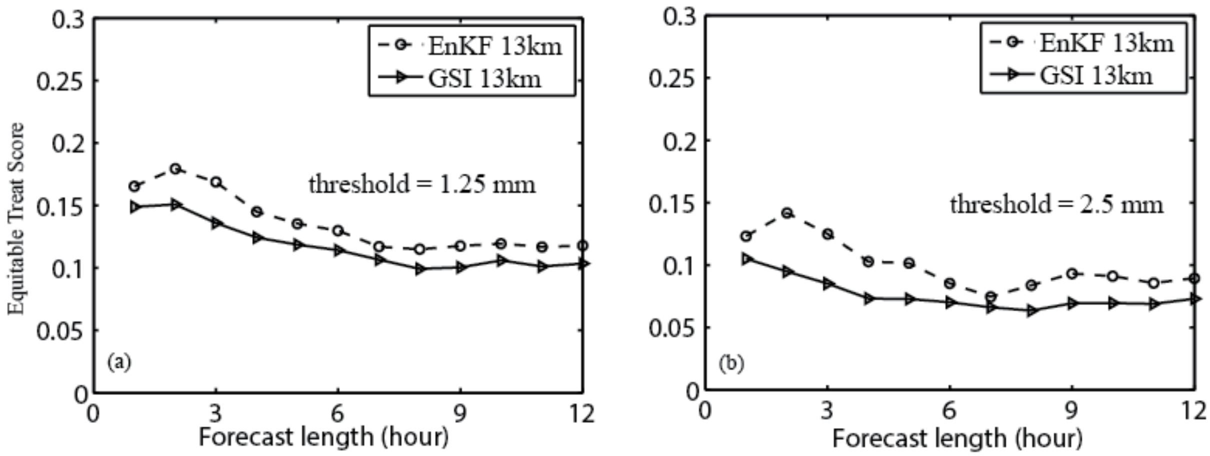
Accomplishments
A paper documenting the performance of a GSI-based EnKF data assimilation system for the Rapid Refresh configuration has been accepted by *Monthly Weather Review* (Zhu et al. 2013) while another paper documenting the development and testing the hybrid system has been submitted to the same journal.

In Zhu et al. (2013), the EnKF system is established for potential operational application by RAP. The system borrows data processing and observation operators from the Grid-point Statistical Interpolation (GSI), and pre-calculates observation priors using the GSI. The ensemble square-root Kalman filter (EnSRF) algorithm is used which updates both the state vector and observation priors. The EnKF is run at 1/3 of the operational RAP resolution or about 40 km grid spacing, and its performance is compared to the GSI using the same data sets and resolution. Short-range (up to 18 hours, the RAP forecast length) forecasts are verified against soundings, surface observations, and precipitation data. Experiments are run with 3 hourly assimilation cycles over a 9 day period from spring 2010 having active convection. Extensive tuning including the use of height-dependent covariance localization scales and adaptive covariance inflation improved the EnKF performance. When the EnKF employs multiple physics parameterization schemes, forecast errors are further reduced, especially in relative humidity and temperature at the upper levels and in surface variables. The best EnKF configuration produces lower forecast errors than the parallel GSI run. Gilbert skill scores of precipitation forecasts on the 13 km RAP grid initialized from the 3 hourly EnKF analyses are consistently better than those from GSI analyses. In Pan et al. (2013), further improvement is achieved when the static covariance is included in the hybrid formulation while the ensemble covariance is provided by the EnKF system documented in Zhu et al. (2013).

This project is ongoing.

Publications
Zhu, K., Y. Pan, M. Xue, X. Wang, J. S. Whitaker, S. G. Benjamin, S. S. Weygandt, and M. Hu, 2013: A regional GSI-based ensemble Kalman filter data assimilation system for the rapid refresh configuration: Testing at reduced resolution. *Monthly Weather Review*, in press. http://dx.doi.org/10.1175/MWR-D-13-00039.1.

Pan, Y., K. Zhu, M. Xue, X. Wang, J. S. Whitaker, S. G. Benjamin, S. S. Weygandt, and M. Hu, 2013: A regional GSI-based EnKF-variational hybrid data assimilation system for the Rapid Refresh configuration: Results with a single, reduced resolution. *Monthly Weather Review*, submitted.



Average hourly precipitation equitable threat scores of all 13-km forecasts initialized from EnKF and GSI analyses, for thresholds (a) 1.25 mm h^{-1}, and (b) 2.5 mm h^{-1}.

CIMMS Task III Project – Advanced Data Assimilation and Prediction Research for Convective-Scale "Warn-on-Forecast"

Ming Xue, Keith Brewster, Youngsun Jung, Yunheng Wang, Chengshi Liu (all OU CAPS)

NOAA Technical Lead: Louis Wicker (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/NSSL)

Objectives

The main objectives of the CAPS portion of the project include: development and application of convective-scale ensemble data assimilation methods and systems; participation in inter-comparison projects for data assimilation methods on selected cases; and development of capabilities towards real-time radar data assimilation cycling experiments during future HWT spring programs, a potential task for follow-on years.

Accomplishments

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. A paper reporting OSSE results have been accepted (Wang et al. 2012a). 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.

Good progress is being made in various data assimilation applications and experiments. The CAPS parallel EnKF system (Wang et al. 2013) has been enhanced to include all conventional observations used by ADAS and ARPS 3DVAR. This EnKF system has been applied to two VORTEX2 cases: the 10 May 2010 Oklahoma-Kansas tornado outbreak and 5 June 2009 Goshen County, Wyoming, tornadic supercell (Supinie et al. 2013). 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. Most recently, this parallel EnKF system has been interfaced with WRF ARW model for it to be directly used with WRF, and the system was successfully applied in realtime for a central U.S. domain during the 2013 HWT Spring Experiment, producing a single-time EnKF analysis including all radars in the domain, to initialize 12-hour forecasts of WRF.

Progress has also been made with the ARPS 3DVAR system. Published and accepted papers documenting the impact of including a diagnostic pressure equation constraint (DPEC) within the 3DVAR on the analysis and forecast of convective storms include Ge et al. (2012, 2013b). Impacts of assimilating measurements of different sate variables are also investigated using the 3DVAR (Ge et al. 2013a), and the system was applied in realtime for the WoF project (Gao et al 2013). Variational assimilation of radar reflectivity has been incorporated into the ARPS 3DVAR system, which also paves the way for assimilating reflectivity in a hybrid system. Initial development with the hybrid-En4DVAR within the ARPS 3DVAR framework has also begun (Liu and Xue 2013).

A serial version of the Local Ensemble Transform Kalman Filter (LETKF) has been implemented within the CAPS EnKF framework, and its performance is found to be comparable to that of ARPS EnSRF, though slightly worse during the initial cycles. The nonlinearity of the reflectivity observation operator is believed to be the cause for the differences (Zhao and Xue 2013).

This project is ongoing.

Publications

Gao, J., T. T. Smith, D. J. Stensrud, C. Fu, K. Calhoun, K. L. Manross, J. Brogden, V. Lakshmanan, Y. Wang, K. W. Thomas, K. Brewster, and M. Xue, 2013: A realtime weather-adaptive 3DVAR analysis system for severe weather detections and warnings. *Weather and Forecasting*, **28**, 727-745.

Ge, G., J. Gao, M. Xue, and K. K. Droegemeier, 2012: Diagnostic pressure equation as a weak constraint in a storm-scale three dimensional variational radar data assimilation system. *Journal of Atmospheric and Oceanic Technology*, **29**, 1075-1092.

Ge, G., J. Gao, and M. Xue, 2013: Impacts of assimilating measurements of different state variables on the analysis and forecast of a supercell storm using three dimensional variational method. *Monthly Weather Review*, **141**, 2759-2777.

Ge, G., J. Gao, and M. Xue, 2013: Impact of diagnostic pressure equation constraint on the prediction of tornadic supercell thunderstorms with assimilation of radar data using a three-dimensional variational system. *Advances in Meteorology*, accepted.

Liu, C., and M. Xue, 2013: A unified framework for four-dimensional ensemble-variational hybrid data assimilation. *Quarterly Journal of the Royal Meteorological Society*, submitted.

Supinie, T. A., Y. Jung, M. Xue, D. J. Stensrud, M. M. French, and H. B. Bluestein, 2013: Impact of special VORTEX2 observations on the analyses and forecasts of the 5 June 2009 Goshen County, Wyoming, supercell. *Monthly Weather Review***,** to be submitted.

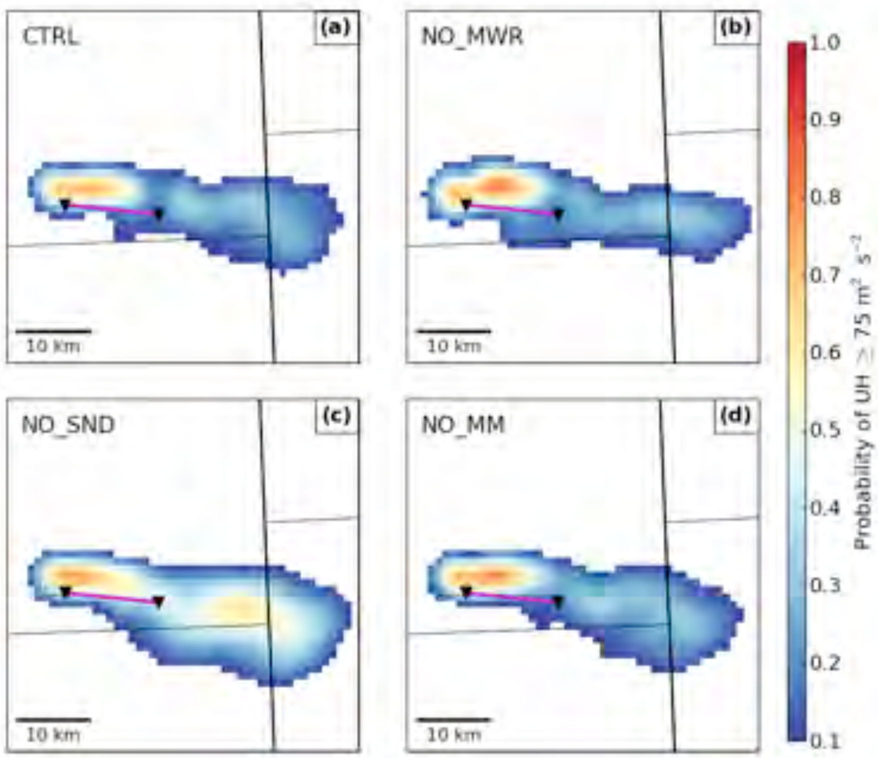
Stensrud D.J., L.J. Wicker, M. Xue, D.T. Dawson II, N. Yussouf, D.M. Wheatley, T.E. Thompson, N.A. Snook, T.M. Smith, A.D. Schenkman, C.K. Potvin, E.R. Mansell, T. Lei, K.M. Kuhlman, Y. Jung, T.A. Jones, J. Gao, M.C. Coniglio, H.E. Brooks, and K.A. Brewster, 2013: Progress and challenges with Warn-on-Forecast. *Atmospheric Research*, **123**, 2-16.

Wang, S., M. Xue, and J. Min, 2013: A four-dimensional asynchronous ensemble square-root filter (4DEnSRF) algorithm and tests with simulated radar data. *Quarterly Journal of the Royal Meteorological Society*, **139**, 805-819.

Wang, S., M. Xue, A.D. Schenkman, and J. Min, 2013: An iterative ensemble square root filter and tests with simulated radar data for storm scale data assimilation. *Quarterly Journal of the Royal Meteorological Society*, in press. DOI: 10.1002/qj.2077.

Wang, Y., Y. Jung, T. A. Supinie, and M. Xue, 2013: A hybrid MPI/OpenMP parallel algorithm and performance analysis for an ensemble square root filter suitable for dense observations. *Journal of Atmospheric and Oceanic Technology*, **30**, 1382-1397.

Zhao, G., and M. Xue, 2013: A comparison between EnSRF and LETKF algorithms for convective-scale radar data assimilation: OSSEs and effects of nonlinear observation operator. *Quarterly Journal of the Royal Meteorological Society***,** to be submitted.



Neighborhood ensemble probability of updraft helicity (UH) ≥ 75 m^2 s^{-2} over the duration of the forecast for the 5 June 2009 Goshen County, Wyoming, tornadic supercell storm. UH is integrated over the 0-3 km AGL layer, and the neighborhood is 2 km in radius. The observed tornado is plotted in magenta. Ensemble initial conditions were obtained using EnKF (from Supinie et al. 2013). CNTL assimilated routine (3 WSR-88D radar, ASOS and wind profiler data), MWR-05XP (an X-band phased array radar, denoted MWR), and mobile soundings, mobile mesonet and 'sticknet' (denoted MM) observations. NO_MWR, NO_SND and NO_MM exclude MWR, sounding, and MM data, respectively.

CIMMS Task III Project – National Sea Grant Weather & Climate Extension Specialist

Kodi Monroe (CIMMS at NSSL), Kevin Kelleher (NSSL), Peter Lamb (CIMMS at OU), Heather Moser Grams (CIMMS at NSSL), and Joe Ripberger (CIMMS/CASR at OU)

NOAA Technical Leads: Leon Cammen (NOAA Sea Grant) and Kevin Kelleher (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events; and*

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task III (NOAA Sea Grant)

Objectives

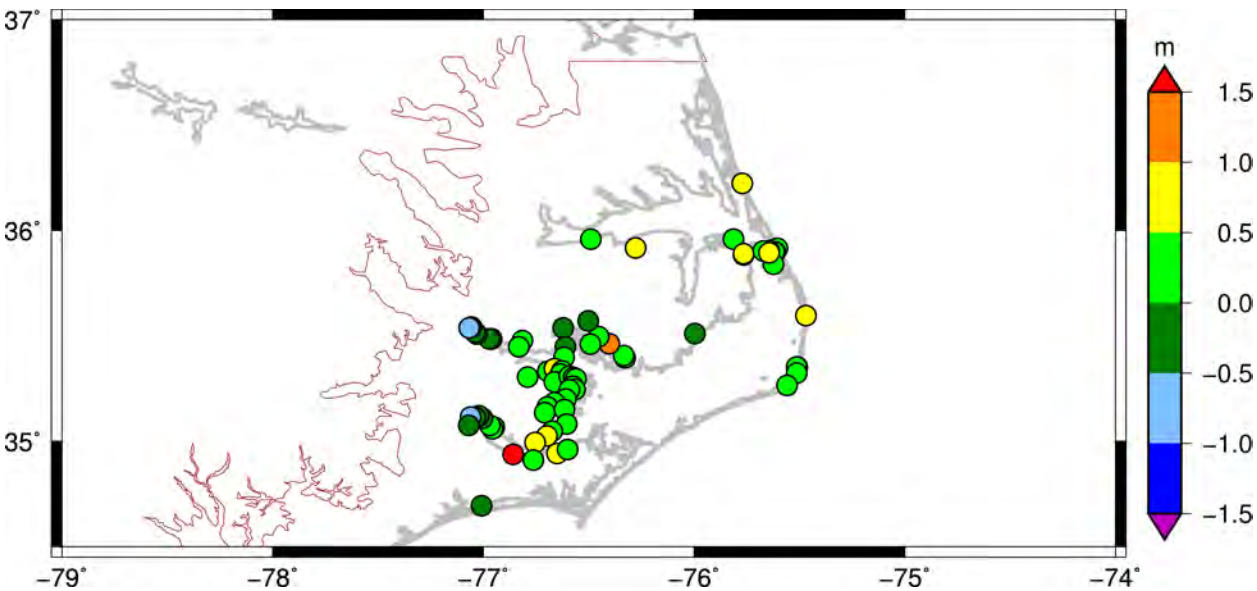
Connect National Sea Grant research and outreach programs with NOAA's NSSL and other NWC organizations; lead the Coastal and Inland Flooding Observation and Warning (CI-FLOW) research project to improve hydrologic information for coastal watersheds.

Accomplishments

The Sea Grant Weather & Climate Extension Specialist at CIMMS/NSSL leads NOAA's CI-FLOW project and actively participates in NSSL's hydrometeorological research activities. During the 2012 and 2013 Atlantic hurricane seasons, the CI-FLOW collaborators continued real-time predictions of coastal water levels during Tropical Depression Alberto, Tropical Storm Beryl, and Hurricane Sandy. Although these storms just glanced the North Carolina coast with minor impacts, they were well predicted by the CI-FLOW system. QPE produced by the NSSL Q2 system provided input data to the 128-member ensemble of the NWS Hydrologic Lab-Research Distributed Hydrologic Model (HL-RDHM). At four points on the Tar-Pamlico and the Neuse Rivers, discharge information served as upstream boundary conditions for the ADvanced CIRCulation (ADCIRC) hydrodynamic model to incorporate freshwater contributions into coastal water level simulations. The CI-FLOW coupled model system runs in real time every six hours. Real-time simulations of coastal water levels are available on the CI-FLOW web site (https://secure.nssl.noaa.gov/projects/ciflow/), the NOAA nowCOAST web site (http://nowcoast.noaa.gov/ciflow/), and the Coastal Emergency Risks Assessment web site (http://nc-cera.renci.org/cgi-cera-nc/cera-nc.cgi).

The Sea Grant Weather & Climate Extension Specialist is collaborating with colleagues at OU, NSSL, and the NWS Office of Hydrologic Development to conduct complementary research projects on the use of one- and two-dimensional hydraulic models within the CI-FLOW system to reduce the computational requirements of ADCIRC. This research will help design a coupled model system that can be more

broadly implemented into operations for the Gulf and Atlantic coasts. At the same time, the Extension Specialist is facilitating the transfer of the CI-FLOW coupled model system to the Pearl River in Mississippi and Louisiana. Stakeholders from the US Fish and Wildlife Service, Louisiana Department of Wildlife and Fisheries, and St. Tammany Parish participated in a meeting to organize the collection of river channel cross-sections to refine the ADCIRC computational grid. In addition, the Extension Specialist is actively collaborating with NOAA's Storm Surge Roadmap and the National Hurricane Center to address important research questions before such a system can be transferred to operations.



Plot of the differences between high water marks collected after Hurricane Irene by the USGS and other partners in North Carolina and the total water level results for the best track of Irene from the CI-FLOW coupled model system.

Joe Ripberger, a Post-Doctoral Research Associate, jointly housed in CIMMS and CASR, facilitated regular communication and a culture of collaboration between the research groups. He observed parts of the HWT 2013 Spring Experiment and attended regular meetings with the CASR/Center for Risk and Crisis Management (CRCM) faculty; Warn-on-Forecast team; Weather, Climate, Sustainability and Social Science Discussion Group; and National Sea Grant Social Science Community of Practice.

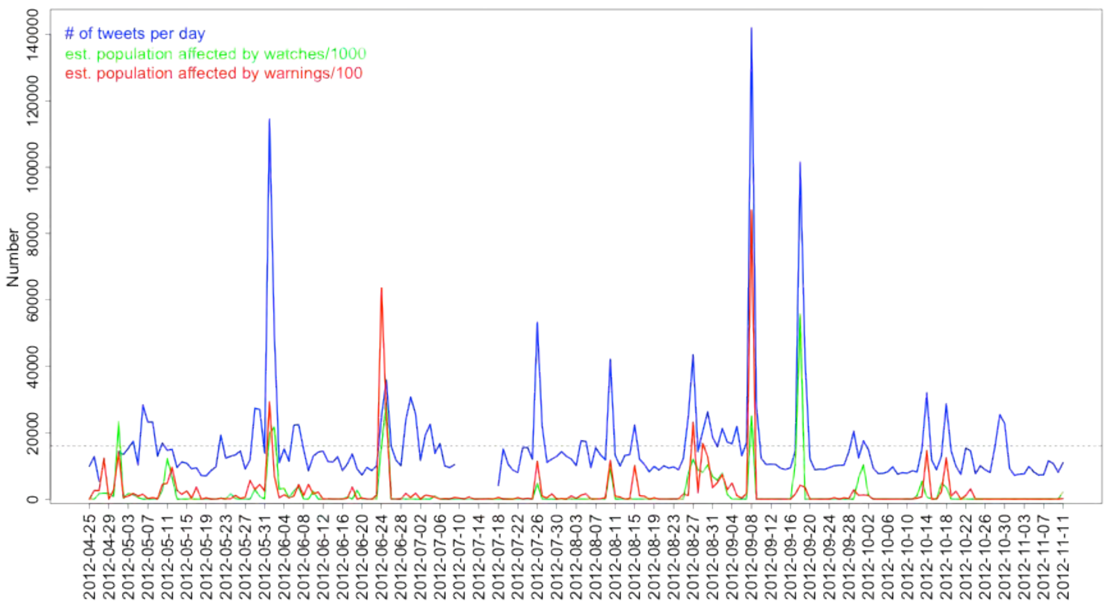
The Sea Grant Post-Doctoral Research Associate also is assisting in the evaluation of the end-to-end severe weather warning process. Quantitative and qualitative data were collected via multiple sources, including social media, the Hazardous Weather Testbed (HWT) 2013 Spring Experiment, and Internet surveys of US residents that live in tornado-prone regions of the county. In collaboration with the CASR and CRCM, these data are being used to study:

- The extent to which members of the public utilize and trust information from social media about severe weather;

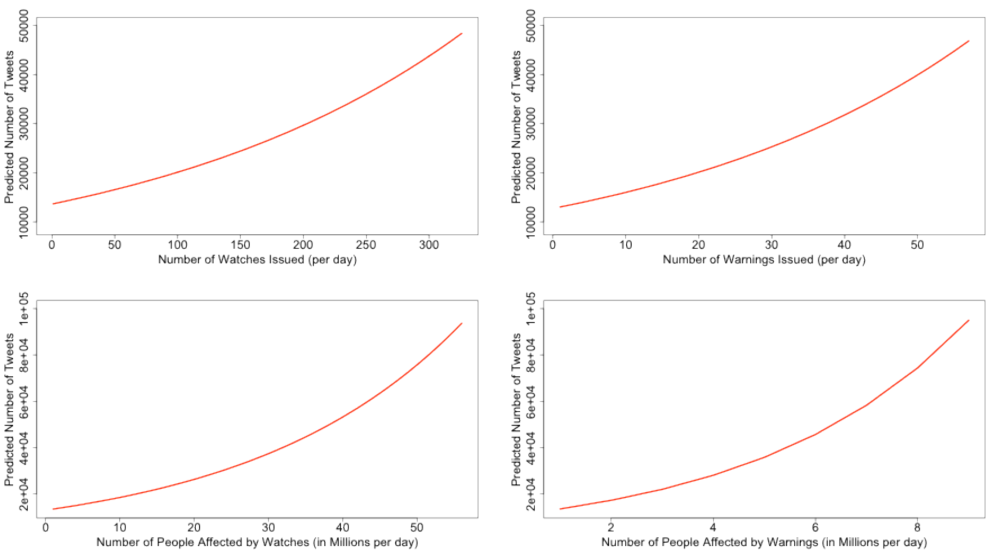
- Patterns of public attention and communication before, during, and after severe weather events;
- The relationship between warning system accuracy, credibility, and public responses to warnings;
- The influence of consequence-based messages on public responses to warnings;
- The impact of objective risk from severe weather on subjective perceptions of risk and preparatory/mitigation behavior; and
- The relative costs of protective action during warnings and the factors that influence these costs.

The findings from this research will inform future discussions about how to better connect the front (warning decision making) and back (public response) ends of the warning process. Example results are shown below.

This project is ongoing.



Daily comparison of tweets containing the word "tornado" and the approximate number of people affected by tornado watches and warnings.



Predicted number of tweets containing the word "tornado" given the number of tornado watches/warnings issued per day and the number of people affected by those watches/warnings.

Publications

Dresback, K. M., J. G. Fleming, C. Kaiser, J. J. Gourley, E. M. Tromble, R. A. Luettich, R. L. Kolar, Y. Hong, S. Van Cooten, H. J. Vergara, Z. L. Flamig, B. O. Blanton, H. M. Lander, K. E. Kelleher, and K. L. Nemunaitis-Monroe, 2013: Skill assessment of a real-time forecast system utilizing a coupled hydrologic and coastal hydrodynamic model during Hurricane Irene (2011). *Continental Shelf Research*, accepted.

CIMMS Task III Project – Storm Tracking and Lightning Cell Clustering using Geostationary Lightning Mapping Data for Assimilation and Forecast Applications

Kristin Calhoun (CIMMS at NSSL), Donald MacGorman (NSSL), Benjamin Herzog (OU School of Meteorology at CIMMS)

NOAA Technical Lead: Donald MacGorman (NSSL)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NESDIS GOES-R)

Objectives

The focus of this project is to determine thresholds of lightning rates and lightning density that define storm clusters for use by forecasters and in numerical forecast models.

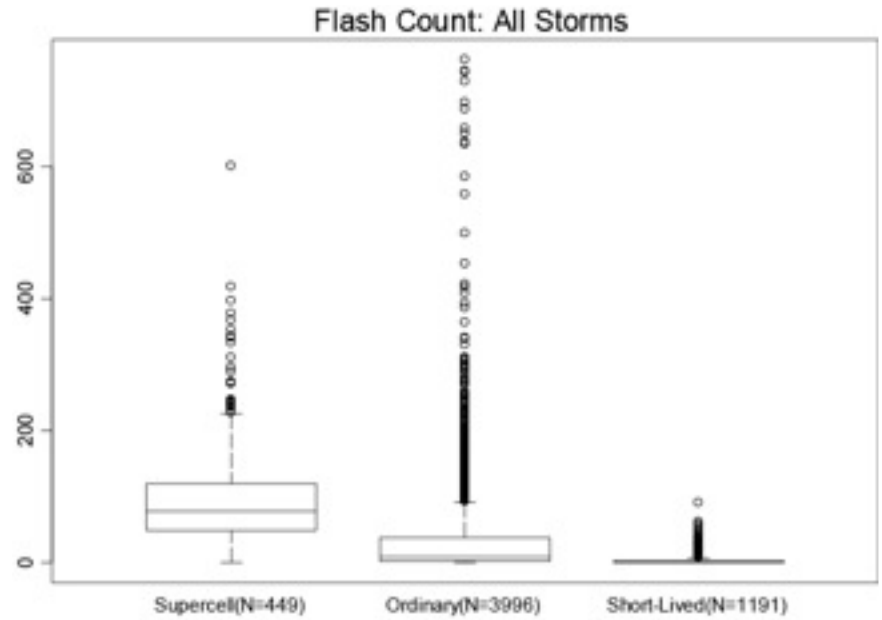
Accomplishments

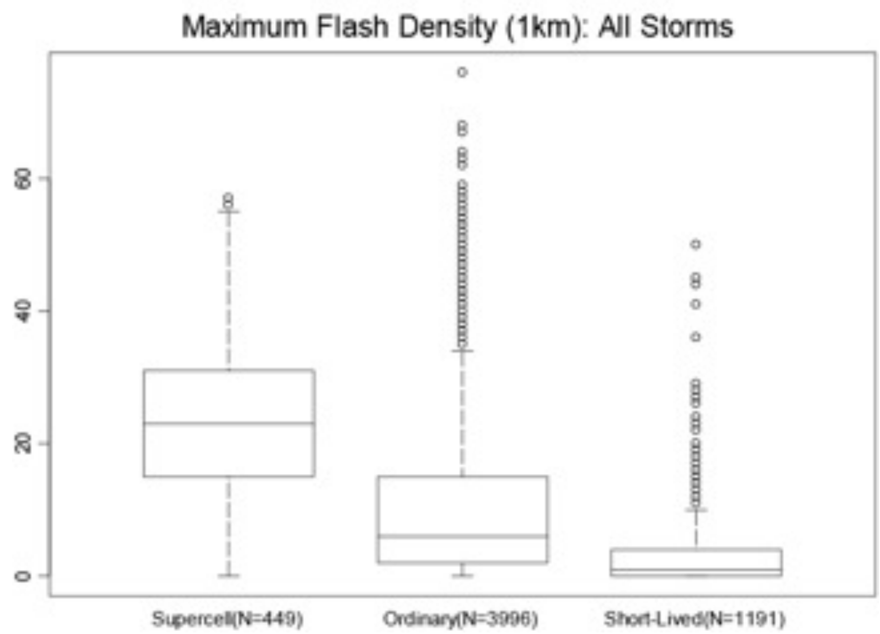
Lightning data will be available with a higher temporal resolution than that of the radar network once the Geosynchronous Lightning Mapper (GLM) on GOES-R is implemented for operational use. The enhanced temporal resolution of total lightning data and its ability to serve as a proxy for storm intensity may be exploited both to enhance the situational awareness of forecasters in an operational setting and to allow these complementary data to be assimilated into numerical weather prediction models to improve their forecasts. However, there is much work to be done to investigate exactly how lightning activity is relevant to operational forecasters and to determine how lightning activity relates to model state variables. Furthermore, little work has been done examining how lightning varies across different storm types and different climatological regions.

Real-time storm tracking for use in an operational setting has been developed within the WDSSII and tested using both total lightning data and radar data. Additionally, pseudo-Geostationary Lightning Mapper (pGLM) products have been created from Lightning Mapping Array (LMA) systems in various locales for testing lightning data within the Spring Experiment, GOES-R Proving Ground activities, and various algorithms.

While there have been many studies examining relationships between lightning activity and measures of storm intensity for individual storms, there have been relatively few studies aimed at exploring these relationships in the framework of a multi-year climatology. This research examines relationships between lightning activity and radar derived storm attributes over five years across three different geographic domains (central Oklahoma, northern Alabama, and Washington, D.C.), with each domain corresponding to the location of an lightning mapping array network. Specifically, this research: (1) examines correlations between lightning characteristics and radar derived storm attributes in thunderstorms, (2) determines how lightning characteristics of thunderstorms vary between different geographic regions, and (3) determines how lightning characteristics vary between different thunderstorm types (i.e., supercell, multicell, ordinary) – see figure below. Through the examination of these relationships over a period of several years, we will be capable of more accurately understanding and harnessing total lightning information, thus greatly improving the value of the information available from the GLM.

This project is ongoing.





Box plots of the (a) flash rate and (b) maximum flash density for different storm-types (supercells, ordinary – or multicell convection, and short-lived convection) during 12 active storm days over three different LMA regions (central Oklahoma, northern Alabama, and Washington, D.C). This initial examination shows different lightning behaviour for different storm types using a sample size of 5636 different tracked storm clusters. This research is being expanded to 5 years and will be completed in FY14.

CIMMS Task III Project – Prototyping and Evaluating Key Network-of-Networks Technologies

Jerry Brotzge (OU CAPS), Fred Carr (OU School of Meteorology), and Lee Carlaw and Nicholas Gasperoni (OU School of Meteorology at CAPS)

NOAA Technical Lead: Tim McClung (OS&T Science Plans Branch)

NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (OS&T)

Objectives

Utilize the resources associated with the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) Urban Demonstration Network to improve NOAA's understanding and use of in situ and remotely sensed observations. The specific objectives of this project are threefold: (i) Test and evaluate an experimental LIDAR system; (ii) Evaluate observation sensor impact using an Observation System Simulation Experiment (OSSE); and (iii) Evaluate observation sensor impact using an Observation System Experiment (OSE).

Accomplishments

1. Test and Evaluate a LIDAR System

A team consisting of Rit Carbone, Tammy Weckwerth and colleagues from the Earth Observing Lab (EOL) at the National Center for Atmospheric Research (NCAR) and Montana State University (MSU) deployed a new, low-cost, laser-based, differential absorption lidar (DIAL) water vapor profiler to test its capabilities in a humid environment. This lidar, which can be made eye-safe, should provide higher vertical resolution (100-200 m) up to higher heights (4-6 km) than competing infrared and microwave water vapor sensors, and therefore has the potential to become a very important component of a national Network of Networks (NoN) system.

In order to conduct a thorough evaluation of the DIAL, a short Intensive Operation Period (IOP) was conducted between 28 September and 5 October, 2012, at the NWS Weather Forecast Office at Fort Worth – Dallas (FWD). Experiment participants included Tim Lim, Bruce Morley, Scott Spuler, and Tammy Weckwerth (all from NCAR); Kevin Rapasky (Montana State University); Dave Turner (NSSL); Tom Bradshaw, Greg Patrick, and support staff (NWS FWD WFO); and Fred Carr and Jerry Brotzge.

The DIAL system was sited with other instruments that measure water vapor to evaluate the relative strengths and weaknesses of each sensor. Referred to as the "NWS Water Vapor Profiling Experiment", three separate profiling systems were operated during an 8-day period. The DIAL provided 15-min, 300 m resolution and had ~80% uptime

during the IOP. In addition to the DIAL system, an Atmospheric Emitted Radiance Interferometer (AERI) was provided by the University of Wisconsin-Madison and operated by NSSL. The AERI provided 20-sec temporal resolution and variable spatial resolution. A Microwave Radiometer (MWR) Profiler, on loan to the National Weather Center by Radiometrics, Inc. and operated by NSSL, was also tested and provided 3-min temporal resolution and variable spatial resolution. Both the AERI and MWR operated from 20 Sep – 5 Oct and had 100% uptime during this period. Data from the AERI and MWR were available in real-time. For additional verification, Vaisala RS-92 radiosondes were launched daily at 03, 09, 15, and 21 UTC using the NCAR mobile sounding system. Regular NWS Sipican radiosondes were launched daily at 00 and 12 UTC.

NWS funds directly supported the transport of the DIAL system to and from the Testbed, the travel and lodging of EOL personnel, and some support equipment including the purchase of 25 radiosondes and helium. Data from the IOP continues to be evaluated. This project is ongoing.

2. Evaluate Observation Sensor Impact Using an OSSE

Determining the value added to a forecast from a specific subset of observations is important in order to make sure observations are used in the best way possible. In this way, we can avoid using observations that have little to no impact, or even negative impact, on a forecast. Additionally, we can investigate by instrument type, observation type, and location, which observations have the most impact or which observations are most needed in a forecast. Brute force data-denial (OSE) experiments are one way of measuring such impact, but take tremendous computing resources to accomplish because of the need for multiple separate analysis-forecast experiments. Another option is an adjoint-based method. Different from the data denial method, this method can provide an observation impact estimate for all observations simultaneously. However, developing adjoints for high-resolution nonlinear models can be challenging. With the rise of ensemble assimilation and forecasting, ensemble methods have been recently developed to estimate the impact of observations on a forecast. Such methods avoid the development of an adjoint and can also provide estimates of observation impacts simultaneously. The impact estimate given by the ensemble-based method can be limited by ensemble size. The smaller the number of ensembles, the more sampling error is present due to spurious correlations. The goal of the project is to evaluate the ensemble based observation impact estimate, explore new covariance localization methods to reduce the sampling error and therefore improve the estimate, and implement it for meso/storm scale observations and numerical forecasts.

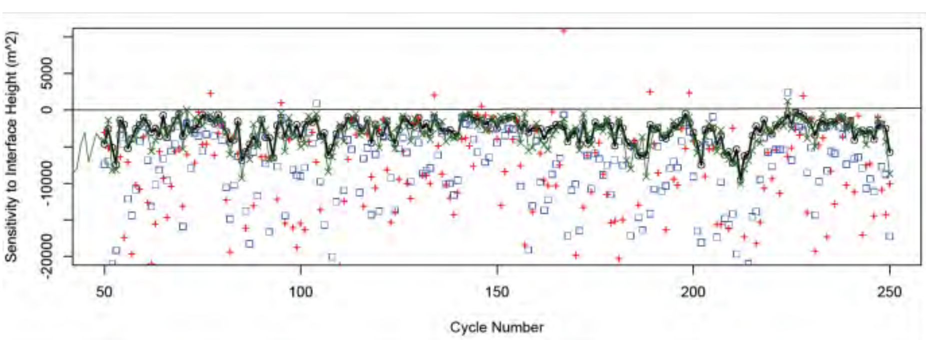
To evaluate and explore methods to improve the ensemble based observation impact, we first conduct experiments with a simplified primitive equation model and simulated observations. The model has been used in both perfect- and imperfect-model ensemble-based data assimilation experiments.

A two-level global model run at T127 resolution serves as a nature run, or true state. The assimilation-forecast cycles are run at T31 resolution for 250 model days (with the data assimilation cycle and sensitivity evaluations done at *24* hr intervals), using 16 ensemble members throughout. Observations of the interface height between levels were generated from the truth by adding error drawn from a fixed standard deviation, and assimilated via LETKF (Local Ensemble Transform Kalman Filter) every 24 hours. There are 362 equally-spaced observations distributed over the global domain. The Gaspari-Cohn (GC) covariance localization was applied at each assimilation step with a cutoff radius of 4,000 km.

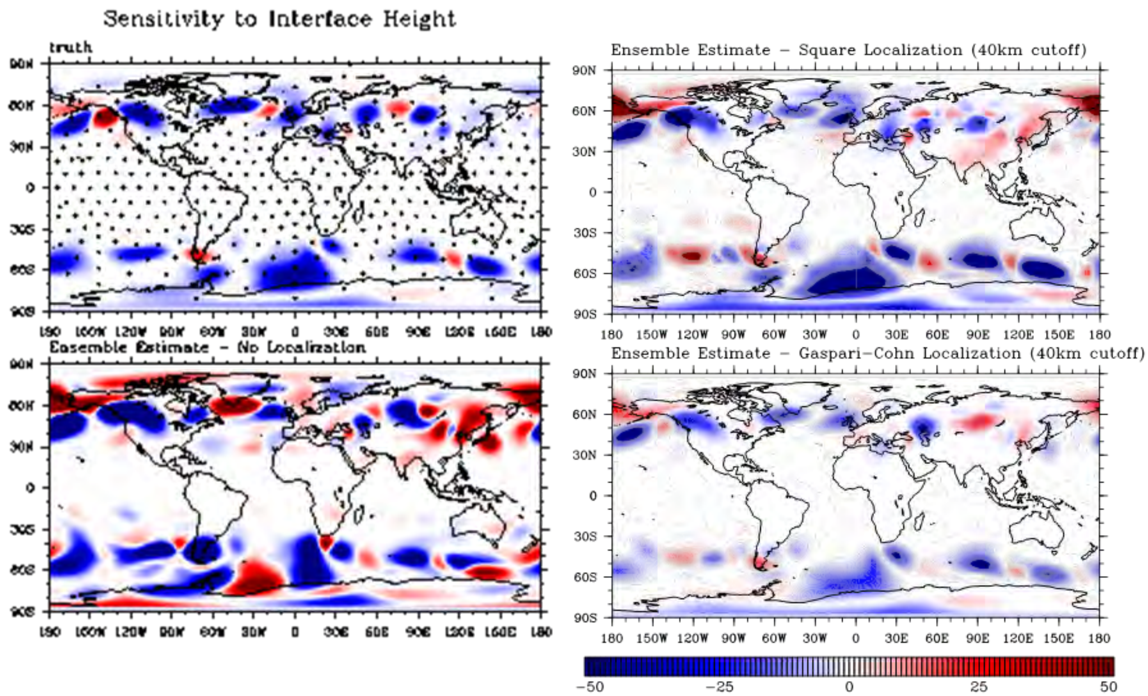
The ensemble impact estimate was implemented in these assimilation-forecast cycles for 1-, 2-, and 3-day forecasts, with no localization. Additional sets of experiments were conducted using two types of fixed localization, Square and GC, each with a 4,000 km cutoff radius (same as assimilation step). The estimated impacts were compared with the actual impacts.

The first figure below shows the globally averaged impact estimated for each localization type over the last 200 data assimilation cycles. Note that negative values refer to positive impact of the observations. With GC localization, the impact estimate matched closest with the actual impact, while square and no localization estimates tended to grossly overestimate the average impact. When looking at the results for the day 2 and day 3 forecasts (not shown), the accuracy of the estimated impact began to degrade. GC localization still performed best.

The second figure below shows one example of a spatial distribution of observation impact. Most of the impact was confined to mid-latitudes, where the model dynamics are most active. With no localization (lower left panel), the ensemble based observation impact estimate was very noisy and showed the biggest discrepancies to the actual impact (upper left). Square localization (upper right) appeared to capture many of the spatial structure much better, though there was still large magnitude error in some spots. With GC localization (lower right), the spatial structure tended to match the actual impact even better. This project is ongoing.



Time series of globally-averaged observation impact for one-day forecast of interface height (m^2). The black line and circles is the actual impact. Red plusses, blue squares, and green x's are ensemble-estimated impact with no localization, square localization, and GC localization applied, respectively.



Spatial distribution of observation impact (blue: positive impact, red: negative impact). Upper left panel is the truth with observation locations. The other panels are ensemble estimates with no (lower left), square (upper right), and GC (lower right) localization.

3. Evaluate Observation Sensor Impact Using an OSE

In order to begin to evaluate observations from some of our current systems, this study used a brute-force, OSE approach and assimilated data already available from across the DFW region, including the WSR-88D, two TDWR radars, surface ASOS/AWOS sites, ACARS data, radiosondes, surface site data from EarthNetworks, and mobile weather observations from GST. Analyses were created from these data and compared against the NWS Real-time Mesoscale Analysis (RTMA). Data collected during two significant weather events in Dallas – Fort Worth formed the basis for this study. The two events included the 3 April 2012 tornado outbreak, which produced 17 tornadoes (4 of which were EF2 or higher), and the 13 June 2012 severe hail event, which caused around $900 million in damage along with reports of softball-sized hail (see http://www.srh.noaa.gov/fwd/?n=june132012 and also http://www.srh.noaa.gov/fwd/?n=april32012sum).

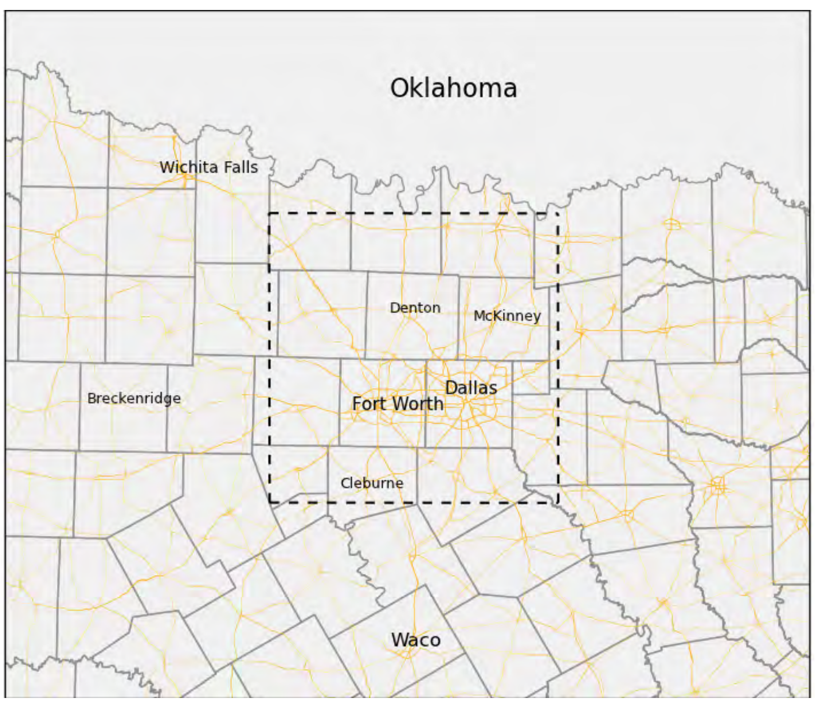
For this study, the ARPS (Advanced Regional Prediction System) prediction model and its three-dimensional variational data assimilation and cloud-analysis packages (ARPS 3DVAR) were utilized. The data assimilation experiments were performed on a 400-m horizontal-resolution grid with a domain 161 x 161 km in size. The domain covered the immediate Dallas/Fort-Worth metropolitan region and surrounding suburbs, and the analysis grid consisted of 53 levels and is stretched in the vertical according to a hyperbolic tangent function with minimum vertical grid spacing of 20 m near the surface.

This vertical profile placed the first model level at 10 m AGL, to facilitate comparisons between the ARPS 3DVAR and RTMA analyses, with roughly 7 grid-points falling below 200m. A map of the analysis domain is shown in the first figure below.

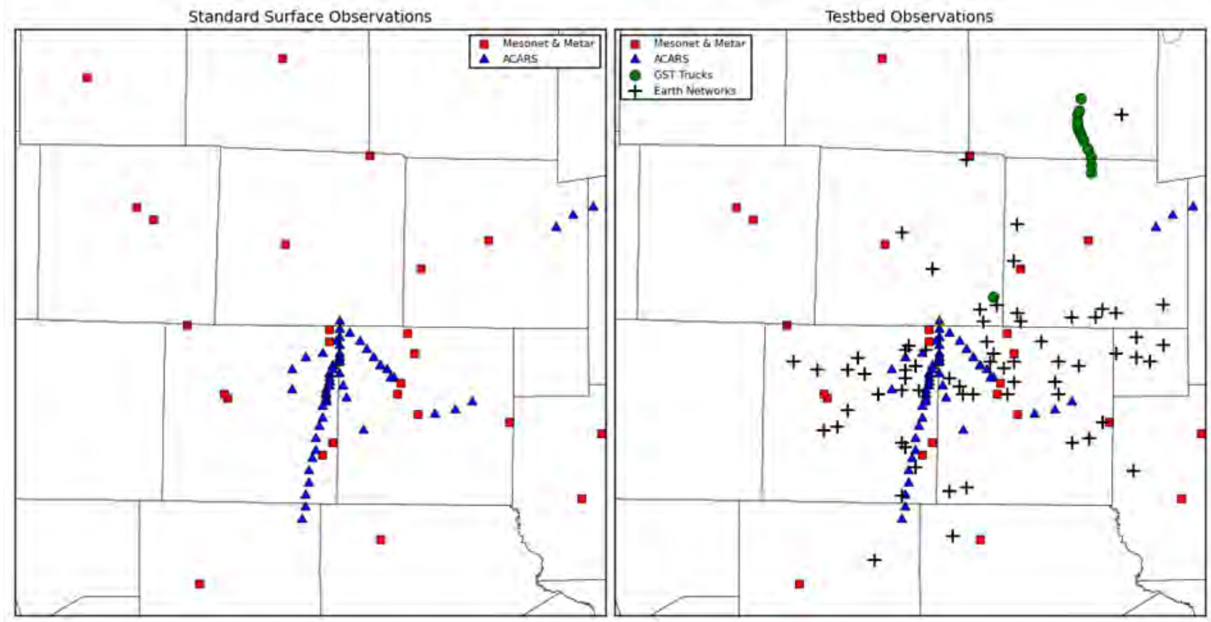
The initial analysis background consisted of 5-km RTMA near-surface fields interpolated to the 400 m ARPS grid. Above-surface information was provided by a one hour 13-km Rapid Update Cycle (RUC) forecast interpolated first to the 5-km RTMA grid and then to the 400 m ARPS grid. Thus, no additional information was added to the background fields in this process. Background analyses were created in this manner from 1500 UTC to 2300 UTC on 3 April 2012 using the 5-km RTMA NDFD terrain elevation dataset.

A comparison of 'typically assimilated' surface observations (including ACARS) to those available for our case studies is shown in the second figure below for 15 UTC on 3 April 2012. While data void regions still exist (particularly across the northwestern and southwestern corners of the analysis domain), the addition of roughly 100 observations from EarthNetworks and GST greatly increased the data density in and around the immediate metropolitan region. It is worth noting here that significantly more GST truck observations were available at most assimilation times, but because they tended to be grouped in clusters, many were combined into a "superob", which better conditioned the 3DVAR cost function and reduced the random errors of close individual observations.

Work on this project during 2012-2013 has thus far been limited to data ingest, and model and experiment setup. Analysis of the observational impact is now beginning with preliminary results expected by mid-autumn. This project is ongoing.



Dallas/Fort Worth data assimilation domain (dashed lines).



Distribution of surface and ACARS observations for typical data assimilation (left) and the DFW testbed (right).

Theme 4 – Impacts of Climate Change Related to Extreme Weather Events

CIMMS Task I Project – Building Resilience to Face Recurring Environmental Crisis in the African Sahel

Emily Boyd and Rosalind Cornforth (University of Reading), Peter Lamb (CIMMS at OU), Aondover Tarhule (OU Department of Geography and Environmental Sustainability), M. Issa Lélé (OU School of Meteorology at CIMMS), and Alan Brouder (Oxfam GB)

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task I

Objectives
Building climate resilient management systems across the West African Sahel.

Accomplishments
The present food shortages in the Horn of Africa and the West African Sahel are affecting 31 million people. Such continuing and future crises require that people in the region adapt to an increasing and potentially irreversible global sustainability challenge. Given this situation and that short-term weather and seasonal climate forecasting have limited skill for West Africa, the Rainwatch project illustrates the value of near real-time monitoring and improved communication for the unfavorable 2011 West African monsoon, the resulting severe drought-induced humanitarian impacts continuing into 2012, and their exacerbation by flooding in 2012. Rainwatch is now coupled with a boundary organization (Africa Climate Exchange, AfClix) with the aim of integrating the expertise and actions of relevant institutions, agencies and stakeholders to broker ground-based dialogue to promote resilience in the face of recurring crisis.

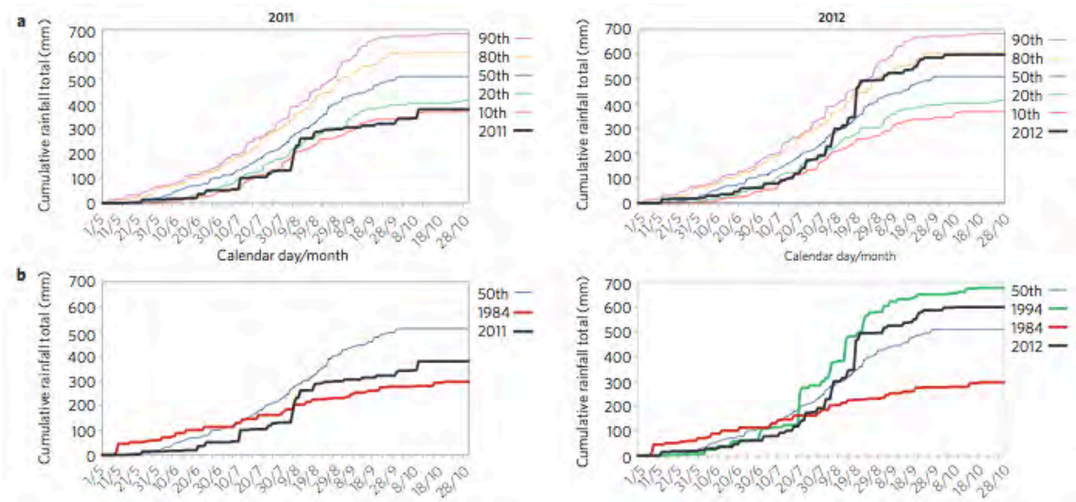
While we recognize a gulf between the availability of information and the ability of vulnerable groups to act on that information, we maintain that timely information is a pre-requisite for informed decision-making. This practical perspective is illustrated through local monitoring of the unfavorable 2011 and extremely wet 2012 West African monsoons. Real-time monitoring of 2011–2012 for nine stations in Niger was accomplished using Rainwatch – a prototype geographical information system (GIS) designed to increase interactions between local climate information users, their providers and supporting groups. Those nine stations are distributed across, and represent fully, the economically vital southern (agricultural) region. Rainwatch was developed at OU to build African capacity to minimize the adverse impacts of Sahelian rainfall variability of the type characterizing the previous 40+years. The effort cost around US$75,000 and was led by our West African co-author (Aondover Tarhule) from his regional background and hydroclimatology research experience. The Rainwatch database includes historical rainfall for each station. Graphics features allow users to view cumulative daily station rainfall plots for one year (or part thereof) against up to five percentile thresholds for the historical reference period. It also lets users compare such plots with counterparts for other stations in the same year or other (extreme) years for

the same station. The high GIS license cost is a major constraint to the wider adoption of Rainwatch, but that challenge will diminish as GIS software and its use become more widespread across the region. Future development using open source GIS will make Rainwatch available to all African countries at low cost.

Rainwatch is ongoing.

Publications

Boyd, E., R.J. Cornforth, P.J. Lamb, A. Tarhule, M. Issa Lélé, and A. Brouder, 2013: Building resilience to face recurring environmental crisis in African Sahel. *Nature Climate Change*, **3**, 631-637.



Rainwatch cumulative precipitation depiction for Niamey (Niger) for 2011–2012: a) comparison of progression of 2011 and 2012 rainy seasons (thick black lines) versus indicated historical percentiles for 1965–2000; b) comparison of 2011 and 2012 with infamous 1984 drought year (thick red lines), very wet 1994 (thick green line), and historical median.

CIMMS Task III Project – Program Support for the Assimilation, Analysis, and Dissemination of Pacific Rain Gauge Data: PACRAIN

Mark Morrissey and Susan Postawko (OU School of Meteorology), and Scott Greene (OU Department of Geography and Environmental Sustainability)

NOAA Technical Lead: Mike Johnson (NOAA Climate Program Office)

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task III (NOAA Climate Program Office)

Objectives

Tropical rainfall data taken over both land and ocean is particularly important to the understanding of our climate system. Not only is it a tracer of latent heat, it is vital to the

understanding of ocean properties as well, such as latent and sensible heat flux, salinity changes and attendant local ocean circulation changes. In addition, rain gauge observations from low-lying atolls are required to conduct verification exercises of nearby buoy-mounted rain gauges, most of which are funded by NOAA's Climate Observations and Monitoring Program (COM) Program.

This project supports the effort to "build and sustain the global climate observing system that is needed to satisfy the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments". Our current and future efforts include expanding our mission to collect, analyze, verify and disseminate global rainfall data sets and products deemed useful for Operational Forecast Centers, International Research Programs and individual researchers in their scientific endeavors. Housed in the Environmental Verification and Analysis Center (EVAC) at OU, the Comprehensive Pacific rainfall Database and the Schools of the Pacific Rainfall Climate Experiment (SPaRCE) have built upon work from past NOAA-supported projects to become a unique location for scientists to obtain scarce rain gauge data and to conduct research into verification activities. These data are continually analyzed to produce error-assessed rainfall products and are easily assessable via our web page (http://pacrain.evac.ou.edu/). We're also actively involved in research of the tropical rainfall process using data obtained from this project (Morrissey et al. 2012).

Scientists need only to access the PACRAIN website (http://pacrain.evac.ou.edu/) to obtain the most comprehensive Pacific rainfall data set anywhere in the world. Also available are validation data for various regions. Many of these regional data sets are impossible or impractical to obtain elsewhere. The EVAC serves the research community by actively working with individual countries in environmentally important locations to help provide them with infrastructure, education and other short and long-term support. One example is our collaboration with the International Precipitation Working Group in conducting satellite rainfall algorithm verification studies. The return on this investment by NOAA has been significant in terms of enabling EVAC to provide the scientific community with critical, one-of-a-kind rain gauge data sets and to have established ongoing mutually beneficial relationships that should lead to future collaborations. Past successes with this strategy have proven very worthwhile on a cost-benefit basis.

Our Pacific educational program, SPaRCE contributes in a direct way to the PACRAIN database through the contribution of Pacific schools taking manual read daily rain gauge measurements while learning about the importance of weather and climate. Underlying these projects is the long-term effort to help build the capacity of the all the Pacific Nations Meteorological Services (PNMS) to better serve their constituents. This ultimately will result in the PNMS being able to self-sustain their data networks. We continue to contribute to this effort by providing what we can in terms of needed supplies, education and communication infrastructure (e.g. involvement in the Radio/Internet (RANET) project) until the PNMS become completely self-sustainable.

Accomplishments

1. Data Collection Archiving and Web Access Development

Due to the importance of tropical Pacific rainfall data to climate research and operational and climate forecasting we work collaboratively with the Pacific Island Global Climate Observing System (PI-GCOS) program to effectively and efficiently match the areas of commonality among both COM's and PI-GCOS's objectives. One of these common areas is the strengthening of the existing Pacific observation climate network for both atmosphere and ocean.

Specifically, we collect all available rain gauge data 1) in environmentally critical locations (e.g. tropical Pacific), 2) where dense rain gauge networks exist and 3) where agreements can be made to help construct rain gauge networks in these critical locations. These data are assimilated, homogenized, and error-checked and then made available to the general research community. To create the most comprehensive Pacific rain gauge database possible it is necessary to continue to work closely with the Pacific meteorological services to help them sustain high their quality gauge networks. One of our most successful efforts during the last few years is the implementation of a large network of new manual-read rain gauges and automatic data-logger equipped tipping bucket rain gauges located on various atolls and islands managed by the local Pacific meteorological services. A total of approximately 60 automatic, high quality tipping bucket gauges are being operated by various Pacific Island meteorological services. We currently are collecting the data in tip format and converting it to 1-minute resolution. One of new efforts this year has been to conduct research using the tipping bucket data. Researchers have used the PACRAIN data set for a variety of purposes (e.g. Delcroix et. al, 1996, Xie et al., 2007). The uses include incorporation into climate models, climate studies, and the verification of satellite rainfall algorithms. The data set is also referenced by many programs (e.g., the International Precipitation Working Group, (IPWG), the Global Energy and Water Cycle Experiment (GEWEX), etc.) and is included in NASA's Global Change Master Directory.

It is our belief that by working directly with local Pacific island meteorological services, we bring tangible benefits to the global climate research community through data base development and enhancement. In turn, the local meteorological services also benefit directly through enhanced forecast products developed by the scientific community using these critical data sets.

2. Pacific Rainfall Climate Network Development, and Delivering vital Rainfall Data to the Research Community Through Online Access of the PACRAIN Database

Rain rate measurements over open ocean regions are very important in the assessment of satellite rain algorithms and climate change and modeling of physical processes. Until recently, no Pacific island rainfall measurements have been available at resolutions less than one hour. Our new MetONE rain gauges tipping bucket gauges are equipped with data loggers and have been donated by OU for this project. In turn,

they have been given to the PI-GCOS Coordinator, headquartered at SPREP, for distribution to the various PNMS. We have deployed over 50 of these gauges throughout the Pacific region since 2008. We are currently receiving rainfall tip data back from many PNMS and these data are inserted into the PACRAIN database. These data are particularly important in the understanding of basic tropical rain systems and consequently, more accurate global climate models. These data are all included in the PACRAIN database.

The achievement of this objective could not be accomplished without the close collaboration of the PI-GCOS Steering Group and the current PI-GCOS Coordinator. Other important collaborative groups are the Global Ocean Observing System (GOOS), the New Zealand Meteorological Service, and the New Zealand Institute for Research in Water and Atmosphere, the Australian Bureau of Meteorology, Meteo-France, and the U.S. NWS. The PI-GCOS website is http://www.pi-gcos.org/.

During the fiscal year, the Oklahoma Mesonet donated several solar panels and other climate equipment to the Vanuatu Meteorological Service. The equipment is in support of an experimental project to link data received from the PACRAIN tipping bucket rain gauge deployed in 2011 to the meteorological service on a near-real time basis.

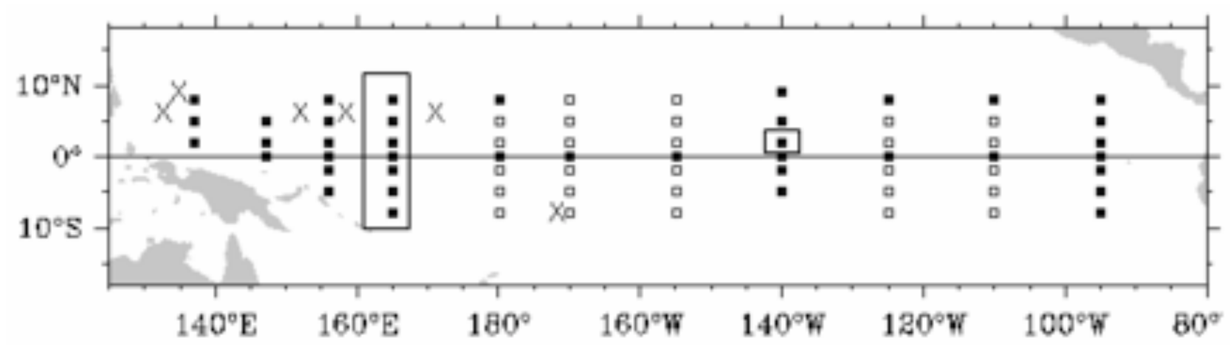
3. Provide High Spatial Density World Regional Rain Gauge Datasets for Use in Satellite Rainfall Algorithm Verification

The PACRAIN project maintains a database of selected high-density rain gauge network data for use in satellite rainfall algorithm assessment. Part of our responsibilities includes providing surface validation rainfall data to researchers associated with the Global Precipitation Climatology Project (GPCP) and the IPWG. Our tasks in this capacity include identifying and collecting these data sets and making them available to researchers for this purpose. We also conduct studies on the errors involved when comparing satellite and rain gauge data. The results of our research, one of the first on stochastic modeling of tropical rainfall, (e.g., Morrissey, 2009) indicate that the model is able to reproduce the rain rate statistics computed from Tongan METOne gauges quite well. This study would not have been possible without the tipping bucket data. The model now can be further tested at other sites that will allow the assessment the statistical characteristics unique to tropical rainfall.

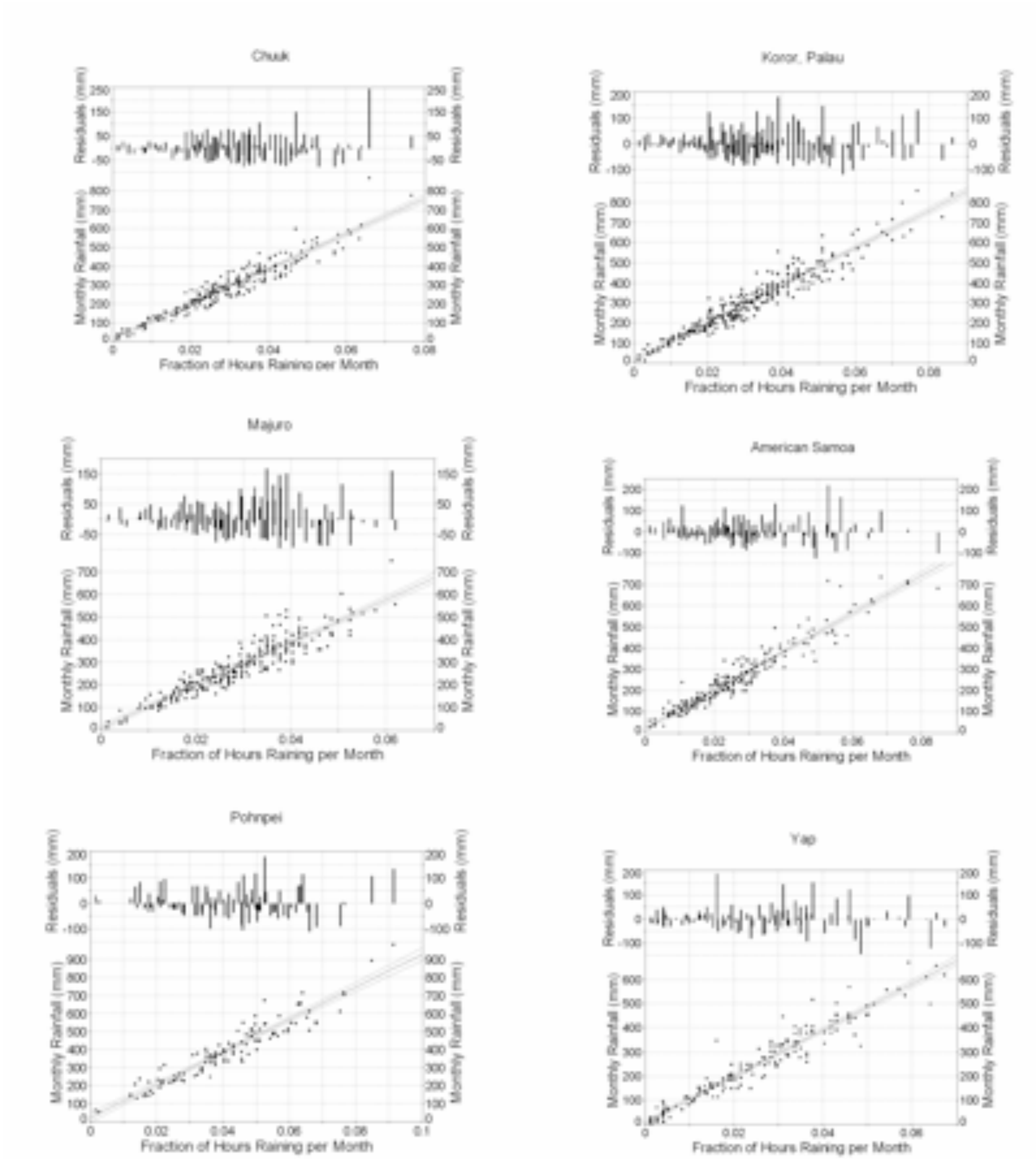
4. Assess the Consistency of the TAO/TRITON Buoy Capacitance Rain Gauges through a Comparison with PACRAIN Island Tipping Bucket Gauges

Collaboration with oceanographers is one of our top priorities. The common use of remotely located, buoy-mounted capacitance rain gauges in the tropical oceans for satellite rainfall verification studies provides motivation for an *in-situ* gauge bias assessment. A comparison of the biases in rainfall catchment between Pacific island tipping bucket rain gauges and capacitance rain gauges mounted on TAO/TRITON moored buoys in the tropical Pacific was conducted using the relationship between the fractional-time-in-rain and monthly rainfall initially investigated by Morrissey et al.

(1994). This study utilized the widespread spatial homogeneity of this relationship in the tropics to assess the rain catchment of both types of gauges at given values for the fraction-time-in-rain. The results indicate that the capacitance gauges are not statistically significantly biased relative to the island-based tipping bucket gauges. In addition, given the relatively small error bounds about the bias estimates any real bias differences among all the tested gauges are likely to be quite small compared to monthly rainfall totals. The paper was published in the *Journal of Atmospheric and Oceanic Technology* (Morrissey et al. 2012).



Solid squares indicate TAO/TRITON buoy locations mounted with capacitance gauges. Solid squares surrounded by a rectangle are the 8 Pacific buoys with capacitance gauges used in this study. Island TB gauges used in this study are located by an 'x'. Note buoys located at 8N^o,125^o W, 8N^o , 110^o W and 8N^o 180^o W were only equipped with gauges for a few years and, thus, have limited records.



Graphical results of the six Pacific island WSO stations having TB gauges. The upper portion of the graph shows the deviations of the values from the best fit linear function.

5. Investigation into Differences Observed Between the PACRAIN Data and the Global Historical Climate Network

The Global Historical Climate Network (GHCN) was developed and housed at the National Climatic Data Center. It is a compilation of climate data from around the world. A significant source of Pacific data in the GHCN came from the PACRAIN database. It has been recently observed that are significance differences in the data records between corresponding sites in the GHCN and the PACRAIN data set. We are presently involved in an investigation into the nature of these differences and how they came about. Our preliminary results comparing the TD3200 data set to GHCN and

PACRAIN will be presented at the 2014 American Meteorological Society Annual Meeting.

6. Rainfall Trends in the Pacific

It is known that global warming has an effect on the prevalence of precipitation extremes, with both high-precipitation events and droughts becoming more common. These changes in rainfall distribution can have significant hydrologic consequences even if the average precipitation in an area does not change. Areas with limited groundwater and surface water capacity will face the greatest consequences, which describes most of the islands in the central Pacific Ocean. Research presented at the 2013 American Meteorological Society Annual Meeting focused on the geographic distribution of trends in extreme rainfall associated with three of the models used in the Coupled Model Intercomparison Project. Some of the key results, in this case focused on the Australian CSIRO Mk 3.3 model: 1) trends are consistent with an increase in total rainfall and extreme rainfall events across the northwest tropical Pacific (i.e. Micronesia) during the Northern Hemisphere (NH) cool season; no large-scale spatial trends were evident outside of this region; 2) at the individual analysis sites across the Tropical Pacific, wet trends outnumbered dry trends by 7:1 during the NH cool season and 2:1 during the NH warm season; and 3) most of the statistically significant trends were observed during the NH cool season.

7. Outreach and Education Through the SPaRCE Program

For the past 21 years the SPaRCE project at OU has been working directly with elementary and high school teachers around the Pacific. During this time, we have also worked informally with the Pacific island meteorological services to aid them with their own local educational outreach projects. However, given the age of the SPaRCE materials there is a need to upgrade them to include more relevant information, e.g. the PI-GCOS program, Global Warming, cyclones, cyclone preparation brochure, etc.

As the meteorological services in the Pacific islands continue to expand and enhance their technological capabilities, there is an increased awareness and appreciation by meteorological service personnel for the need of an educated public. For example, more cooperative climate observer networks are being proposed and implemented in these countries, modeled after the U.S. Cooperative Observers Network (e.g. in Vanuatu, Samoa, and Tonga). There are many challenges in implementing a sustainable cooperative observer program in the developing tropical Pacific island nations, one of which is the availability of easily understood educational materials that can be used by meteorological service personnel in recruiting and training potential observers. In addition, disasters such as the December 2004 tsunami have emphasized the need for a basic understanding of any potentially dangerous phenomenon, such as hurricanes, by the general public. The SPaRCE program is uniquely situated to be able to both continue collaborating directly with schools, and to aid the meteorological personnel in the islands to develop easily understood educational materials that can be used in a variety of circumstances. Additional funding for the

SPaRCE program will be used to provide Pacific island meteorological services with low-cost rain gauges for their cooperative observer networks, and to hire a student to work with meteorological service personnel to develop and deliver educational materials aimed at both potential cooperative observers as well as the general public. In addition, these additional materials would be available through the Pacific-RANET project's satellite/internet broadcasts.

Specific progress related to the SPaRCE Program included:

- 23 schools actively participating: 9 new schools have yet to send in data, 7 new schools have sent in data past 12 months;
- SPaRCE data are available via a dedicated online interface at (http://sparce.evac.ou.edu/);
- Participants can enter data online at the SPaRCE website;
- A quarterly SPaRCE newsletter is published and distributed to participants and others
- Ten new or reinstated sites in past 12 months;
- Updated application and supporting documents;
- Mailed out recruitment packets to over 200 schools;
- Sent letters to dormant schools;
- Contacted each Pacific meteorological service to obtain more schools;
- Created SPaRCE calendar for participants;
- Maintained a new electronic mailing list for newsletter and information distribution; and
- Maintained a SPaRCE Facebook group to encourage participant networking.

Ongoing SPaRCE activities include:

- Rewriting the SPaRCE brochure;
- Contacting various meteorological services for addresses of local schools;
- Work on distributing a large mailing to schools; and
- Workbook updates.

Publications

Morrissey, M.L., H.J. Diamond, M.J. McPhaden, H.P. Frietag and J.S. Greene, 2012: An Investigation of the consistency of TAO buoy-mounted capacitance rain gauges along the equatorial tropical Pacific. *Journal of Atmospheric and Oceanic Technology,* **29**, 834-845.

Theme 5 – Societal and Socioeconomic Impacts of High Impact Weather Systems

NSSL Project 8 – Warning Process Evolution and Effective Communication to the Public

NOAA Technical Lead: David Stensrud (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task II

Overall Objectives
Facilitate the incorporation of Warn-on-Forecast numerical forecast guidance into the Hazardous Weather Testbed, and test ways in which this guidance could be useful through an SPC/Norman Forecast Office briefing on rapidly updating convective outlook, short-period products. Also, understand forecaster reasoning in order to understand where new products might be streamlined into warning operations.

Accomplishments

1. Use of the NSSL Mesoscale Ensemble Within the Hazardous Weather Testbed

James Correia Jr. (CIMMS at SPC)

The NSSL Mesoscale Ensemble (NME) is an hourly data assimilation and forecast system using the WRF model at 18km. The NME has 36 members and was used to provide guidance to forecasters participating in the 2013 Spring Program's Experimental Forecast Program, to support rapidly updating 3-h convective outlooks particularly for severe weather environment analysis. Additionally, data displays were developed to help forecasters understand which observations were successfully assimilated and thus understand how the model was using observations.

This project is ongoing.

2. Special Projects in Effective Communication

James Correia Jr. (CIMMS at SPC)

Correia served as liaison to several groups within and concerning social science activities, including: the Weather and Water social science group within NOAA; a local social science group involving NOAA, CIMMS, CASR, and CAPS personnel; the SPC communications team that also included Susan Jasko (a public relations and communications specialist at the University of California-Pennsylvania), and the NWS customer satisfaction survey team. In all of these efforts, information is being gathered

on increasing the effectiveness of SPC products such as watches and experimental convective outlooks. This activity includes surveying the NWS users/public about SPC product use (NWS Customer Satisfaction Survey 2012) and efforts towards clarifying the language used in the outlooks for the upcoming 2013 NWS Survey. This survey also includes questions related to social media, which will be analyzed to see where the NWS stands in current practice and plot a course for the future. All of the groups listed above were critical for gathering feedback on the questions asked and thus served as an effective collaboration.

These projects are ongoing.

3. HWT-EFP-EWP Collaboration

James Correia Jr. (CIMMS at SPC)

The EFP desire to issue frequently updating short-period convective outlooks fit well within the EWP operations during the 2013 Spring Program. Correia collaborated with the EWP to conduct multiple afternoon briefings of EFP products, including all updated high-resolution convection allowing model guidance and the NME. These briefings were meant to simulate aspects of the SPC watch collaboration call and offer risk assessments, as needed, to the warning and mesoscale forecasters of the EWP. The briefings ran between 5 and 15 minutes, occurring at least 3 times per week and roughly twice per day. Both EFP products and risk assessments were briefed and a question and answer period was used to foster discussion.

This project is completed.

4. Use and Impact of Convection-Allowing Models in Operational Forecasting

Gabe Garfield (CIMMS at OUN)

Data from 2012 Spring Program was used to better understand the impact of high-resolution modeling in a warning environment. These data – in the form of multiple interviews – were analyzed and connected with forecast outcomes. It was found that high-resolution model output can be useful in confirming or de-confirming a mental model based on environmental parameters, yielding a better forecast. Also, model biases can be detrimental to the forecast, but can also yield better forecasts if accounted for. Finally, high-resolution model output can increase forecaster confidence when other forecast tools suggest a similar result. A report describing these findings was produced.

This project is completed.

5. Assessment of Forecast Reasoning

Gabe Garfield (CIMMS at OUN)

Based on the findings from the 2012 Spring Experiment, it was determined that it was necessary to understand more about forecaster reasoning in an operational environment. In particular, we wanted to understand where – in the forecast process – new products might provide an advantage. So, during the 2013 Spring Experiment, Garfield asked visiting forecasters to describe the process that led to their forecast conclusions to identify needs for new forecasting products. These data will be used to inform the development of new OUN WRF products for 2014 Spring Experiment.

This project is ongoing.

6. Damage Surveys for May 2013 Tornadoes

Gabe Garfield (CIMMS at OUN) and Chris Karstens (CIMMS at NSSL)

After the tornadoes on 19 May (Shawnee), 20 May (Moore), and 31 May (El Reno), Garfield assisted with NWS damage surveys. Using the Damage Assessment Toolkit, assessments were made of dozens of damage indicators. Additionally for the El Reno survey, Garfield coordinated with a mobile radar group (OU RaXPol) to aid in the synthesis of this information into a damage map and timeline. The results of these surveys will be useful for future studies of societal impacts during major tornadoes.

Karstens coordinated NSSL's damage survey efforts for the Norman-Shawnee, OK tornado of 19 May 2013. Several teams of surveyors from NSSL were assigned small sub-sections of the damage path to survey. Information collected by the group was transmitted to the NWS by entering it into the Damage Assessment Toolkit (DAT) soon after the event. Additionally, he worked with the Norman NWS in assigning EF4+ ratings to residential structures damaged in the Moore, OK tornado of 20 May 2013. These efforts help us to learn more about the damage caused by tornadoes, and help us understand the impacts from these events on society.

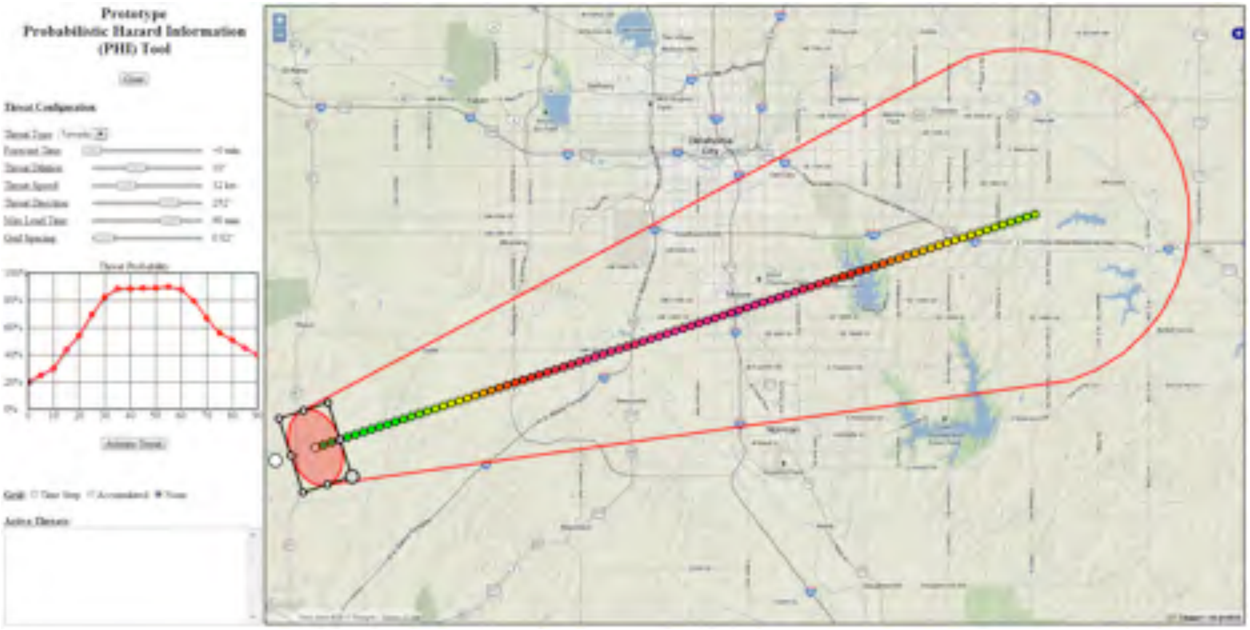
This project is completed.

7. Prototype Interface for Probabilistic Hazard Information

Chris Karstens (CIMMS at NSSL)

Work started on developing a prototype web-based interface that will allow forecasters to rapidly convert guidance information from projects like Warn-on-Forecast into probabilistic hazard information (see figure below). The goal is to create a tool that allows forecasters to more readily convey their uncertainty about the severity and evolution of severe convective phenomena, therefore allowing end-users to make more informed decisions.

This project is ongoing.



Screenshot of the prototype probabilistic hazard information tool.

NSSL Project 9 – Evaluating the Impact of New Technologies, Data, and Information in the Operational Forecasting Environment, *AND* CIMMS Task III Project – 2012 Phased-Array Radar Innovative Sensing Experiment (PARISE)

Pam Heinselman (NSSL), Daphne LaDue (OU CAPS), Darrel Kingfield (CIMMS at NSSL), James Murnan (INDUS), and Katie Bowden (OU School of Meteorology at CIMMS)

NOAA Technical Lead: Pam Heinselman (NSSL)

NOAA Strategic Goal 2 – *Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA/NSSL)

Objectives
Identify key judgments and decision points of NWS forecasters when using data from the experimental multi-function phased array radar (MPAR); test for improvement in tornado warning performance.

Accomplishments

A total of 12 forecasters participated in PARISE 2012. Six forecasters worked through two tornado cases and two cases where storms were not tornadic for the period of the case + 45 min. Each forecaster individually worked each case. Following each case they completed the NASA Task Load Index and a case walk-through. In the walk-through each forecaster was paired with a researcher and explained their actions and decision processes, scan-by-scan, as they watched a playback of their computer screen. Forecasters also drew pictures and described the conceptual model they developed during each case.

Knowledge and career history data were used to identify the likely expertise level of participants. This resulted in one forecaster being identified as likely functioning at the journey journeyman level. Of the remaining 11 forecasters, five were likely functioning at a journeyman, or intermediate skill group, and six were likely functioning as experts. Initial plans had been to compare warning behaviors of two strongly contrasting groups, the hypothesis being that the largest improvements in warning performance would be seen in the least experienced forecasters. This portion of the research led to analyzing case data for all forecasters individually and seeking similarities in strategies across all 12 without regard to prior experience.

The verification method used by the NWS was used to analyze participants' warning performance for all four cases. Detailed analysis of warnings for the four tornadoes that occurred show a majority of forecasters outperformed national average tornado lead times, suggesting a positive effect of working with the frequent, approximately 1-min volume updates. Analysis of subsequent warnings after the first warning issued within a case suggest that variations in location and duration of prior warnings affected subsequent warnings. The case walk-through data is being analyzed to better understand when and how rapid-update data is affecting warning decisions. Forecaster situation awareness, judgments, and decisions were captured in the case walk-through protocol. These were being analyzed for two of the four cases at the end of this reporting period: one case where a tornado occurred during the case (any warning would be assessed for location/time) and one where no tornado occurred until at least 45 min after case time ended (any warning would be a false alarm).

The average tornado warning lead-time for this experiment was 21 minutes with a distribution of high polygon probability of detection (PPOD) and relatively low probability of false alarm (POFA) values. These finding indicates the potential for rapid-scan radar data to extend tornado warning leading times for similar event types.

Both PARISE 2010 and PARISE 2012 reported promising results as demonstrated by improved warning performance when using MPAR data over the existing NEXRAD WSR-88D data. PARISE 2013 built on the previous experimental methodologies but shifted the forecasting emphasis to severe hail and damaging wind events. This experiment followed an independent measures design with four forecasters assigned to a control group and 4 forecasters assigned to an experimental group. Forecasters in the control group worked three cases with MPAR data updating every 4 minutes while

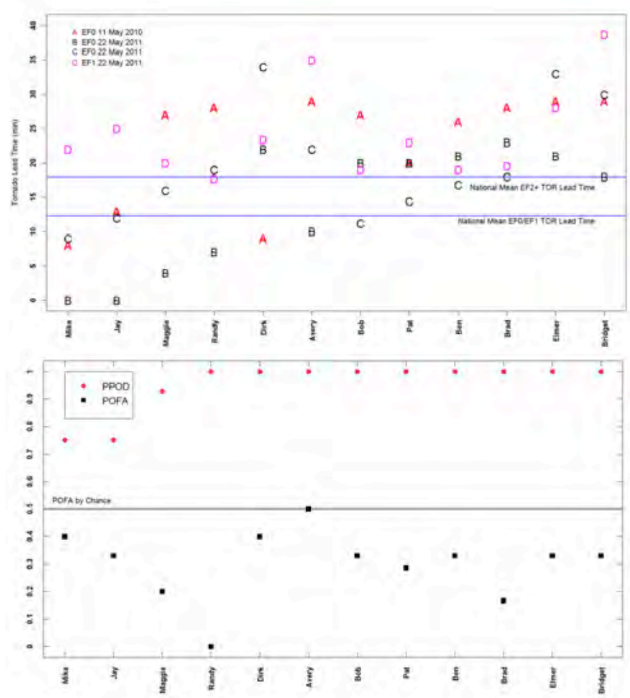
forecasters in the experimental group had cases with MPAR data updating every 1-minute.

Forecasters viewed these data in displaced real-time using the AWIPS-II environment. During each case, forecasters were recorded on video to assist in the post-mortem analysis by researchers. At the end of each case, forecasters completed the NASA Task Load Index and reviewed the case video with the researcher to document their actions and decision processes on a scan-by-scan basis for the duration of the case event. Data collection is ongoing; at least four additional forecasters will participate to complete the data collection phase of this project.

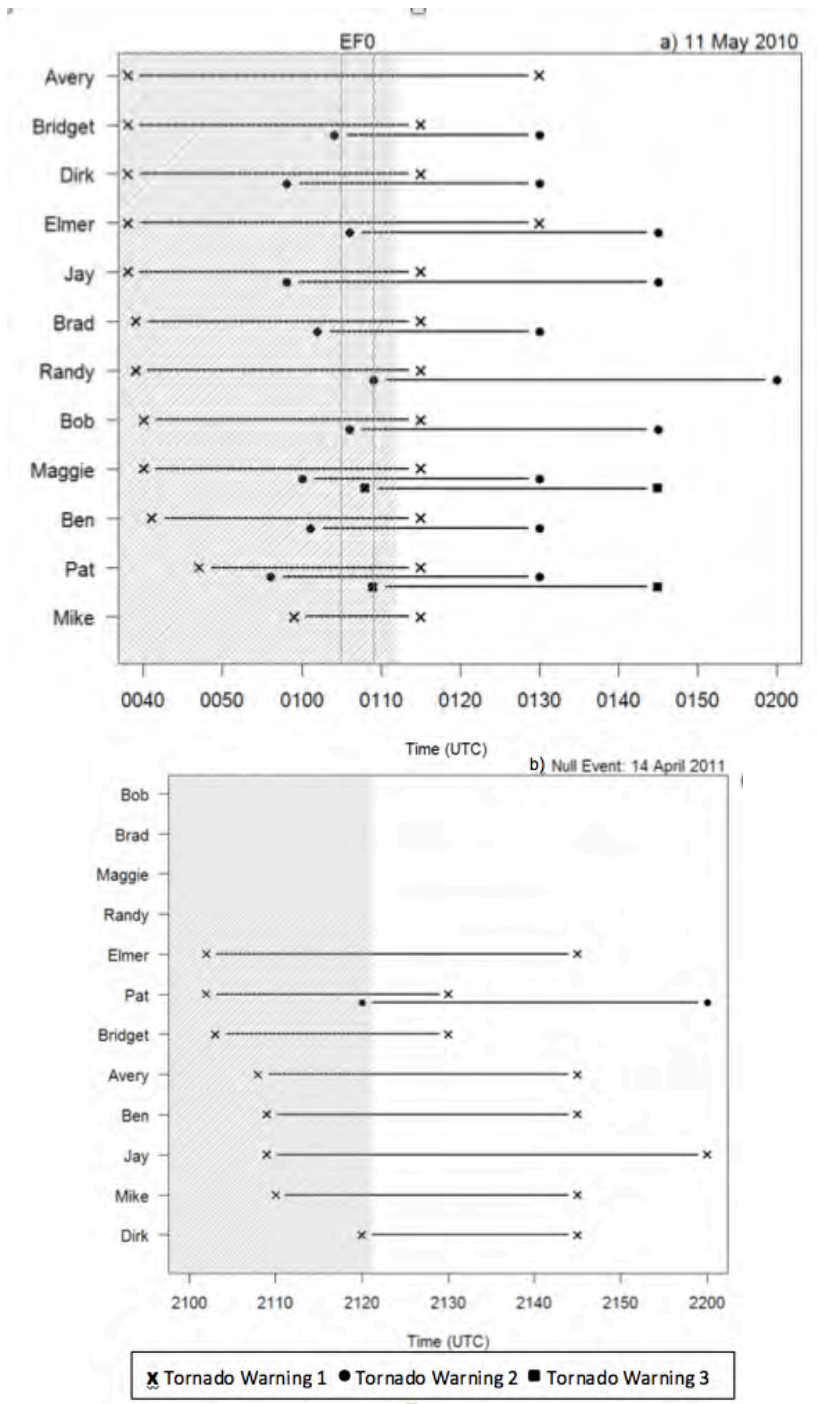
This project is ongoing.

Publications

Heinselman, P. L., D. S. LaDue, and H. Lazrus, 2012: Exploring impacts of rapid-scan radar data on NWS warning decisions. *Weather and Forecasting,* **27**, 1031-1044.

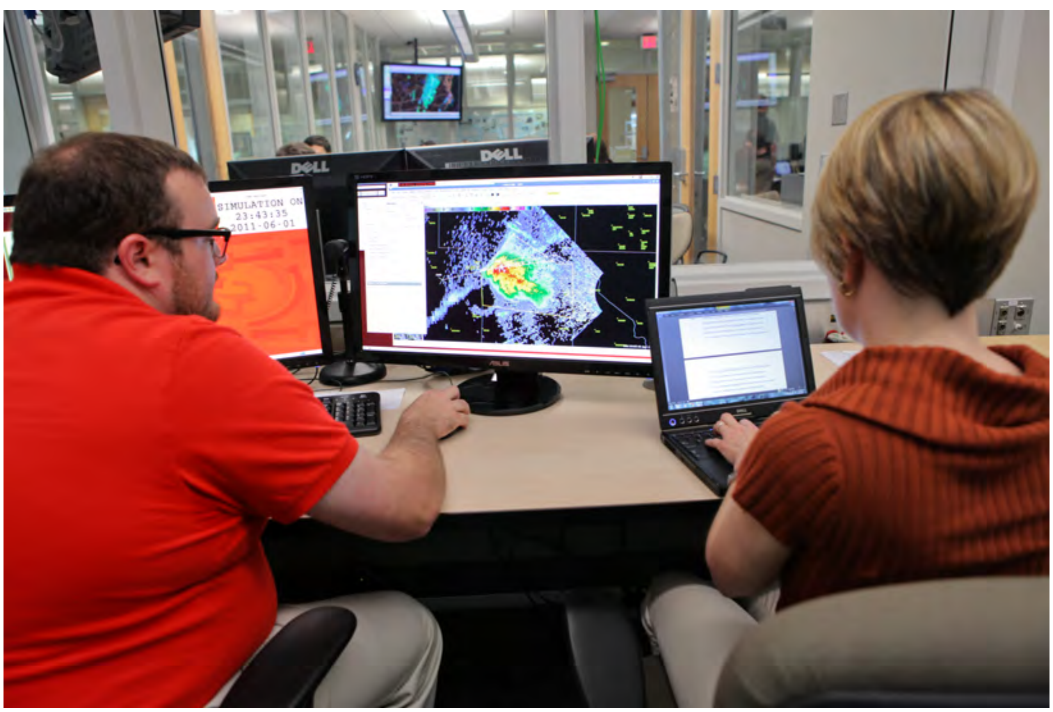


(Top) Distribution of tornado lead times (min) computed for 11 May 2010 and 22 May 2011 events: EF0-rated tornado on 11 May 2010 (A) and 3 tornadoes on 22 May 2011 (B,C,D), listed in chronological order. Horizontal blue lines denote the mean national lead time computed from 1 January 2008 to 31 October 2013 for EF0 and EF1 tornadoes (12.5 min) and EF2 and higher rated tornadoes (18 min). (Bottom) Distribution of polygon probability of detection (PPOD) and probability of false alarm (POFA) computed for 11 May 2010 and 22 May 2011 events. The horizontal line at 0.5 indicates the POFA attainable by chance.



Start and end times of tornado warnings issued by participants on: Top – 11 May 2010; and Bottom – 22 April 2011. The first, second, and third tornado warnings are denoted by an x, filled circle, and filled square, respectively. Case duration is shaded grey and tornado duration is shown by vertical gray lines.

A forecaster loading a four-panel image of MPAR base velocity in AWIPS-II during PARISE 2012.



A forecaster issues a severe thunderstorm warning with MPAR data during the PARISE 2013 experiment.

CIMMS Task III Project – Southern Climate Impacts Planning Program (SCIPP) Year 5 Funding

Mark Shafer (OU OCS), Barry Keim (LSU), Renee Edwards (LSU), Yang Hong (OU Department of Civil Engineering and Environmental Sciences), Peter Lamb (CIMMS at OU), Mark Meo (OU Department of Geography and Environmental Sustainability), Kevin Robbins (LSU), and May Yuan (OU Geoinformatics)

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Graduate Research Assistants: L. Becker (LSU), A. Billiot (LSU), J. Denham (LSU), R. Jones (LSU), C. Kovacik (OU), C. Pavlowsky (OU), Z. Zhang (OU)

NOAA Technical Lead: Caitlin Simpson (CSI/RISA Program Manager, NOAA Climate Program Office)

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task III (NOAA RISA/NOAA Climate Program Office)

The SCIPP project is ongoing.

Objectives

SCIPP's mission is to increase the resiliency and level of preparedness for weather extremes now and in the future, in our 6-state region of Oklahoma, Texas, Arkansas, Louisiana, Tennessee, and Mississippi.

Accomplishments

During FY13, SCIPP accomplished several workshops, reports and research, which capitalized on the major focus points of SCIPP: extreme events and hazards, climate education, and hazard planning. These are described below.

1. Seasonal Climate Communication Workshop

First, federal and state climate scientists, decision makers, and communication experts gathered in Norman, Oklahoma on 27 September 2012 to discuss the ways in which seasonal climate information should be communicated to various audiences. SCIPP, the National Integrated Drought Information System (NIDIS), and the NOAA Southern Regional Climate Services Director organized the workshop. Seventeen people participated in total. The purpose of this workshop was to bring together climate scientists, decision makers and communication experts to discuss the methods that were used to communicate drought information in the Southern Plains during 2010-

2012 and to determine the areas in which scientists can improve their communication of seasonal climate information. The discussion focused on several topics including tips for managing webinars, useful products, product deficiencies, communication challenges, the role of social media, and several unresolved issues. Climate information and products are often used as evidence to a governing board, state agency, or the public for why a particular decision is being made, so it is important that it is displayed and formatted in a way that effectively and accurately communicates the data. Climate science information is complex but that should not deter scientists from communicating in a way that is relevant to decision makers and via various media platforms. The information that is communicated through these channels helps society manage the impacts of climate hazards such as droughts, floods, and heat waves.

2. SURGEDAT

SCIPP researchers Barry Keim and Hal Needham have created SURGEDAT (http://surge.srcc.lsu.edu), the world's most comprehensive archive of storm surge data, to provide additional context on storm surges. Utilizing 67 sources of data including federal government sources, books, academic journals and more than 3,000 pages from historical newspapers, SURGEDAT initially identified over 200 surges along the U.S. Gulf Coast since 1880. The project has now expanded, incorporating hundreds of sources from all over the world to generate a global dataset and map. The database is not just a useful tool for researchers. Decision makers have also seen many benefits from SURGEDAT. Keim and Needham have been in contact with decision makers along the Gulf Coast including the Houston/Galveston National Weather Service office, the Rice University Houston Ship Channel Project, and the Texas A&M-Galveston Ike Dike Project. The latter two of these groups are working on multi-million to multi-billion dollar projects for surge protection, and Keim and Needham are providing valuable climatological perspectives in each of these cases.

During FY13, the scope of this dataset was greatly expanded. Most noticeably, ALL high water marks for each storm were identified, not just the peak height. Data available for the east coast was also expanded. These changes enlarged the dataset from around 200 high-water marks to around 7,000 high-water marks. Scripts were also written to create high water profiles of storm surge events. Enough data is available now to create more than 150 of these high-water profiles. This work has generated a lot of interest from various research groups wanting to collaborate. A web-based tool that estimates the 100-year, 50-year, etc. storm surge level for specific locations along the U.S. Gulf and Atlantic Coasts is currently in development.

Amongst the research and collaboration efforts generated by the creation of SURGEDAT, this continually expanding dataset, along with researchers Keim and Needham, have gained generous positive publicity.

3. National Climate Assessment

SCIPP has been an active contributor to the NCA process. To provide regional context, SCIPP conducted two needs assessments (Oklahoma and the Gulf Coast) and participated in the technical input reports for the Great Plain and Southeast Regions. During this past year, SCIPP has remained involved as Convening Lead Authors on the Great Plains (Mark Shafer) and the Southeast and the Caribbean (Lynne Carter) chapters. Lynne also serves as a Lead Author on the Adaptation chapter and as a member of the FAC for ongoing leadership of the Assessment process. SCIPP has promoted engagement with the NCA process through meetings and webinars throughout the two regions and nationally.

During this process, SCIPP has looked at a vast array of climate-related challenges to the region. In the Southeast, this includes seas level rise; the effects of rising temperatures on public health, natural and built environments, energy, agriculture and forestry; and decreased water availability in the context of population growth and land use change. SCIPP will continue to participate in completion of the 2013 report and in the ongoing assessment process.

4. Field Photos Weekend

SCIPP collaborated with CoCoRaHS to invite participants to create a national picture of our landscape on 8-10 September 2012 and 16-18 February 2013. The goal of these Field Photos Weekends was to get as many observers as possible to take pictures of water bodies, fields, forests, or any other facet of our environment that they believed represented the conditions around them. It could be a picture of their favorite fishing hole, a nearby farmer's field, or a nice secluded spot amongst the trees. All of these landscapes were and are affected by rainfall, or in the case of many places this past year, the lack thereof. So why was SCIPP doing this?

Having everyone taking pictures at approximately the same time allowed SCIPP researchers to see this landscape as it relates to the things we measure - how it compares to the amounts of rain that have fallen or if it looks like we might expect according to the U.S. Drought Monitor. Is the land around you as green as the satellite seems to think? SCIPP hopes this will become a somewhat regular event. So while the weather around participants may seem normal this year, these photos should give everyone a point of reference for what is maybe different next year or in another season.

To create this archive, SCIPP and CoCoRaHS partnered with the Earth Observation and Modeling Facility (EOMF) at OU. EOMF hosts an international field photos archive, satellite imagery, and landscape models. The addition of nearly 1,000 simultaneous images on each of these weekend events expands the “ground truth” data available to researchers studying land use and land cover change.

5. Pilot Study Reveals NWS Flood Information Used by Many

SCIPP partnered with three NWS River Forecast Centers (RFC) and a Weather Forecast Office in our region to develop a survey that seeks to understand, on an event basis, who is using hydrologic information, how it is being used, and whether it is effective. SCIPP piloted the survey in fall 2011 (n=13) and spring 2012 (n=70). The results showed that almost all of the respondents (n = 61; 96.8%) used NWS flood information. Most of the respondents (n=47; 85.5%) said they had enough information to make good decisions, and majorities agreed or strongly agreed that the floods that impacted them were predicted (n=47; 75.8%) and forecasted with certainty (n=38; 61.3%). Flood information sources were generally cited as being very helpful or somewhat helpful, and only a few respondents cited having problems with information sources.

This project highlighted the value of a partnership between three NWS RFCs and a university-based research team to understand and improve the effectiveness of NWS communication with its customers. SCIPP's role in the project is now complete; the next step is for the NWS partners to submit the tested and finalized survey to the Office of Management and Budget (OMB) for approval. With OMB approval, the NWS will be able to use this survey on an ad-hoc basis before, during, and after specific flood events so that a comprehensive study of the effectiveness of NWS hydrologic information can be completed in the future.

6. Drought Management and Mitigation

SCIPP, in conjunction with the NOAA Regional Climate Services Director for the Southern Region, NIDIS, the National Drought Mitigation Center (NDMC), and the American Association of State Climatologists (AASC), have hosted a series of forums, workshops, and webinars to address the current drought situation in the southern plains and promote planning and preparation for future drought conditions.

This initiative, called *Managing Drought in the Southern Plains*, brought together various state and local agencies, federal officials, and many others tasked with managing drought conditions. Along with focus topic webinars, SCIPP started producing a shortened, 5-minute weekly briefing in May 2012. To date, 28 drought briefings are available for viewing on SCIPP's website and YouTube (with over 1,800 views on YouTube). By shortening these briefings, SCIPP hopes that they will be easier to use as decision makers find the need and opportunity. Likewise, SCIPP provides a weekly newsletter announcing the availability of the webinar for viewing, along with relevant drought graphics from sources such as the U.S. Drought Monitor, the Climate Prediction Center, the U.S. Department of Agriculture, and others.

7. Climate Adaptation Planning

SCIPP was invited to participate with the Consortium on Climate Risk in the Urban Northeast (CCRUN) in their special projects to work with NASA in preparing their facilities for a changing climate. In particular, SCIPP presented *Thinking Adaptation?*

Some things you might want to think about, at the Resilience and Adaptation to Climate Risks Workshop at the Stennis Space Center in Mississippi on 16-18 October 2012.

SCIPP is also partnering with the Department of Interior South-Central Climate Science Center on a number of tribal workshops focusing on education for tribal nations related to climate change and variability. This partnership is an expansion of previous work SCIPP conducted during its first Inter-Tribal Meeting on Climate Change and Variability in December 2011.

SCIPP Co-Sponsored a *Climate Adaptation Training for Coastal Communities* training course on 25-27 February 2013 in Baton Rouge, Louisiana. This training course focused on providing participants, which included local government officials, coastal managers, and others, with practical information about sea level rise, tropical storm intensity, and other coastal climate adaptation issues. The course was a joint effort between SCIPP, NOAA, Louisiana Sea Grant, and the Louisiana Department of Natural Resources Office of Coastal Management.

The City of Biloxi, Mississippi, invited SCIPP researcher Dr. Lynne Carter to present about *Climate Changes - How to Be More Ready* on 28 February 2013. The City of Biloxi also recently created a handout that incorporated climate change information from SCIPP. This handout was mailed to Biloxi residents.

SCIPP has reached out to supporting climate education and information needs for a variety of regional entities through climate presentations, discussions, and information sheet development. A few recent examples include working with:

- Sea Grant Louisiana with communities, extension agents, teachers, and in public presentations
- The National Estuarine Research Reserve (NERRS) for presentations with Mississippi and Texas regional communities;
- The NOAA Educational Partnership Program at their Education and Science Forum reaching STEM students and researchers;
- The Coastal Zone Management Program in Louisiana reaching all of the coastal zone programs in the state and educators;
- The NSF funded CLiPSE program;
- The National Caucus of Environmental Legislators as an invited presentation at their 4th Annual Mississippi River Forum; and
- The Rand Roundtable, with an invited presentation entitled: *Exploring Resilience in a Changing World: Bridging the Science of Disaster with a Dialogue about Human Impact*.

Publications

Liu, L., Y. Hong, C. Bednarczyk, B. Yong, M. Shafer, R. Riley and J. Hocker, 2012: Hydro-climatological drought analyses and projections using meteorological and hydrological drought indices: A case study in the Blue River Basin, Oklahoma. *Water Resources Management,* **26**, 2761-2779.

Liu, L., Y. Hong, J. Hocker, M. Shafer, L. Carter, J. Gourley, C. Bednarczyk, B. Yong and P. Adhikari, 2012: Analyzing projected changes and trends of temperature and precipitation in the southern USA from 16 downscaled global climate models. *Theoretical and Applied Climatology,* **109**, 345-

360.
Needham, H.F., B.D. Keim, D. Sathiaraj, and M. Shafer, 2013: A global database of tropical storm surges. *Eos, Transactions American Geophysical Union,* **94**, 213-214.
White, E., M. Shafer, and J. Hocker, 2013: Trends in heavy precipitation in the Southern United States. *Weather*, in press.

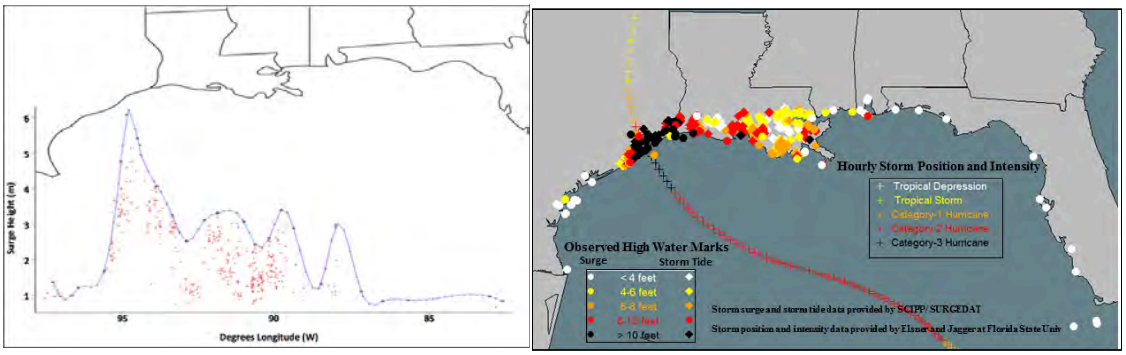
Non-OU Project Publications

Bierbaum, R., J.B. Smith, A. Lee, M. Blair, L. Carter, F. S. Chapin III, P. Fleming, S. Ruffo, M. Stults, S. McNeeley, E. Wasley, and L. Verduzco, 2012: A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change*, DOI 10.1007/s11027-012-9423-1.
Ingram, K.T., K. Dow, and L. Carter, 2012: *Southeast region technical report to the national climate assessment.* US Global Change Research Program. 334 pp. Available online at: http://downloads.usgcrp.gov/NCA/Activities/NCA_SE_Technical_Report_FINAL_7-23-12.pdf
Needham, H.F., and B.D. Keim, 2012: A storm surge database for the U.S. Gulf Coast. *International Journal of Climatology,* **32**, 14, 2108-2123.
Shankman, D., C. Lafon, and B.D. Keim, 2012: Western range boundaries of floodplain trees in the southeastern United States. *Geographical Review* **102**, 35-52.
Shankman, D., B.D. Keim, T. Nakayama, R. Li, D. Wu, and C. Remington, 2012: Hydroclimatic analysis of severe floods in China's Poyang Lake region. *Earth Interactions,* **16**, Article No. 14. DOI: 10.1175/2012EI000455.1.

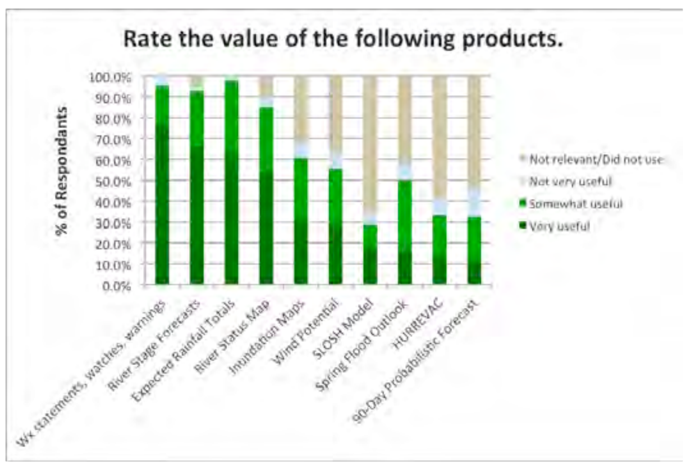
Awards

Community Service Award for the Gulf Coast Community of Practice – Dr. Lynne Carter (LSU): The Gulf Coast Community of Practice is for climate practitioners in the Gulf Region.

Seasonal Climate Communication Workshop – A four-pronged approach was used to communicate drought information 2010-2012, including state drought planning, outlook and assessment forums, media engagement, and a Managing Drought in the Southern Plains webinar series.



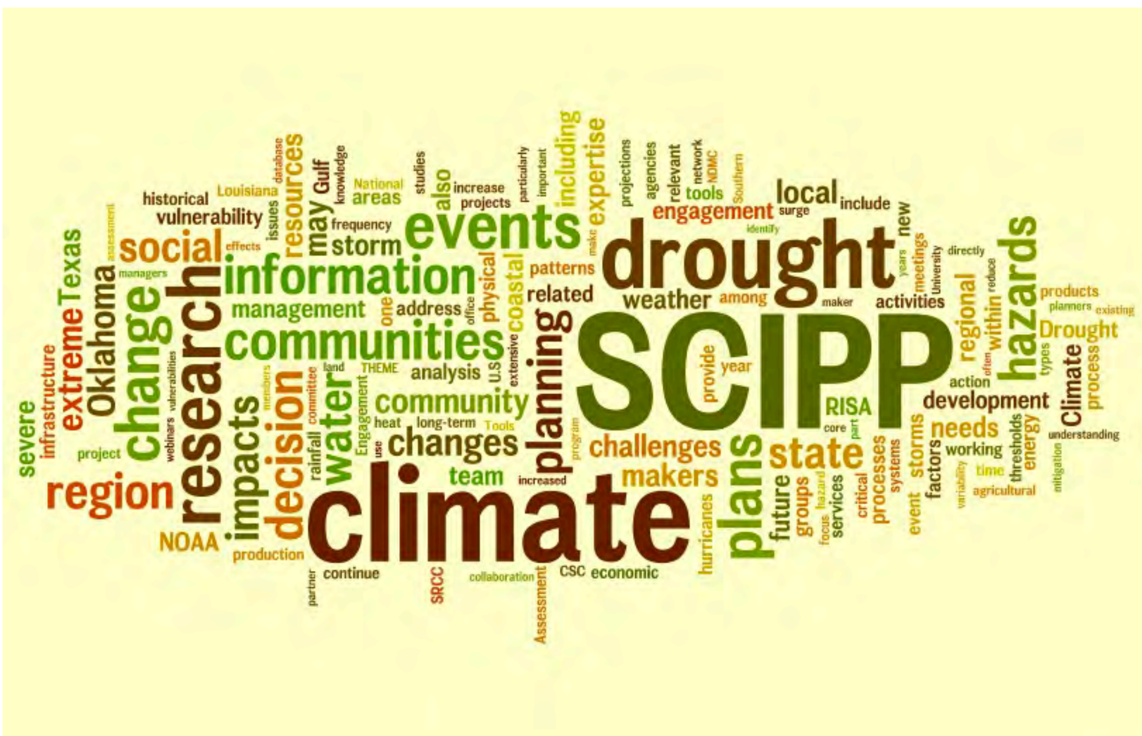
SURGEDAT – (Left): Hurricane Ike (2008) high-water profile generated by SURGEDAT; (Right): Hurricane Ike (2008) storm surge/storm tide map.



NWS Flood Information – In one part of the survey respondents were asked to rate the value of a variety of NWS hydrologic products, ranging from not relevant/did not use to very useful. The results show that the top-rated products included the expected rainfall totals map, weather statements, watches and warnings, river stage forecasts, and the river status map.

Drought Management and Planning – (Left) West Texas Drought Outlook and Assessment Forum in Abilene, Texas; (Right) Spring 2013 Southern Great Plains Drought Outlook and Forum in Goodwell, Oklahoma.

Climate Adaptation Planning – SCIPP Program Manager Dr. Lynne Carter presenting at the Lafourche Parish Coastal Hazards Workshop on 10 January 2013.



SCIPP in Words – SCIPP as visualized by a Word Cloud.

CIMMS Task III Project – Local Assessment of Drought Impacts and Climate Change Adaptation

Mark Shafer (OU OCS) and Gregg Garfin (University of Arizona)

NOAA Technical Lead: David Brown (NOAA Regional Climate Services Director for the Southern Region)

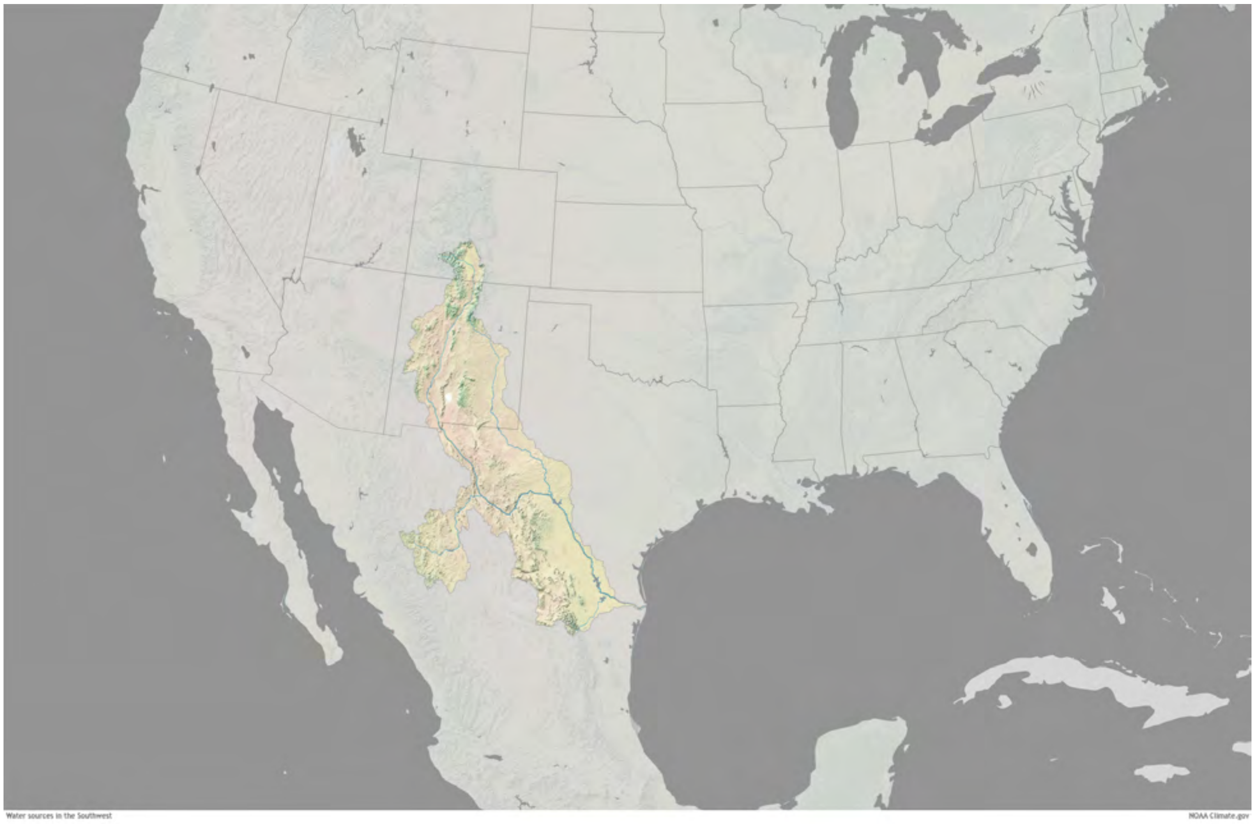
NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task III (NOAA/RISA)

Objectives
The project will bring together climate services partners and climate risk managers in the Rio Grande/Rio Bravo region, including cross-border collaboration with Mexican colleagues. The project will conduct a one-day Drought Forum, patterned after the bi-annual U.S. Drought Monitor Forum, to discuss the needs for monitoring, communication, and impacts of drought in the trans-border region. The project will investigate scales of drought from paleoclimate and paleohydrologic information to projections for the likelihood of drought under Global Climate model projections for mid and late-century.

Accomplishments
The project team has developed a prospectus for the workshop and has engaged with our counterparts in Mexico and with other climate information providers. Materials for the workshop are being developed. Due to difficulties of scheduling and efforts to include this project within the context of a larger NOAA collaboration on the Rio Grande/Rio Bravo basin, we have not completed the project and have requested a one-year no-cost extension.

This project is ongoing.



The Rio Grande – Rio Bravo River Basin has been severely affected by drought since 2002. The project investigates the impacts of the drought, management practices, and adaptation strategies used by agencies and communities within the watershed. Source: NOAA Climatewatch (http://www.climatewatch.noaa.gov/article/2012/drought-on-the-rio-grande).

Public Affairs and Outreach

NOAA NSSL Public Affairs and Outreach

NOAA Technical Lead: Keli Pirtle (NOAA Public Affairs)

NOAA Engagement Enterprise – *An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions*

Funding Type: CIMMS Task II

Objectives
Communicate NSSL and CIMMS research to OAR, NOAA, Department of Commerce leadership, the U.S. Congress, decision makers, partners, collaborators, and the public.

Accomplishments

1. NSSL Website

Susan Cobb (CIMMS at NSSL) and Vicki Farmer (INDUS)

The new NSSL website was introduced during the fiscal year. This work included a significant reorganization and rewrite of all content to include the most recent research and awards. It also was designed with tablets and smart phones in mind.

2. Social Media

Susan Cobb (CIMMS at NSSL)

Social media currently is the most effective way to reach the public about NSSL and CIMMS research and activities. NSSL has a significant presence on Facebook and Twitter. Cobb manages all NSSL social media accounts including Facebook, Twitter Instagram, and Flickr, along with the CIMMS Facebook presence, and posts or tweets at least a few times a week, but often more.

Facebook “likes”:
- NSSL – 25,782 (2012 16,002)
- CI-FLOW - 297 (2012 267)
- CIMMS - 146 (2012 88)
- NOAA Hazardous Weather Testbed – 731 (new in 2013)
- mPING - 133

Twitter “followers”:
- NSSL – 12,600 (2012 6189)
- CI-FLOW – 37 (25)
- CIMMS - 97 (43)

3. Legislative Affairs

Susan Cobb (CIMMS at NSSL)

The **NSSL Fact Sheet** format is provided by the OAR Legislative Affairs team each year and is used for visits to Capitol Hill to inform members of Congress about NSSL and CIMMS research. Cobb works with NSSL leadership to update content annually.

The **NOAA In Your State** initiative is organized by NOAA Legislative Affairs to maintain a spreadsheet of NOAA activities in each state for use when briefing the U.S. Congress. Cobb provides updates on NSSL projects that occur in each state.

4. NOAA and OAR Communications

Susan Cobb (CIMMS at NSSL)

OAR Hot Items are the primary means of communication with NOAA/OAR leadership. These informative articles are written about new NSSL research on a regular basis and posted on the OAR Hot Items site, NSSL's Hot Items website and NSSL Briefings Online. During this period Cobb authored 29 OAR Hot Items.

NOAA Research News – the OAR Hot Items are also a way to catch the interest of OAR Communications for possible stories to rotate onto the NOAA Research front webpage. In 2013, Cobb wrote 3 stories that rotated onto the NOAA Research website.

NOAA News – New stories that rotate onto the NOAA Research website sometimes catch the interest of NOAA Communications and are re-purposed for the main NOAA webpage. Since the NOAA webpage reaches a much wider audience, these stories go through an editing and clearance process before posting. In 2013, Cobb wrote and edited three stories for the NOAA webpage.

Department of Commerce Secretary's Weekly Report – OAR Hot Items determined by OAR Headquarters to be of enough significance to notify the Secretary of Commerce are condensed into a few sentences to be put into the Department of Commerce Secretary's Weekly Report. In 2012-2013, six OAR Hot Items were included in the Weekly Report.

Press Releases – Two press releases were authored during the fiscal year.

5. NSSL Fact Sheets

Susan Cobb (CIMMS at NSSL)

NSSL produces fact sheets for individual projects. Cobb designed, wrote, and edited seven fact sheets in 2012-2013 and contributed to a CIMMS Fact Sheet used for Congressional visits.

6. NSSL Briefings Online

Susan Cobb (CIMMS at NSSL)

All OAR Hot Items are posted on NSSL's News Blog, called NSSL Briefings Online. Successes of NSSL researchers, significant publications photo of the month or all posted here. In 2013, Cobb posted 38 stories.

7. NSSL Briefings Subscriber Emails

Susan Cobb (CIMMS at NSSL)

NSSL has 650 people subscribed to NSSL Briefings email updates. Cobb keeps this list up to date and sends emails to update interested public, colleagues and decision makers.

8. NSSL Outreach Emails

Susan Cobb (CIMMS at NSSL)

Questions from the public are submitted to the NSSL Outreach email account. Cobb answered 149 emails, and two written inquiries.

9. "Significant Contribution" Paper Reporting

Susan Cobb (CIMMS at NSSL)

NOAA leadership has requested to be notified of significant papers published by NSSL and CIMMS researchers. Cobb reviews early online releases and table of contents of journals used by our scientists, and prepares a list for the NSSL Director to review for significance. She formats information about each significant paper as required by headquarters and sends it to the appropriate personnel at headquarters. She reported 14 significant papers in 2013.

10. NSSL News Flash

Susan Cobb (CIMMS at NSSL)

The NSSL News Flash is a mostly internal informative email sent to NSSL and CIMMS staff to raise awareness about the activities of the different research groups, significant papers, and to celebrate achievements. Fifty News Flashes were issued during the fiscal year.

Public affairs and associated outreach activities are ongoing.

NOAA Weather Partners Educational Outreach

NOAA Technical Lead: Keli Pirtle (NOAA Public Affairs)

NOAA Engagement Enterprise – *An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions*

Funding Type: CIMMS Task II

Objectives
Communicate and extend NOAA science to the public.

Accomplishments

1. National Weather Center Tours

Daphne Thompson (CIMMS at NSSL)

The NOAA Weather Partners offer scheduled tours of the NWC throughout the week for groups interested in learning more about the five NOAA organizations and related OU activities in Norman. These tours are offered to anyone from 3rd grade and up. During FY13, Thompson gave tours to more than 2,500 people who visited the building during 115 scheduled tours. These include public school groups, homeschoolers, private schools, church groups, engineering groups, senior citizen groups, and many others.

A tour of the NWC includes a presentation about NSSL along with a weather safety lesson followed by another presentation on the Science on a Sphere. Visitors then see the 7th floor observatory where the NSSL and ROC radars located in north Norman are pointed out. The training done provided by WDTB also is discussed. On the second floor, the SPC and Norman NWS Forecast Office are shown so that visitors can see forecasters at work and learn about the watch/warning process.

In addition to these scheduled tours, another important event where we are able to educate the public on the science and forecasting done by the NOAA Weather Partners in the NWC is the National Weather Festival, which was held in 2012 on 3 November. About 2,000 people attended it.

2. Additional Outreach Highlights

Daphne Thompson (CIMMS at NSSL)

Additional NOAA Weather Partners outreach included participation in WeatherFest at the 2013 AMS Annual Meeting in Austin, Texas, and assisting with the NWC booth in the AMS Exhibit Hall; assisting with the National Tornado Summit Meeting held in spring 2013 in Oklahoma City; providing severe weather safety talks to Department of Homeland Security groups; helping program NOAA All Hazards Radios for the public;

arranging and participating in special evening tours of the NWC for American Red Cross and FEMA personnel (see photo below); and assisting with the Oklahoma Mesonet Summer Camp. Thompson also serves on the NOAA Weather Partners Communication Team, participates as chair for the Norman Chamber of Commerce Weather Committee, and is a board member of the National Weather Museum and Science Center.

Educational outreach activities are ongoing.

American Red Cross and FEMA volunteers at an evening tour of the National Weather Center.

CIMMS Staff at WDTB Outreach

Steven Martinaitis, Clark Payne, Tiffany Meyer, Chris Spannagle, Dale Morris, Veronica Holtz, Mark Sessing, Les Lemon, Dan McKemy, and Andrew Wood (all CIMMS at WDTB)

NOAA Technical Lead: Ed Mahoney (WDTB)

NOAA Engagement Enterprise – *An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions*

Funding Type: CIMMS Task II

CIMMS staff at WDTB regularly engages in various outreach activities. Some of the activities involve partnerships with other organizations in the NWC. Some of 2013's outreach activities included:

- Volunteering to work support "shifts" at the Norman Weather Forecast Office during severe weather events;
- Aiding the Norman Forecast Office during damage surveys following the various May 2013 tornado outbreaks;
- Participating in career fairs for OU School of Meteorology students;
- Assisting the NOAA Weather Partners by participating in media-requested interviews;
- Providing speakers for OU School of Meteorology iTunes University video offerings;
- Facilitating two lab exercises for OU School of Meteorology students on severe weather warning decision making and using AWIPS to issue severe weather warnings;
- Volunteering in the planning and presentation of the National Weather Festival;
- Participating actively in the National Employees Association (NEA) and Central Oklahoma Chapter of the American Meteorological Society (COCAMS) boards; and
- Volunteering with other NWC organizations during Norman's United Way Day of Caring.

Other outreach activities involving CIMMS staff at WDTB included:

- Visiting with high school and college students to talk about careers in meteorology; and
- Assisting different charitable organizations in Central Oklahoma following the May 2013 tornado outbreaks.

WDTB outreach is ongoing.

Appendix A

CIMMS AWARDS AND HONORS

Travis Smith (CIMMS at NSSL), Kiel Ortega (CIMMS at NSSL), Valliappa Lakshmanan (CIMMS at NSSL), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), Kevin Manross (former CIMMS at NSSL, now at Unidata), and Karen Cooper (INDUS), David Jorgensen (NSSL), Madison Miller (former OU School of Meteorology at CIMMS), and John Cintineo (former OU School of Meteorology at CIMMS, now at CIMSS/University of Wisconsin), received the 2013 NOAA Technology Transfer Award for "leading the development of an on-demand, near real-time, web-based tool for tracking severe weather and hail swaths across the continental US." (http://www.nssl.noaa.gov/briefings/2013/09/nsslcimms-team-receives-2013-noaa-technology-transfer-award/)

Charles Doswell III (CIMMS at OU) was bestowed the 2013 Nikolai Dotzek Award, presented at each European Conference on Severe Storms, for *an outstanding contribution to the science of severe storms*. Dr. Doswell was honored in June 2013 for an accumulation of important accomplishments during his distinguished scientific career.

The Youcun Qi (CIMMS at NSSL) et al. paper titled "Correction of radar QPE errors for non-uniform VPRs in mesoscale convective systems using TRMM observations" that is in press in *Journal of Hydrometeorology* was referred to NOAA/OAR Headquarters as a "Significant" contribution.

The Nusrat Yussouf (CIMMS at NSSL) et al. paper "The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes" was referred to NOAA/OAR Headquarters as a "Significant" contribution.

The Adam Clark (CIMMS at NSSL) et al. paper "Tornado Pathlength Forecasts from 2010 – 2011 Using Ensemble Updraft Helicity" was referred to NOAA/OAR Headquarters as a "Significant" contribution. Subsequently, this paper was featured on the NOAA/OAR Research website.

Adam Clark (CIMMS at NSSL) was awarded the Mark and Kandi McCasland Award for Outstanding Undergraduate Research for his role as mentor to three undergraduate students that completed their Capstone course at OU.

Alexandre Fierro (CIMMS at NSSL) was awarded 2012 Editors' Citation for Excellence in Refereeing for *Geophysical Research Letters.*

WDTB was awarded the National Weather Association's Operational Achievement Group Award "For delivering an innovative and highly effective training course, ahead of schedule, for NWS forecasters and partners as a critical element of the nation's dual polarization weather radar upgrade."

James Kurdzo (OU School of Meteorology at ARRC), Boon Leng Cheong (OU ARRC), Robert Palmer (OU ARRC), and Guifu Zhang (OU School of Meteorology and ARRC) filed a *Provisional Patent* in 2012 titled "Optimized pulse compression waveforms for high-sensitivity radar observations."

James Kurdzo (OU School of Meteorology at ARRC) was awarded a McNair's Choice Award and Second Place Overall (Science Category) at the OU Student Research and Performance Day in spring 2013.

Appendix B

PUBLICATION SUMMARY*

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2005-06	2006-07	2007-08	2008-09	2005-06	2006-07	2007-08	2008-09	2005-06	2006-07	2007-08	2008-09
Peer Reviewed	40	55	55	52	20	15	16	13	32	33	37	45

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2009-10	2010-11	2011-12	2012-13	2009-10	2010-11	2011-12	2012-13	2009-10	2010-11	2011-12	2012-13
Peer Reviewed	32	28	31	32	25	22	13	8	40	44	35	45

**Publication numbers are approximate.*

Appendix C

PERSONNEL SUMMARY – NOAA FUNDED RESEARCH ONLY

Category	Number	B.S.	M.S.	Ph.D.
Research Scientist	57	2	32	23
Visiting Scientist	3	2		1
Postdoctoral Fellow	7			7
Research Support Staff	17	6	11	
Administrative	2	1		
Total (>50% support)	**86**	**11**	**43**	**31**
Undergraduate Students	23			
Graduate Students	42	25	17	
Employees that receive <50% NOAA Funding (not including students)	**30**	**6**	**2**	**22**
Located at Lab	NWSTC-4, NSSL-87, ROC-8, SPC-5, WDTB-11, OUN-1			
Obtained NOAA employment within the last year	1			

Appendix D

COMPILATION OF CIMMS-RELATED PUBLICATION 2012-13

Publications compiled here were reported for projects funded under Cooperative Agreement NA11OAR4320072.

Peer-Reviewed Journal Articles, Books, and Book Chapters *Published, In Press, or Accepted*

Andrić, J, M. R. Kumjian, D. S. Zrnić, J. M. Straka, and V. M. Melnikov, 2013: Polarimetric signatures above the melting layer in winter storms: An observational and modeling study. *Journal of Applied Meteorology and Climatology*, **52**, 682-700.

Bikos, D., D. T. Lindsey, J. Otkin, J. Sieglaff, L. Grasso, C. Siewert, J. Correia Jr., M. Coniglio, R. Rabin, J. S. Kain, and S. Dembek, 2012: Synthetic satellite imagery for real-time high-resolution model evaluation. *Weather and Forecasting*, **27**, 784–795.

Bodine, D., M. Kumjian, R. Palmer, P. Heinselman, and A. Ryzhkov, 2013: Tornado damage estimation using polarimetric radar. *Weather and Forecasting,* **2**, 139-158.

Boyd, E., R.J. Cornforth, P.J. Lamb, A. Tarhule, M. Issa Lélé, and A. Brouder, 2013: Building resilience to face recurring environmental crisis in African Sahel. *Nature Climate Change*, **3**, 631-637.

Cao, Q., Y. Hong, J.J. Gourley, Y. Qi, J. Zhang, Y. Wen, and P. Kirstetter, 2013: Statistical and physical analysis of vertical structure of precipitation in mountainous west region of US using 11+ year spaceborne TRMM PR observations. *Journal of Applied Meteorology and Climatology*, **52**, 408-424.

Cao, Q., Y. Hong, Y. Qi, Y. Wen, J. Zhang, J. Gourley, and L. Liao, 2013: Empirical conversion of vertical profile of reflectivity (VPR) from Ku-band to S-band frequency. *Journal of Geophysical Research*, **118**, 1-12.

Cintineo, J., T. M. Smith, V. Lakshmanan, H. E. Brooks, and K. L. Ortega, 2012: An objective high-resolution hail climatology of the contiguous United States. *Weather and Forecasting*, 27, 1235-1248.

Clark, A.J., S. J. Weiss, J. S. Kain, I. L. Jirak, M. Coniglio, C. J. Melick, C. Siewert, R. A. Sobash, P. T. Marsh, A. R. Dean, M. Xue, F. Kong, K. W. Thomas, Y. Wang, K. Brewster, J. Gao, X. Wang, J. Du, D. R. Novak, F. E. Barthold, M. J. Bodner, J. J. Levit, C. B. Entwistle, T. L. Jensen, and J. Correia Jr., 2012: An overview of the 2010 Hazardous Weather Testbed Experimental Forecast Program Spring Experiment. *Bulletin of the American Meteorological Society*, **93**, 55–74.

Clark, A.J., J.S. Kain, P.T. Marsh, J. Correia, Jr., M. Xue, and F. Kong, 2012: Forecasting tornado path lengths using a 3-dimensional object identification algorithm applied to convection-allowing forecasts. *Weather and Forecasting*, **27**, 1090-1113.

Clark, A. J., J. Gao, P. T. Marsh, T. Smith, J. S. Kain, J. Correia Jr., M. Xue, and F. Kong, 2013: Tornado pathlength forecasts from 2010 to 2011 using ensemble updraft helicity. *Weather and Forecasting*, **28**, 387–407.

Coffer, B. E., L. C. Maudlin, P. G. Veals, and A. J. Clark, 2013: Dryline position errors in experimental convection-allowing NSSL-WRF model forecasts and the operational NAM. *Weather and Forecasting*, **28**, 746-761.

Coniglio, M. C., J. Correia Jr., P. T. Marsh, and F. Kong, 2013: Verification of convection allowing WRF model forecasts of the planetary boundary layer using sounding observations. *Weather and Forecasting*, **28**, 842-862.

Dresback, K. M., J. G. Fleming, C. Kaiser, J. J. Gourley, E. M. Tromble, R. A. Luettich, R. L. Kolar, Y. Hong, S. Van Cooten, H. J. Vergara, Z. L. Flamig, B. O. Blanton, H. M. Lander, K. E. Kelleher, and K. L. Nemunaitis-Monroe, 2013: Skill assessment of a real-time forecast system utilizing a coupled hydrologic and coastal hydrodynamic model during Hurricane Irene (2011). *Continental Shelf Research*, accepted.

Fierro, A. O., J. Gao, C. Ziegler, E.R. Mansell, D. R. MacGorman and S. Dembek 2013: Evaluation of a cloud scale lightning data assimilation technique and a 3DVAR method for the analysis and short term forecast of the 29 June 2012 derecho event. *Monthly Weather Review*, accepted.

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Fierro A. O., and L. M. Leslie 2013: Links between Central Western Australian rainfall variability and large-scale climate drivers**.** *Journal of Climate,* **26***,* 2222-2246*.*

Gallo, K., T. Smith, K. Jungbluth, and P. Schumacher, 2012: Hail swaths observed from satellite data and their relation to radar and surface-based observations: A case study from Iowa in 2009. *Weather and Forecasting*, **27**, 796-802.

Gao, J., T. Smith, D. Stensrud, C. Fu, K. Calhoun, K. Manross, J. Brogden, V. Lakshmanan, Y. Wang, K. Thomas, K. Brewster, and M. Xue, 2013: A realtime weather-adaptive 3DVAR analysis system for severe weather detections and warnings with automatic storm positioning capability. *Weather and Forecasting,* **28**, 727-745.

Ge, G., J. Gao, M. Xue, and K. K. Droegemeier, 2012: Diagnostic pressure equation as a weak constraint in a storm-scale three dimensional variational radar data assimilation system. *Journal of Atmospheric and Oceanic Technology*, **29**, 1075-1092.

Ge, G., J. Gao, and M. Xue, 2013: Impacts of assimilating measurements of different state variables on the analysis and forecast of a supercell storm using three dimensional variational method. *Monthly Weather Review*, **141**, 2759-2777.

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Hobson, A., V. Lakshmanan, T. Smith, and M. Richman, 2012: An automated technique to categorize storm type from radar and near-storm environment data. *Atmospheric Research*, **111**, 104-113.

Jones, T. A., D. J. Stensrud, P. Minnis, and R. Palikonda, 2013: Evaluation of a forward operator to assimilate cloud water path into WRF-DART. *Monthly Weather Review*, **141**, 2272–2289.

Jones, T. A., J. Otkin, D. J. Stensrud, and K. Knopfmeier, 2013: Assimilation of satellite infrared radiances and Doppler radar observations during a cool season Observing System Simulation Experiment. *Monthly Weather Review,* in press. doi: http://dx.doi.org/10.1175/MWR-D-12-00267.1

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Kumjian, M., 2013: Principles and applications of dual-polarization weather radar. Part I: Description of the polarimetric radar variables. *Journal of Operational Meteorology*, accepted.

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Liu, L., Y. Hong, C. Bednarczyk, B. Yong, M. Shafer, R. Riley and J. Hocker, 2012: Hydro-climatological drought analyses and projections using meteorological and hydrological drought indices: A case study in the Blue River Basin, Oklahoma. *Water Resources Management,* **26**, 2761-2779.

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Appendix E

OTHER AGENCY AWARDS

Project Name	PI	Funding Period	Agency	Amount Funded
Impact of Cloud Dynamics on Chemical and Electrical Properties of Storms Observed ruing DC3	Biggerstaff/ Mansell/ Heinselman/ Schuur	11/1/11- 10/31/14	NSF	$661,233
Object-Based Time-Domain Diagnostics for High-Resolution Ensemble Forecasting and Evaluation in the NOAA/HWT Spring Forecasting Experiments	Clark	3/26/13- 9/30/13	UCAR/ Dev. Testbed	$11,858
Storms, Forms and Complexity of the Urban Canopy: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather	de Beurs/ Stensrud	9/1/12- 8/31/15	SD State Univ.	$377,200
NMQ-FLASH Landslide	Gourley/Hong	2/11/13- 2/10/14	NASA	$173,251
Parameterization of Cumulus Convective Cloud Systems in Mesoscale Forecast Models	Kogan	8/1/11- 7/31/14	ONR/ DoD	$594,221
Soil, Water and Temperature System (SWATS) Instrument Mentor FY13	Lamb	10/1/12- 9/30/13	Argonne	$30,000
Operation and Upgrade of the Oklahoma Lightning Mapping Array	MacGorman/ Beasley	12/23/11- 12/22/13	NASA	$175,000
Microphysical and Kinematic Storm Properties Affecting Electrification and Lightning Production	MacGorman/ Schuur/Rust	9/1/09- 8/31/13	NSF	$521,579
Thunderstorm Influences on Lightning and Atmospheric Chemistry Production in Oklahoma during the Deep Convective Clouds and Chemistry Experiment	MacGorman/ Rust/Ziegler	5/1/11- 4/30/14	NSF	$510,452
Water Decisions for Sustainability in the Arbuckle-Simpson Aquifer	McPherson/ Monroe	2/2/12- 8/31/13	NCAR	$91,926
MRI: Development of a Mobile Thermodynamic Profiling Facility for the Atmospheric Boundary Layer	Parsons/Klein/ Chilson/ Cheong/ Turner	9/30/12- 9/24/14	NSF	$663,257

Data Quality Manager for the ARM Program	Peppler/Kehoe	5/1/13-4/30/16	Battelle	$690,000
Investigations of Hazardous Weather Events using Polarimetric Radar and Cloud Model	Ryzhkov	10/1/11-9/30/15	US-Israel Binational Science Foundation	$56,000
Winter Precipitation Microphysics with Polarimetric Radar and Explicit Modeling	Ryzhkov/ Kumjian	6/15/12-5/31/15	NSF	$370,256
Investigation of Microphysical Processes in Clouds Using Spectral Cloud Models Coupled with Polarimetric Radar Measurements at Multiple Frequencies	Ryzhkov/ Kumjian	9/1/12-8/31/15	DOE	$430,711
Improved Understanding of Convective-storm Predictability and Environment Feedbacks from Observations during the Mesoscale Predictability Experiment (MPEX)	Stensrud/ Coniglio/ Doswell	10/1/12-9/30/15	NSF	$367,877
Improved Understanding of Convective-storm Predictability and Environment Feedbacks from Observations during the Mesoscale Predictability Experiment (MPEX) (Supplement)	Stensrud/ Coniglio/ Doswell	10/1/12-9/30/15	NSF	$23,832
Lidar Investigations of Aerosol, Cloud and Boundary Layer Properties over the ARM ACRF Site	Turner	9/15/11-9/14/14	DOE	$378,372
Increased Understanding of Atmospheric Processes from ARM Spectral Radiation Measurements	Turner	9/1/12-8/31/15	DOE	$140,191
Adaptive Radar Data Quality Control and Ensemble-Based Assimilation for Analyzing and Forecasting High-Impact Weather	Xu	5/1/10-9/30/13	ONR/ DoD	$498,600
Combining Communication Signals and Radar Measurements to Better Monitor Communication and Weather Conditions	G. Zhang/ Lakshmanan	9/1/12-9/5/13	AT&T	$25,000

Advanced Study of Precipitation Microphysics with Multi-Frequency Polarimetric Radar Observations and Data Assimilation	G. Zhang/Xue/ Schuur/ Cheong	6/1/11- 5/31/14	NSF	$637,728

Total	**$7,428,544**

Appendix F

NOAA SSWR COMPETITIVE AWARD RECIPIENT REPORTS

These reports are presented largely in the format provided to CIMMS and to relevant NOAA Program Managers – In some cases only the summary is provided for space considerations.

The Impact of Uncertainty Information on Tornado Warning Response: Developing Recommendations for Warning Best Practices (NA12OAR4590118)

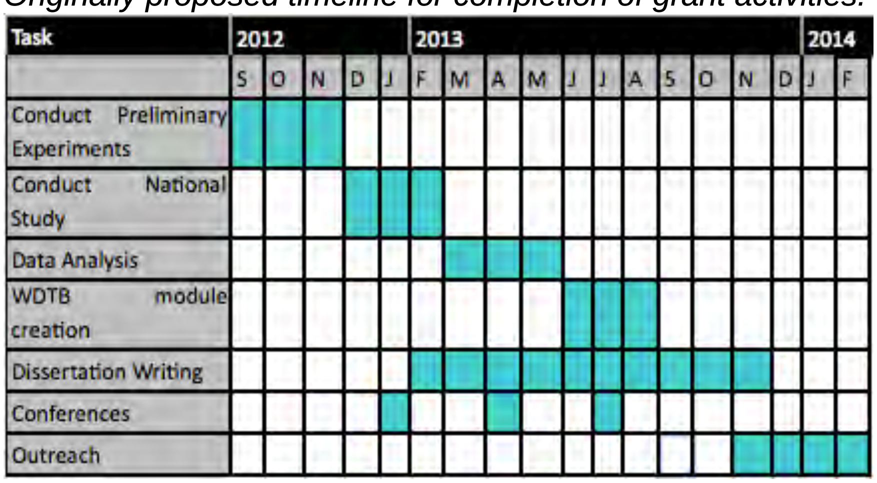
Project PIs

Dr. Renee A. McPherson, Dr. Rick P. Thomas, and Dr. Kimberly E. Klockow – University of Oklahoma

Project Objectives

The eight project objectives are as follows: (1) the construction of a web-based experimental platform, (2) a pilot study with undergraduates to test the experimental design, (3) a nationally implemented study drawing from a representative sample of the U.S. population, (4) analysis of experimental results, (5) the creation of a training module for NWS forecasters highlighting the value and implications of using uncertainty information, (6) publications preparation, (7) presentations of the work at conferences, and (8) outreach.

Originally proposed timeline for completion of grant activities:



Summary of Actions from September 2012 – February 2013, by Grant Activity:

Objective 1 ***(completed November 2012)*** **–** This objective originally did not appear on the proposed timeline because the PI team anticipated having experiment setup completed by August 2012. The dissertation research of Co-PI Klockow focused on qualitative analysis of the 27 April 2011 tornadic outbreak during that time. The qualitative analysis was meant to help frame the questions for the

quantitative experiments. The web-based platform development began immediately in September and was completed in November for the pilot study.

Objective 2 *(completed December 2012)* – Using PI McPherson and Thomas' classes (and others), 135 undergraduates were recruited from introductory courses in physical geography and psychology at the University of Oklahoma to participate in the experimental pilot study. In part, the pilot was to help determine how quickly participants could answer questions and if there were problems in the study design. These data were collected during the first week of December 2012.

Objective 3 *(completed April 2013)* – Data from the pilot study were analyzed from December 2012 through early February 2013. Improvements were identified for the national study, including the addition of a few questions that measure certain severe weather-related attitudes, the addition of a probabilistic graphic with no color scheme (as an experimental control), and a change in logic for how the "biased forecast" condition was designed. Programming activities included working through logic issues, quality controlling database functions, improving graphics, and conducting informal tests of the experiments. An example of the web-based survey is attached.

The Institutional Review Board approved the modifications to the protocol in March. The approved IRB forms attached. Please note that according to the protocol, elements of the dataset (e.g., names of individuals) cannot be disclosed to NOAA. De-identified results that will be available include decisions made over all 96 experimental trials for each participant, the experimental condition of each participant (e.g., graphic type, verbal information, bias type) and trial (e.g., objective probability 85%, etc.), and answers to the follow-up questions at the end.

The research team then worked with Survey Sampling International (SSI) — the survey company — to prepare their database and interface for implementing the national study. Data collection commenced during the first week of April, and approximately 5900 participants completed the experiment. SSI ensured that there were at least 100 participants from every state and the demographics of the sample was representative of the U.S. population. Raw data are stored on servers at the Oklahoma Climatological Survey, where PI McPherson serves as State Climatologist. The servers are backed up daily.

Objective 4 *(completed July 2013)* – After performing quality control on the data, results from 5594 participants were analyzed. From the original sample of 5900, a number of experiments were incomplete and others were completed too quickly for the results to be reliable. Key findings are summarized in an article that is pending submission to a journal (see Objective 6). Quality-assured data are stored on Klockow's work computer (with redundant backup), and on the servers of the Oklahoma Climatological Survey.

PI Klockow documented the analyses of the results of this quantitative study (NOAA funded) and its partner qualitative study (non-NOAA funded) in her dissertation, which was completed on July 26, 2013, and successfully defended on August 9, 2013. Consistent with the guidelines of her advisor (PI McPherson) and her department (Geography and Environmental Sustainability), Klockow's

dissertation includes three draft manuscripts, one of which focuses on the NOAA-funded portion of her research.

Objective 5 *(pending)* – In early March 2013, the PI team met with our colleagues in NOAA's WTDB and NSSL to discuss the development of the future training module. As a result of the conversation, module development will begin in October 2013 instead of May. This delay results primarily from WDTB's annual schedule for training module development as well as workforce accommodations they must make due to sequestration.

Objective 6 *(ongoing)* – Klockow has prepared an article summarizing key findings from this work entitled "The Effects of Geospatial Risk Representations on Decision-Making for Tornado Hazards." It is currently pending submission to the Annals of the Association of American Geographers. (PI Thomas has requested a few additional paragraphs prior to submission.) NOAA Grant #NA12OAR4590118 has been referenced in the acknowledgements section.

Objective 7 *(completed April 2013)* – Klockow presented preliminary findings from the pilot study at the Society for Risk Analysis Annual meeting in December 2012 and the American Meteorological Society Annual Meeting in January 2013. She also presented preliminary findings from the national study at the Association of American Geographers Annual Meeting in April 2013. She has submitted an abstract to discuss the full quantitative study at the 2014 American Meteorological Society Annual Meeting, and she will overview her entire research to the National Weather Center community in Norman at her departmental colloquium on August 23, 2013.

Objective 8 *(pending)* – No outreach activities have been completed yet.

Budget expended as of August 22, 2013:

Salaries and wages: **$14,306 of $27,285**
Fringe benefits: **$930 of $2,722**
Other direct costs: **$28,289 of $30,406**
Indirect costs: **$10,722 of $14,697**
Total: $54,246 of $75,110

Social and Behavioral Influences on Weather-Driven Decisions (NA12OAR4590119)

Submitted to: **NOAA OAR Office of Weather and Air Quality, Dorothy Fryar, Program Officer**

Team Members
Kenneth J. Galluppi, PI Arizona State University
Rachel E. Riley, Co-PI University of Oklahoma
Dr. Burrell E. Montz, Co-PI East Carolina University
Dr. James Correia, Jr. University of Oklahoma
Jessica Losego, Co-PI Univ. of North Carolina

Introduction

The goal of the Social and Behavioral Influences on Weather-Driven Decisions (SBI) project is to develop an understanding, characterization, and prioritization of the major social and behavioral influences on weather-driven emergency management (EM) decision-making to protect life and property, and to make recommendations to the National Weather Service on how to minimize negative influences in their products and services and accentuate the positive.

Our team from Arizona State University, East Carolina University, the University of North Carolina, and the University of Oklahoma explores the major influences on EM decisions in complex social networks and collaborates with National Weather Service entities including the Storm Prediction Center, Central Region Headquarters, and the Tulsa WFO. We use efficient agile approaches to highlight significant issues that inhibit the understanding of risk and the employment of good risk management practices. This project is organized around the National Research Council's Risk Paradigm that connects hazards to personal and institutional risk management. Influences manifest themselves in a disruption of the risk connections.

Activities (9/1/12-2/28/13)

Many activities, or iterations, took place during the reporting period to get the project underway and begin to meet project goals and milestones. Findings from other projects, such as research done for the NWS Central Region Impact-Based Warnings project and our collaboration with the NWS Weather Prediction Center Winter Weather Experiment, were leveraged to help determine influences for this project. SBI iterations include:

- Held introductory meeting about SBI with collaborators to discuss what SBI comprises and lay out ideas for short-term activities and milestones. (September)
- SBI collaborators from the SPC and Tulsa WFO established their baseline from their perspectives on EM decision-making and issues they see in communicating with the EM community (September-October)
- Administered paper survey at the North Carolina EM Fall Conference to establish the baseline of EM timelines, decision processes, trigger points, and information needs during a severe convective event. Received 23 responses. (October 14-15)
- Administered paper survey at the International Association of EM Annual Conference that was similar to the one administered at the NC EM Fall Conference, but with participants from a larger geographical region. Received 34 responses. (October 28-31)
- Assisted Operational Proving Ground collaborator with semi-structured interviews about changes to winter weather products at the International Association of EM Conference Annual Conference. (October 28-31)
- Conducted four focus groups, two with EMs and two with NWS/SPC forecasters, in Oklahoma to continue to establish baseline understanding of EM and forecaster processes and influences. (November 13-15)
- Based on previous iterations, generated first list of influences that affect EM decision-making and categorized them based on the risk paradigm components

(see Appendix 1 for latest version of list). (December)

- Began process of adding to list of influences and prioritizing influences based on team discussions and the development of a survey for the Tornado Summit/National Severe Weather Workshop in March.

Presentations

- Galluppi, K.J., J. Losego, B. Montz, Using the Risk Paradigm to Link Weather to Emergency Management Decisions, Society for Risk Analysis Annual Meeting 2012, December 2012, San Francisco, CA.

- Galluppi, K., Decision Processes: Key to Effective "Decision Support", NWS Southern Region Science and Operations Officers Virtual Conference, February 2013.

Milestones

Tasks and milestones listed below are from the proposal and fall into the reporting period:

Task 1. Identify the most critical influences on weather related decisions to protect life and property and their placement within the risk paradigm.

Milestones:
Completed: Meeting with partners to establish initial subtasks and work team – September 30, 2012
Completed: Completion of initial focus groups – October 2012
Completed: Completion of baseline identification of influences – October 31, 2012

Task 2. Characterize the influences, when they occur, who or what causes them, and how they manifest themselves within the risk paradigm.

Milestones:

Completed: Completion of initial analyses – November 15, 2012
Completed: Define refinement iterations – November 30, 2012
Postponed: Conduct initial directed interviews and observations – December 31, 2012

- Postponed until spring severe weather events occur to reserve travel budget. New milestone date: June 30, 2013

Task 3. Define a scale of relative importance and priority for assessment of influences on decisions.

Milestones:

Completed: Completion of initial priority ordering, - December 31, 2012
Completed: Define refinement iterations – December 31, 2012
Postponed: Workshop to assess priority influences prior to severe weather season –

January 31, 2013.

- Postponed until spring severe weather events occur. Also postponed due to NOAA/NWS travel restrictions. Instead of formal workshop, we will discuss with NWS staff during other opportunities, such as Missouri Emergency Management Conference in April.

Task 4. Demonstrate through prototyping, what changes to products and services can be made to incorporate positive influences on decisions.

Milestones:

Postponed: Workshop to assess priority influences prior to severe weather season – January 31, 2013.

- Postponed until spring severe weather events occur. Also postponed due to NOAA/NWS travel restrictions. Instead of formal workshop, we will discuss with NWS staff during other opportunities, such as Missouri Emergency Management Conference in April.

Task 5. Repeat process used for severe weather for a tropical weather use case to verify influences.

Upcoming Activities (March 1, 2013-August 31, 2013)

- Present introductory information and findings at the Tornado Summit/National Severe Weather Workshop in Oklahoma City, OK (March 2013)
- Conduct semi-structured interviews with EMs and administer a survey during the Tornado Summit/National Severe Weather Workshop in Oklahoma City, OK to prioritize influences. (March 2013)
- Attend Missouri Emergency Management Conference to collect data from EMs to prioritize influences via semi-structured interviews (April 2013)
- Continue developing and prioritizing influences based on data collected from EMs (March-June 2013)
- As severe weather events occur, conduct semi-structured interviews of EMs (including Emergency Support Functions) in affected region to determine importance of influences to decision-making process. Decisions on whether interviews will be via phone or in-person will be made by the team based on several factors. (March-June 2013)
- Develop prototypes for testing based on prioritized list of influences (May-August 2013)
- Test prototypes with EMs (May-August 2013)
- Prepare abstracts for AMS presentation of results (August 2013)
- Begin tropical weather use case based on methods used for severe weather (May-August 2013)
- Workshop (virtual) with team members, NWS, and NOAA partners to discuss year 2 activities (July 31, 2013)

Appendix I: List of Influences on EM Decision-Making (as of 2/28/13)

Hazard

Forecaster confidence
Informal advance notice from forecaster (time, severity, location)
Formal advance notice from forecaster (time, severity, location)
Event type (time, severity, location)
Other:

Impact Assessment

Media coverage
Communication of meaningful impact information (thresholds)
Event type (time, severity, location)
Information needs for EM vs. public
Other:

Vulnerability Assessment

Location
Population exposure (number and demographics)
Infrastructure exposure
Time of day and day of week of event
Other:

Message Packaging

Cues, perceived or real, given by NWS
Training and background of EM and forecaster
Formatting (structure) of text messages
Formatting (structure) of graphical messages
Missing the means to convey critical information
Means to convey forecaster confidence
Means to convey event characteristics (timing, location, duration, history, what is it/how bad is it)
Other:

Message Reception

Ease of retrieval of information
Missing information
Ineffective communication of information
Reception of inconsistent information from NWS and other sources
NWS method of communication (NWSChat vs. email vs. phone vs. NWR)

Structure of text products
Structure of graphical products

Operational/Processing Considerations

Cues, perceived or real, given by NWS
Years on job
Lessons learned from past experiences
Ability to interpret information
EM interest in weather
NWS method of communication (NWSChat vs. email vs. phone vs. NWR)
Number of EM staff
Media coverage
Amount of advance notice
Time of day and day of week of event
Technology – mode to receive or provide information
Working from EOC, home or vehicle
Standard operating procedures triggering actions

Confidence, Competence, Comfort

Relationship/familiarity with NWS staff
Cues, perceived or real, given by NWS
EM confidence in understanding and applying weather info and explaining to others
Training of EM
Experiences of EM
EM interpretation and use of information
EM interest in weather
Ease of use of information
Missing information
Reception of inconsistent information from NWS and other sources
Forecaster confidence
Technology – ability to receive or provide information

Risk Perception

Ability to understand weather risk information
Ability to characterize risk (NWS and EM collaboration goal)
Ability to communicate risk
Ability to decipher inconsistent information from NWS and other sources
Ability to discern and interpret information

Decision-Making

Public/political pressure
Current policies that are triggered by NWS products
Resource constraints
Inconsistent information from NWS and other sources

Utilization of Real-Time Social Media Data in Severe Weather Events: A Proposal to Evaluate the Prospects of Social Media Data Use for Severe Weather Forecasting, Communication, and Post-Event Assessments (NA12OAR4590120)

Progress Report March 2013

Utilization of Real-Time Social Media Data in Severe Weather Events: Evaluating the Prospects of Social Media Data Use for Severe Weather Forecasting, Communication, and Post-Event Assessments

Carol L. Silva, PI; Hank C. Jenkins-Smith, Co-PI; Paul Spicer, Co-PI; Peter J. Lamb, Co-PI – The University of Oklahoma

Project Overview

This research will focus on two distinct information flows of direct relevance to severe weather prediction and forecasting: (1) how *meteorologists and forecasting specialists* receive social information concerning forecasts, severe weather effects and social responses that are of relevance to their assessments of the societal impacts of their work, and (2) how *affected publics* receive, process and transmit information about severe weather watches and warnings in areas most likely to be affected by severe thunderstorms and tornadoes.

The first component, utilizing ethnographic research based on interviews and observation at the National Weather Center and at the "Spring Experiments" in the Hazardous Weather Testbed in Norman, OK, will characterize the patterns of social information flows that – either explicitly or implicitly – shape the ways regional forecasters employ social information in forecasting. How might they be bringing local knowledge and the experiences of the local publics to whom they provide weather forecasts into these training settings? How do the regional operational forecasters acquire this knowledge about local, public responses to, and experiences with "their" weather? What role does media – traditional/new media and social media networks – play in this local knowledge?

The second component, based on streaming social media data in combination with systematic surveys, will collect real-time data about how members of the public perceive and respond to severe weather prior to, during and after an event. The Twitter data will consist of all posts, collected continuously, that include any of a suite of severe weather terms. The survey data will be collected in an Internet mode, with subsamples taken on a weekly basis over a four-month period, and will permit comparison of data acquisition and use among population subsets as well as evaluation of the breadth of exposure to

social media-based information within episodes of severe weather. Pilot data demonstrate the feasibility and utility of collection of streaming Twitter data. We will be able to characterize several stages of the response to a severe weather event, including (a) the "bow wave phase" consisting of posts prior to the event in which discussion of forecasts, watches, warnings, preparations, and emotive responses to the prospective storm are expected to predominate; (b) the "storm phase" in which postings reflect the arrival of the severe weather, its effects on structures, the behavior of those in the path, and effects (injuries, stress) on people; and (c) the "post storm phase" in which posts are more likely to have content reporting what happened, provide data on damage and location, and discuss personal and official responses to the storm and evaluate them.

The ethnographic analysis will provide a foundation for the introduction of the systematic social data stream results to meteorologists and forecasting specialists in the setting provided by the Spring Experiments in the Hazardous Weather Testbed. We will jointly assess the potential uses and products that can be developed using streaming, real-time social data both for severe storm preparation and severe weather forecasting. Potential applications for emergency response professionals will also be assessed.

Project Timeline and Milestones

September 2012: Sorting and compilation of 2011/2012 Twitter data into an analyzable form

This milestone has been met. We have made excellent progress in compiling the Twitter data and putting it in a format that is appropriate for analysis. For a description of the data and the process we used to collect and compile it see **Progress Report Attachment #1: Social Media and Severe Weather: Do 'Tweets' Provide a Valid Indicator of Public Attention to Tornadoes?** (not included).

October 2012: Begin analysis of the Survey Data with the intent of informing the Twitter analysis

Survey data analysis is underway. A frequency report detailing the distributions of responses to the survey questions is attached. See **Progress Report Attachment #2 Severe Weather and Society Survey: Frequency Report and Data Summary** (not included)

November 2012: Begin on-going analysis of "characteristic signal" of severe weather (pre, during, post) events based on 2011/2012 data

This first stage of this analysis is complete. See **Progress Report Attachment #1: Social Media and Severe Weather: Do 'Tweets' Provide a Valid Indicator of Public Attention to Tornadoes?** (not included). This paper is currently being readied for submission to the *Weather Climate and Society* Journal review process. It is essential that we establish the validly of using Twitter data in the social analysis of public responses to severe weather.

December 2012: Begin Ethnographic/Interviews at the NWC The ethnographic

interviews are underway. See

Progress Report Attachment #3: Ethnographic Interviews (not included) for a summary of current progress.

January 2013: Prepare for Twitter data collection for the 2013 storm season. We are well ahead of schedule for this milestone. We are already in the process of collecting the twitter data in anticipation of the severe weather season.

March 2013: Semi-annual progress report due with preliminary data analysis. We believe that this milestone is met by the submission of this document.

Manuscripts Under Review

- Ripberger, JT, HC Jenkins-Smith, CL Silva, DE Carlson, and M Henderson. "Social Media and Severe Weather: Do Tweets Provide a Valid Indicator of Public Attention to Tornadoes?" [Under review at: *Weather, Climate, and Society*]
- Ripberger, JT, CL Silva, HC Jenkins-Smith, DE Carlson, M James and KG Herron. "False Alarms and Missed Events: The Impact and Origins of Perceived Inaccuracy in Tornado Warning Systems." [Under review at: *Risk Analysis*]

Manuscripts in Preparation for Review

- Ripberger, JT, M James, CL Silva, HC Jenkins-Smith, DE Carlson, and KG Herron. "The Impact of Consequence-Based Messages on Public Responses to Tornado Warnings."
- Ripberger, JT, HC Jenkins-Smith, CL Silva, A Russell, and M Henderson. "The Evolution of Twitter Messages Before, During, and After the May 20th Tornado in Moore, OK."
- Silva, CL, HC Jenkins-Smith, DE Carlson, and JT Ripberger. "The Cost of Taking Cover: Variations in Time Spent Taking Protective Actions During Tornado Warnings."
- Ripberger, JT, CL Silva, and HC Jenkins-Smith. "Public Usage of and Trust in Information from Social Media about Severe Weather."
- Ripberger, JT, CL Silva, and HC Jenkins-Smith. "Preparing for the Storm: The Relative Influence of Objective and Perceived Risk on Preparatory and Mitigation Behavior."

Conference/Workshop Presentations

- "The Cost of Taking Cover: Variations in Time Spent Taking Protective Actions During Tornado Warnings." To be presented at the 2014 American Meteorological Society Annual Meeting in Atlanta, GA.
- "The Evolution of Twitter Messages Before, During, and After the May 20th Tornado in Moore, OK." To be presented at the 2014 American Meteorological Society Annual Meeting in Atlanta, GA.
- "False Alarms and Missed Events: The Impact and Origins of Perceived Inaccuracy in Tornado Warning System." To be presented at the 2013 Society for Risk Analysis Annual Meeting in Baltimore, MD.
- "Social Media and Severe Weather: Do Tweets Provide a Valid Indicator of

Public Attention to Tornadoes?" Presented at the 2013 American Meteorological Society Conference on Weather Warnings and Communication in Nashville, TN.

- "False Alarms and Missed Events: The Impact and Origins of Perceived Inaccuracy in Tornado Warning System." Presented at the 2013 American Meteorological Society Conference on Weather Warnings and Communication in Nashville, TN.
- "Tornadoes and Twitter: How Social Media is Helping us Understand Public Responses to Severe Weather." Presented at the 2013 National Tornado Summit/National Severe Weather Workshop in Oklahoma City, OK.
- "Social Media and Severe Weather." Presented at the 2012 Workshop on Communicating Seasonal Climate Information in Norman, OK.

Water Reservoir Data and Visualization Tools for the Southern Great Plains (NA12OAR4310126)

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Scientific Objectives:

1. Objective #1: Determine stakeholder requirements for design of an integrated reservoir database.

To address the first objective of the Water Reservoir Data and Visualization Tool for the Southern Great Plains, researchers with the Southern Climate Impacts Planning Program (SCIPP) met with the Inter-agency Forum on Monitoring Water Quantity in Oklahoma. This forum is an established working group within the state of Oklahoma that includes members from the local and state governmental agencies, along with representatives from several federal organizations. Members include, but are not limited to, the Oklahoma Water Resources Board, the Oklahoma Water Survey, the US Army Corps of Engineers Tulsa District, and both Oklahoma State University and the University of Oklahoma. On October 29, 2012, SCIPP had the opportunity to be part of this forum's regularly scheduled bi-yearly meeting. By meeting with the water quantity forum, SCIPP aimed to assess the desired characteristics of variables that should be displayed in this water reservoir tool, and what display techniques were the highest priority for these groups.

The initial response to the project description was very positive, and members of the water quantity forum verified the inherent need to have current and historical reservoir information synthesized in one location, with the ability to compare the different variables over time. The members also indicated the key variables to include in the reservoir tool should be water level, percent capacity, height above conservation pool, total storage (acre-feet), conservation storage (acre-feet), surface area (acres), inflow/outflow, and sedimentation. These variables were mentioned most frequently as the highest priority, or most commonly accessed variables.

The primary motivation for this project derived from comments made during webinars, workshops and forums related to the ongoing drought conditions across the Southern Plains. Many of those most directly affected by the drought conditions, including water resources managers, were critical of needing water resource information easily accessible (in one location), easily displayed, and easily comparable to past drought events for future mitigation efforts. Because of this need, SCIPP researchers at Louisiana State University also visited with those tasked with managing the reservoirs across Oklahoma, Texas, and Louisiana. Many managers were happy to provide additional reservoir information, and also provide input as to other high priority variables that a water reservoir tool should display. One such variable that was mentioned several times was boat ramp elevation. This variable is important because boat ramps may become inaccessible if water is too low/too high. Therefore, having the ability to compare current conditions at a reservoir to past conditions might enable a water resource manager to make a more informed decision regarding lesser known impacts (e.g. making boat ramps less accessible thereby impacting recreation, etc.). Engaging stakeholders is a continuing process, but enough information regarding the reservoir variables needed was provided to begin working on objective #2 of the project.

2. Objective #2: Integrate these requirements into an operational system.

SCIPP incorporated suggestions from stakeholders to create a web-based reservoir tool. A screen-shot of this tool is provided in Figure 1. At the upper-left portion of the tool, a map provides the locations of all reservoirs in the region. A graph at the upper-right corner plots the elevation vs. capacity curve. These curves are unique for each reservoir, as the under-water profile of a reservoir will determine the shape of this curve. At the bottom of this tool are graphs that plot the water level and the water capacity over time. The rapid increase in the water capacity visible around June 1, 2013, was a result of a heavy rain event in northeast Oklahoma.

The reservoir tool also plots information related to reservoir infrastructure. Figure 2 depicts the elevation of boat ramps as well as daily water levels at Canton Lake, Oklahoma, for a six-month period ending around June 1, 2013. The graph captures the sudden drop in water levels as more than 30,000 acre-feet of water was released from this lake in late February, 2013, to provide water for the Oklahoma City metro area. Interestingly, the lake level fell below the elevation of the lowest boat ramp, making the lake inaccessible to recreational users for a period of time.

The information provided by this tool is updated daily, as water levels and capacities change on a regular basis. This tool mostly uses data from the United States Geologic Survey and U.S. Army Corps of Engineers. The tool provides information from more than 180 reservoirs, including approximately 120 in Texas, 50 in Oklahoma and 10 in Louisiana.

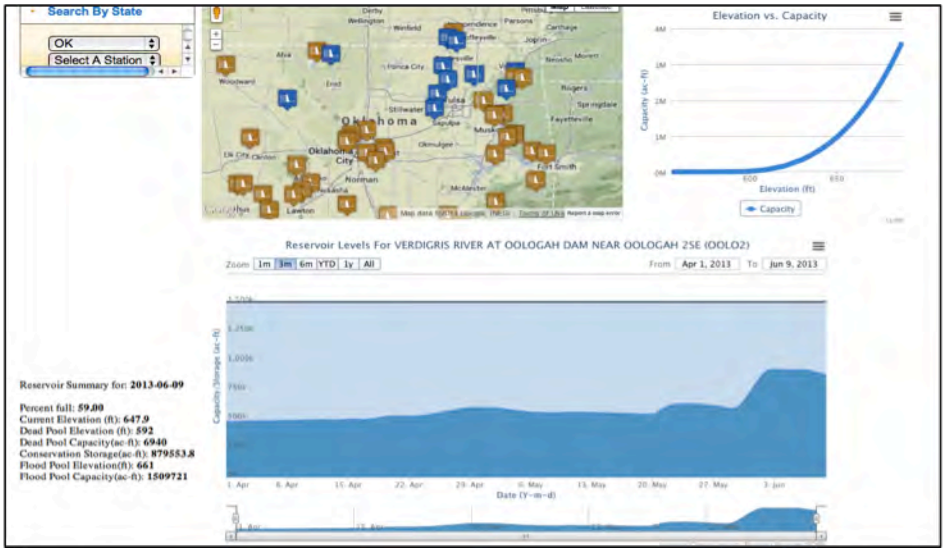

Fig. 1. The Reservoir Tool plots reservoir levels and capacity over time, provides an elevation vs. capacity curve and a map of regional reservoir locations.

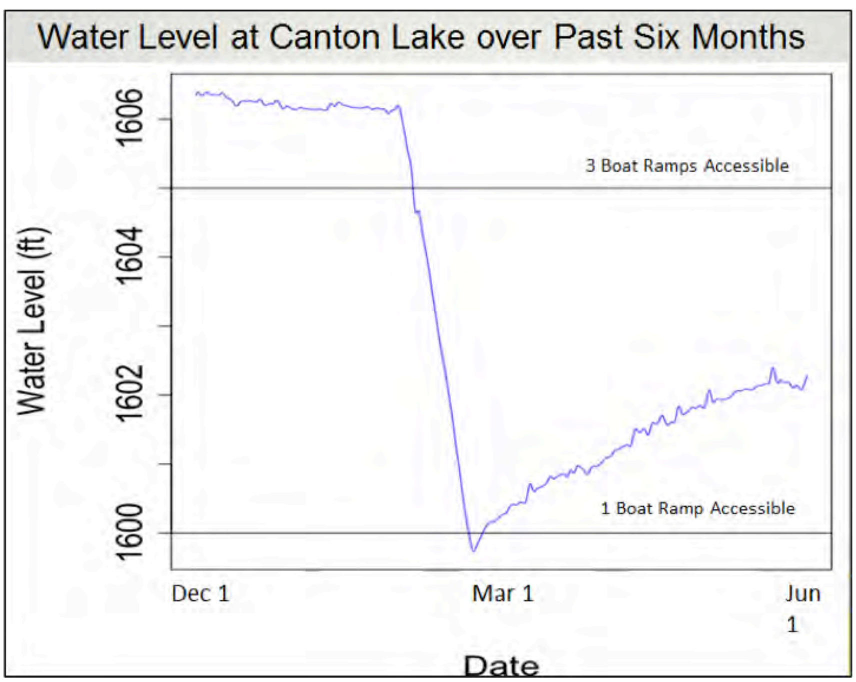

Fig. 2. The reservoir tool also plots information related to reservoir infrastructure. This graph provides the elevation of boat ramps as well as daily water levels.

3. Objective #3: Promote use of a new system among sectors most directly impacted by water restrictions.

The remaining months of this project will be used to complete Objective #3. Through Objective's #1 and #2, SCIPP has engaged various stakeholders to assess their water resource needs, and are now currently building and testing a tool (Figures 1 and 2) that represent those needs. With a prototype of this tool now available, stakeholders can be re-engaged to ensure their needs are being met. Engagement opportunities exist with the continuing Managing Drought in the Southern Plains webinar briefings, the Southern Climate Monitor (SCIPP's monthly newsletter), and through continued discussion at meetings, forums or through phone calls with water resource managers.