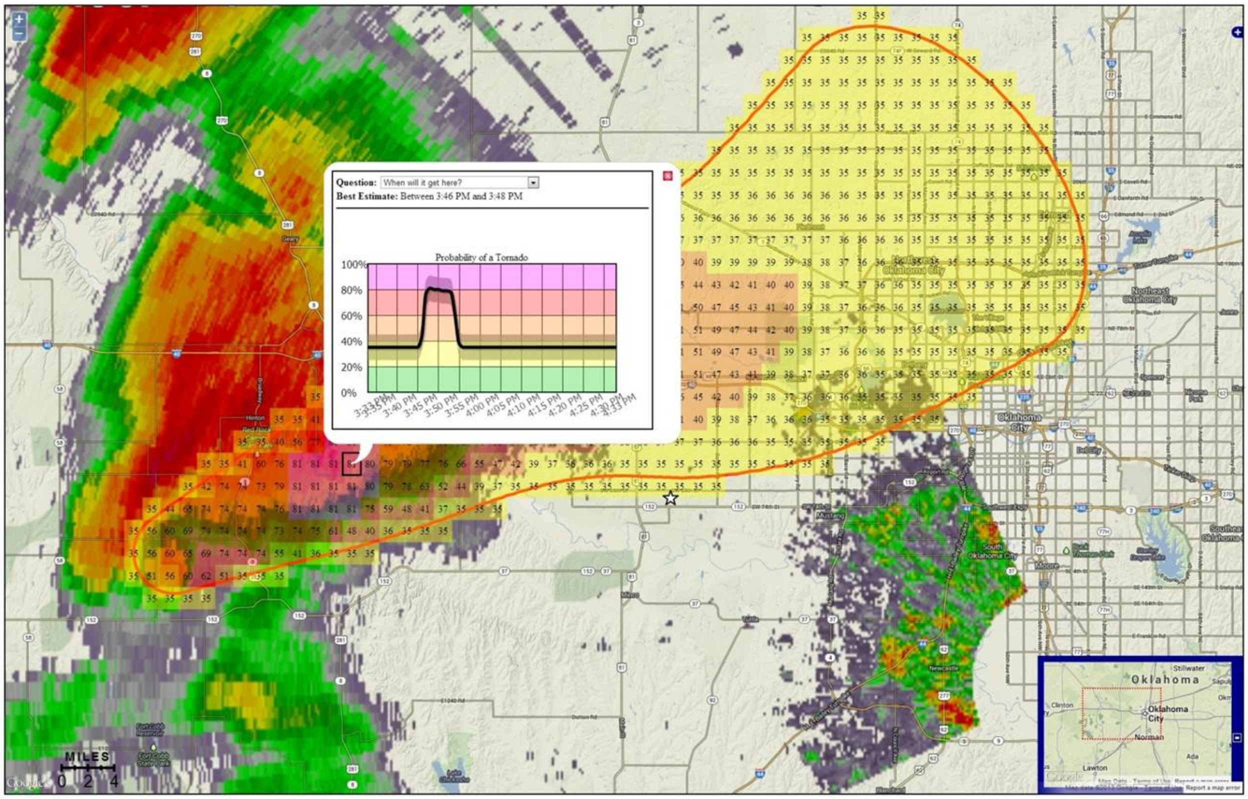

Cooperative Institute for Mesoscale Meteorological Studies

Annual Report

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

Cooperative Agreement NA11OAR4320072

Fiscal Year – 2014

Cover figure – *Screenshot of the Probabilistic Hazard Information (PHI) Tool that was evaluated in the HWT. For more on this work by CIMMS scientists Greg Stumpf, Chris Karstens, and others, see the project "Probabilistic Hazard Information (PHI) Tool" on p. 192-193.*

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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 2014 Fiscal Year

Peter J. Lamb, Director (July 1, 2013-May 28, 2014)
Randy A. Peppler, Associate and Interim 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 Advanced Radar Research Center (ARRC)
- OU College of Atmospheric and Geographic Sciences
- OU School of Meteorology
- OU Department of Geography and Environmental Sustainability

CIMMS 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 2013 through 30 June 2014. Publications written, awards received, and employee and funding statistics are presented in Appendices.

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

An Executive Board and an Assembly of Fellows govern CIMMS under its present cooperative agreement. An updated Memorandum of Understanding is pending.

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 (now Interim) 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 and Jamie Foucher). Scientists, students, and post-docs are housed on the OU campus in its National Weather Center (NWC) and at the NWSTC in Kansas City. Some CIMMS undergraduate students have duty stations off-campus at ROC in Norman.

On May 28, 2014, Peter Lamb passed away unexpectedly. Within a week, Randy Peppler was named Interim Director and will remain in that position until a new Director is hired. Day to day operations of CIMMS remain the same and our research has not been impacted.

Executive Summary Listing of Activities during FY2014

Theme 1 – 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 on:

NSSL Project 1 – Advancements in Weather Radar

- WSR-88D Improvements
    - Range Oversampling Techniques
    - Range-and-Velocity Ambiguity Mitigation
    - Ground Clutter Mitigation
    - Radio-Frequency Interference
    - Dual-Polarization Signal-Processing Improvements
    - Correlation Coefficient Estimation
    - Spectrum Width Estimation
    - Noise Power Estimation
    - Software Development for KOUN
    - Hardware Development and Maintenance for KOUN and Mobile Radars
    - WSR-88D Data Management
    - WDSS-II Ingest and Improvements
    - Radar Reflectivity Quality Control Algorithm
    - Improved Extrapolation Forecasts
    - Extracting Post-Event Storm Tracks
    - MapReduce Mosaic Method
    - Detailed Survey of the 20 May 2013 Moore, OK Tornado
    - NOAA/NWS Radar Functional Requirements: Present through 2030

- Improving Data Quality of Polarimetric WSR-88D Radar

- Dual-Polarization
  - Refinement of the New Polarimetric QPE Algorithm Based on Specific Attenuation
  - Development of the Hail Size Detection Algorithm (HSDA) that Distinguishes Between Small, Large, and Giant Hail
  - Developing a Robust Algorithm for Discriminating Between Weather and Non-Weather Radar Echoes ("MetSignal" Algorithm)
  - Recent Modifications to a New Surface-Based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network
  - Development of a New Melting Layer Detection Algorithm that Combines Polarimetric Radar-Based Detection with Numerical Model Output
  - Sources of Uncertainty in Precipitation Type Forecasting
  - Discrimination Between Winter Precipitation Types Based on Explicit Microphysical Modeling of Melting and Refreezing in the Polarimetric Hydrometeor Classification Algorithm
  - An Automated Method for Polarimetric Tornado Debris Detection
  - Using the Z_{DR} Column Product to Detect Convective Storm Development and Track Updraft Position
  - Introducing the Concept of Quasi-Vertical Profiles of Polarimetric Radar Variables for Analysis of Microphysical Processes in Clouds and Precipitation
  - Microphysical Retrievals Using Polarimetric Radar Data
  - Analysis of Polarimetric Radar Measurements in Polar Clouds
  - Investigation of Microphysical Processes in Mixed-Phase Clouds Using Data Collected by Polarimetric Surveillance Radars, Cloud Radars, Wind Profilers, and Aircraft Probes During the MC3E Field Campaign
  - Measurements of Circular Depolarization Ratio (CDR) with the Radar with Simultaneous Transmission/Reception

- Phased Array Radar
  - NWRT PAR Software Upgrades (MPARSUP)
  - NWRT PAR Operations
  - NWRT PAR Radar Data Management
  - Understanding Strength and Limitations of Scanning Strategies
  - MPAR Dual Polarization
  - PAR Dual-Polarization Demonstration
  - PAR Clutter Characterization and Mitigation
  - PAR Pulse Compression and Range Oversampling
  - Cylindrical Polarimetric PAR (CPPAR)
  - MPAR Program Support

NSSL Project 2 – Hydrometeorological Research

- WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities
- Reflectivity Quality Control for the Canadian Radar Network
- A Three-Dimensional Aviation In-Flight Weather Hazard Product Based on the Hydrometeor Classification Algorithm (HCA)
- Correction of Radar QPE Errors Associated with Low and Partially Observed Brightband Layers
- Improving WSR-88D Radar QPE for Orographic Precipitation Using Profiler Observations
- Development of a Novel Radar QPE Approach Using Specific Attenuation for Two C-Band Dual-Polarization Radars
- Radar Vertical Profile of Reflectivity Correction with Satellite Observations Using a Neural Network Approach
- Producing MRMS QPE Technical Documentation for VLAB
- Evaluating MRMS Quantitative Precipitation, Dual-Polarization Precipitation and NCEP Stage II Estimates
- Quality Control Advancements of Hourly Rain Gauge Observations
- Probabilistic Identification of Enhanced Rain Rates From Warm Rain Processes using Analysis of the Near-Storm Environment
- Multisensor Estimation of Intense Rainfall in Complex Terrain using GOES-R combined with Ground and Space-Based Radars
- Development of Web-Based Tools and Displays for Real-Time QPE and Hydrologic Analysis
    - QPE Verification System
    - Differential Reflectivity Comparison Tool
    - TRMM vs. MRMS Q3 Comparison Tool
- Crowd-sourcing Reports of Hydrometeor Type and Location Using mPING
- Winter Surface Hydrometeor Classification Algorithm

CIMMS Task III Projects

- Next Generation Weather Radar Technology Research at OU *and* Multi-Mission Phased Array Radar Risk Reduction: A Collaborative Effort with the ARRC at the University of Oklahoma
    - Effects of Transmit Schemes on Polarimetric Variables
    - Optimal Pulse Compression Waveforms for MPAR
    - Calibrated and Computationally Efficient Adaptive Beamforming
    - Resource Management for MPAR to Optimize Performance
    - Configurable Phased Array Demonstrator (CPAD) – A Sub-topic of the ARRC's MPAR Risk Mitigation
        - Using CPAD to Demonstrate Circular Phased Array Antennas
        - Application of Full-Wave FDTD Method in Phased Array Antenna Simulation

        - MPAR Backend Analysis
    - Polarimetric Phased Array Radar Configuration and CPPAR Demonstrator Calibration
    - Joint Signal Processing for Simultaneous Weather Measurement and Target Detection with MPAR in the Presence of Clutter
    - Cost-Efficient Antenna Element Designs for MPAR
    - Phase Mode Analysis and Calibration of Large Cylindrical Arrays, Including the CPPAR Demonstrator
    - Real-Time Digital Beamforming for Cylindrical Phased Arrays
- Digital Backend Design and Demonstration for Next-Generation Weather Radar Systems

Theme 2 – 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

- Sensitivity of Forecast Dryline Position and Structure to Boundary Layer Parameterizations in Storm-Scale WRF Model Simulations
- An Automated, Multi-Parameter Dryline Identification Algorithm
- Comparing the NSSL-WRF Model and Convection-Allowing Versions of UKMET's Unified Model During the 2013 and 2014 NOAA HWT Spring Forecasting Experiments
- Implementation and Evaluation of the HAILCAST Algorithm for Explicitly Forecasting Hail Size in Convection-Allowing Models

- Developments and Implementation of the NSSL-WRF Ensemble
- Developing the WRF-LETKF System and Testing Convective-Scale Ensemble Data Assimilation Techniques
- Grid Spacing Sensitivity of Supercell Forecasts
- Impact of Phased Array Radar Data (PAR) Assimilation on Storm-Scale Ensemble Prediction
- Sensitivity of Vortex Production to Environmental Perturbations in High-Resolution Supercell Simulations
- Radar Data Assimilation Using the Local Ensemble Transform Kalman Filter (LETKF) Versus the Ensemble Square Root Filter (EnSRF)
- Forcing Mechanisms of Internal Rear-Flank Downdraft Momentum Surges in the 18 May 2010 Dumas, Texas, Supercell
- Improving Trajectory Analyses Using Advection Correction
- Variational Multiple-Doppler Vertical Wind Retrievals Within Convective Clouds Observed During the Midlatitude Continental Convective Clouds Experiment (MC3E)
- 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 Forecasts for the 27 April 2011 Severe Weather Outbreak in Alabama
- Impact of Assimilating Planetary Boundary Layer Height Observations using an Ensemble Kalman Filter Data Assimilation Technique
- Storm-Scale Data Assimilation and Ensemble Forecasting for Warn-on-Forecast
- Microphysical and Initial-Condition Uncertainty Effects for the 8 December 2013 Surprise Snowstorm
- Complete a Real Time Evaluation of Total Lightning Data Assimilation Algorithm within the WRF framework
- Ensemble Verification of Proxy Severe Storm Reports
- A Four-Year Climatology of Simulated Convective Storms From NSSL WRF
- Evaluation and Acquisition of Computing Resources for Warn on Forecast Efforts
- Identify Potential Hardware Acquisitions in High Performance Computing and Define Requirements
- Investigate Scaling Requirements for the NSSL WRF Ensemble

NSSL Project 4 – Hydrologic Modeling Research

- Hazardous Weather Testbed – Hydrology (HWT-Hydro) Experiment
- Objective Evaluation of FLASH Skill

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

- Complete a Real Time Evaluation of Total Lightning Data Assimilation Algorithm within the WRF framework

- Hazardous Weather Testbed
  - HWT Severe Weather Forecasting
  - SSEO Verification: Hollings Scholarship and REU Students
- Sensitivity of Lake-Effect Snow Forecasts to the Choice of Boundary Layer Parameterization
- Physical Process Studies
- Storm-Scale Data Assimilation and Ensemble Forecasting for Warn-on-Forecast

CIMMS Task III Projects

- Storm Tracking and Lightning Cell Clustering using Geostationary Lightning Mapping Data for Assimilation and Forecast Applications
- Assimilating Satellite Data into NWP Models to Improve Forecasting of High Impact Weather Events
  - Storm-Scale Cloud Water Path Assimilation
  - Storm-Scale GOES-R ABI Radiance Assimilation Using an OSSE
  - Honors and Hollings Student Mentorship

Theme 3 – 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
  - Severe Weather for Use in 24-Hour and 3-Hour Convective Outlooks from ensembles
  - Severe Weather Proxies for Use in 1-Hour Convective Outlooks
  - Collaboration with the EWP-PHI Program
- Experimental Warning Program
  - GOES-R Proving Ground Activities
  - Experimental Warning Guidance
  - Coordination of EWP Experiments
  - Evaluation of Earth Networks Total Lightning Products for NWS Warning Services in the Hazardous Weather Testbed

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

- Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS)
- Warn-on-Forecast Projects
- Severe Hazards Analysis and Verification Experiment (SHAVE)

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

- ROC Applications Branch Projects
- ROC Engineering Branch Projects

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

- Hazardous Weather Testbed
- Objective Verification: Internal Evaluation of Convection Allowing Models
- Local Storm Reports: New, Experimental Decoder and Updated Webpages
- The Usefulness of Winter Weather Local Storm Reports at the SPC
- GOES-R Proving Ground Activities

WDTB Project 12 – Warning Decision-Making Research and Training

- The Advanced Warning Operations Course (AWOC) – Core and Severe Tracks
- Advanced Weather Interactive Processing System (AWIPS) – II Training
- Distance Learning Operations Course (DLOC)
- Experimental Warning Program/NOAA Hazardous Weather Testbed Support: Tales from the Testbed Webinars
- Multiple-Radar/Multiple-Sensor (MRMS) Training
- Weather Event Simulator (WES)
- Weather Event Simulator – II (WES-2)
- WSR-88D Build Improvement Training

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

- MRMS-Severe Best Practices Experiment
- MRMS Product Display for AWIPS2
- MRMS in the NOAA Virtual Laboratory (VLab)
- Probabilistic Hazard Information (PHI) Tool

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

- Forecast Systems Optimization
  - AWIPS Tools Distance Learning
  - Community Hydrologic Prediction System (CHPS)
  - Observational Programs Overview
  - Cooperative Observer Program (COOP) Distance and Residence Courses
  - Safety/Environmental Focal Point Training
  - Linux Essentials Curriculum
- NWS Proving Ground Operational Service Delivery Simulations
  - Develop Operational Proving Ground (OPG) Awareness Display
  - Hazard Simplification Demonstration (HazSimp)
  - First Operational Readiness Evaluation
  - Analyzed Data for Point-and-Click Forecast Survey
- Impact Based Decision Support Services Research and Development
  - Warning Coordination Meteorologist (WCM)/Service Coordination Hydrologist (SCH) Residence Training
  - Decision Support Services (DSS) Boot Camps
  - FEMA Watchstanders Training Course
- Advanced Training Development
  - CIMMS Staff Gain Field Experience to Help with Training
  - Create Training Awareness in NWS through Online Media
  - CIMMS Employees Assist with NWSTC Staff Training
  - CIMMS Staff Attend Professional Development Training to Continue to Push the Boundaries of Instructional Design, Training, and Technology

CIMMS Task III Projects

- GOES-R GLM Lightning Jump Algorithm: A National Field Test for Operational Readiness
- Developing and Testing of Probabilistic Hazard Information Weather Tools for Forecasting a Continuum of Environmental Threats (FACETs)
  - PHI Objects
  - Regional PHI
  - Guidance PHI
  - End-User PHI
  - HWT Spring Experiment
- Development of Short-Range Realtime Analysis and Forecasting System Based on the ARPS for Taiwan Region – Years 3 and 4
- 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

- Prototyping and Evaluating Key Network-of-Networks Technologies (and Project Extension)
  - Evaluate Observation Sensor Impact Using an OSE
  - Case study – 15 May 2013
  - Real-Time, Continuous Analysis System
  - Evaluate Observation Sensor Impact Using an OSSE

Theme 4 – 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 Projects

- Program Support for the Assimilation, Analysis, and Dissemination of Pacific Rain Gauge Data: PACRAIN
  - PACRAIN Database Status
  - Database Enhancements
  - Investigation into Differences Observed Between the PACRAIN Data and the Global Historical Climate Network
  - Schools of the Pacific Rainfall Climate Experiment (SPaRCE)

Theme 5 – 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

- Participation in the FACETS Discussions and Meetings
- Special Projects in Effective Communication
- HWT EFP-EWP Collaboration
- El Reno Tornado – Traffic Study
- Storm Observer Safety Video
- Creation of Numerical Weather Guidance
- Warning Decision-Making and Value to End Users

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) Phase II
    - A Hybrid Procedure for Classifying Synoptic Weather Types for Louisiana with an Application to Precipitation Variability
    - South Central U.S. Hazard and Climate Change Planning Assessment
    - Climate Extremes in the Southeastern United States: Observed Trends, Spatial Variability, and Related Planning
    - May 20 Newcastle/Oklahoma City/Moore Tornado: Post-Disaster Assessment of Preparedness, Planning and Recovery
    - Responses to News Stories about Drought
    - Climate Training for Native American Tribes
    - Intertribal Workshops on Climate Variability and Change
    - Gulf Coast Energy Infrastructure Project
    - State of Oklahoma Hazard Mitigation Plan
    - State of Louisiana Hazard Mitigation Plan
    - Houston Yacht Club
    - Houston Ship Channel

- Local Assessment of Drought Impacts and Climate Change Adaptation
- Rio Grande/Bravo River Basin Climate Outlook

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 Communications, Public Affairs, and Outreach
- CIMMS Staff at WDTB Outreach

Awards and Honors

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

- Presidential Early Career Award for Scientists and Engineers (PECASE): Adam J. Clark (CIMMS at NSSL)

- 2014 Dean's Award for Excellence in Research and Scholarship in the University of Oklahoma's College of Atmospheric and Geographic Sciences: Adam J. Clark (CIMMS at NSSL)

- Young Scientist Travel Award, International Symposium on Data Assimilation, Munich, Germany: Corey Potvin (CIMMS at NSSL)

- Nominated for the Presidential Early Career Award for Scientists and Engineers (PECASE) in July 2014: Corey Potvin (CIMMS at NSSL)

- 2011 OAR Outstanding Paper Award (Awarded in November 2013): Matt Kumjian and Alexander Ryzhkov (both CIMMS at NSSL) for "Storm-Relative Helicity Revealed from Polarimetric Radar Measurements". *Journal of the Atmospheric Sciences*, 66, 667-685.

- AGU Editor’s Award (Geophysical Research Letters), January 2014: Alexandre Fierro (CIMMS at NSSL)

- National Weather Associate Annual Meeting, October 2013: Best Graduate Student Oral Presentation – Ben Herzog; Best Graduate Student Poster Presentation: Race Clark (CIMMS at NSSL)

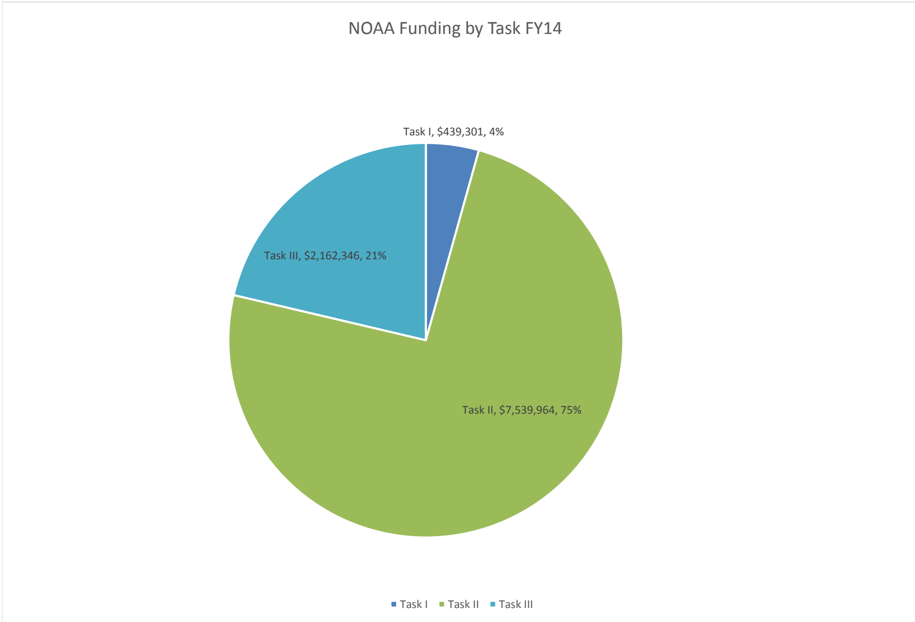
- AGU Annual Meeting, December 2013: Outstanding Student Paper Award: Sean Waugh (CIMMS at NSSL)

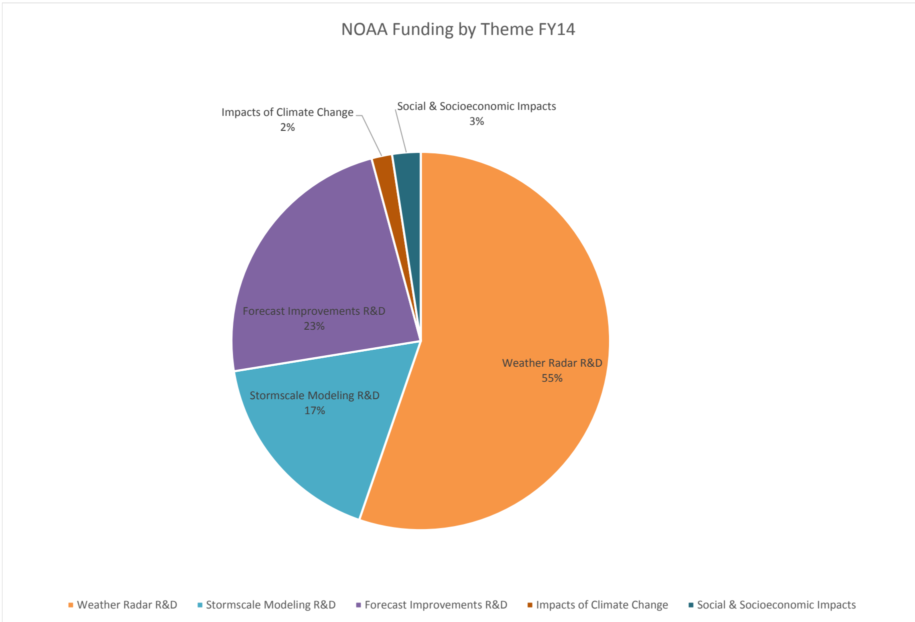
- Significant Papers Award – NSSL Director, January 2014: Kim Elmore, Zac Flamig, Valliappa Lakshmanan, Brian Kaney (all CIMMS at NSSL), Vicki Farmer (INDUS), Heather Reeves (CIMMS at NSSL), and Lans Rothfusz (NSSL), “mPING Crowd-Sourcing Weather Reports for Research”. *Bulletin of the American Meteorological Society*, Early Online Release 2014. doi: 10.1175/BAMS-D-13-00014.

- Third place at the Institute of Industrial Engineers' South Central Regional Conference Technical Paper competition (collaboration with Dr. Chen Ling, February 2014): Chris Karstens (CIMMS at NSSL)

- College of Atmospheric and Geographic Sciences/National Weather Center Photo Contest, 2013: “Pure Oklahoma” – First and Second Place, Steve Martinaitis (CIMMS at NSSL), Honorable Mention, Brandon Sullivan (OU School of Meteorology); “World Travels” – First Place, Bethany Hardzinski (OU School of Meteorology), Honorable Mention, Steve Martinaitis (CIMMS at NSSL)

Distribution of NOAA Funding by CIMMS Task and Research Theme





CIMMS Executive Board and Assembly of Fellows Meeting Dates and Membership

The Executive Board convened on 23 September 2013 and 19 December 2013. No Assembly of Fellows meetings took place.

Executive Board membership for 2014 is as follows:

- Dr. Randy Peppler (Chair), Interim Director, CIMMS, and Lecturer, Department of Geography and Environmental Sustainability, OU
- 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)
- Dr. Kirsten de Beurs, Assistant Professor, Department of Geography and Environmental Sustainability, OU (Provost designated)
- Mr. Lans Rothfusz, Acting Deputy Director, NSSL (OAR designated)
- Dr. Jack Kain, Chief, Forecast Research and Development Division, NSSL (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. Terry Clark, Acting 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)

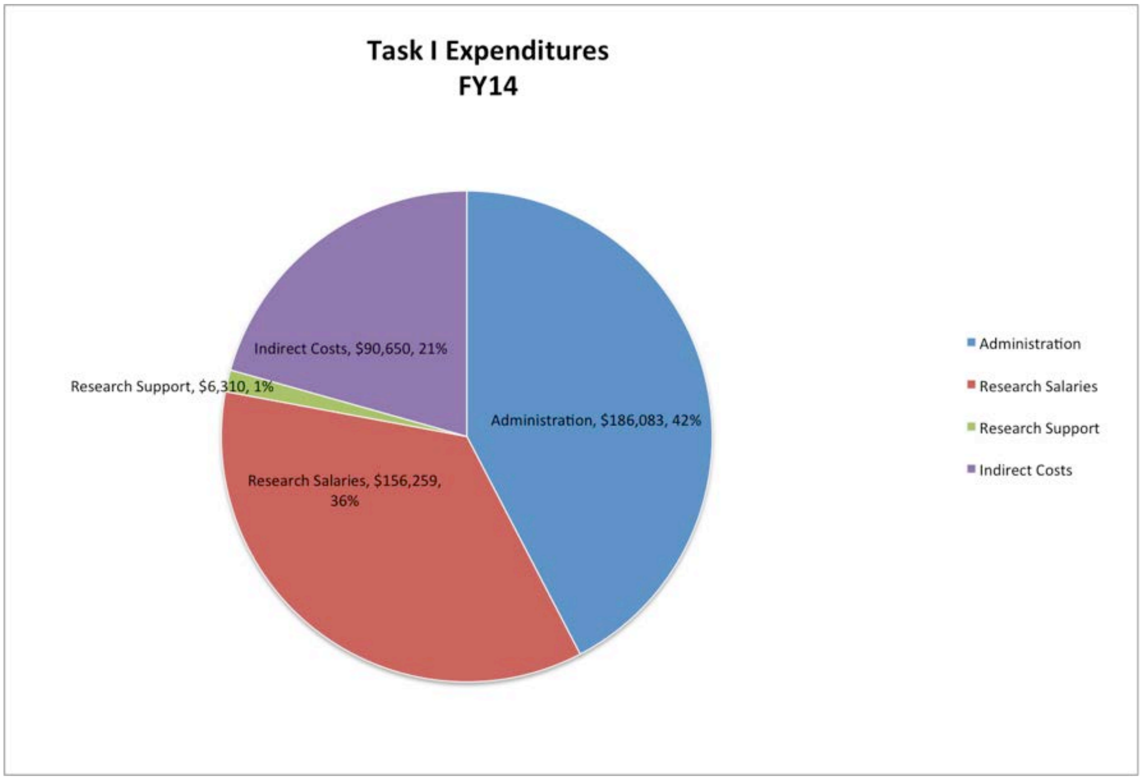
Assembly of Fellows membership for 2012-2014 is as follows:

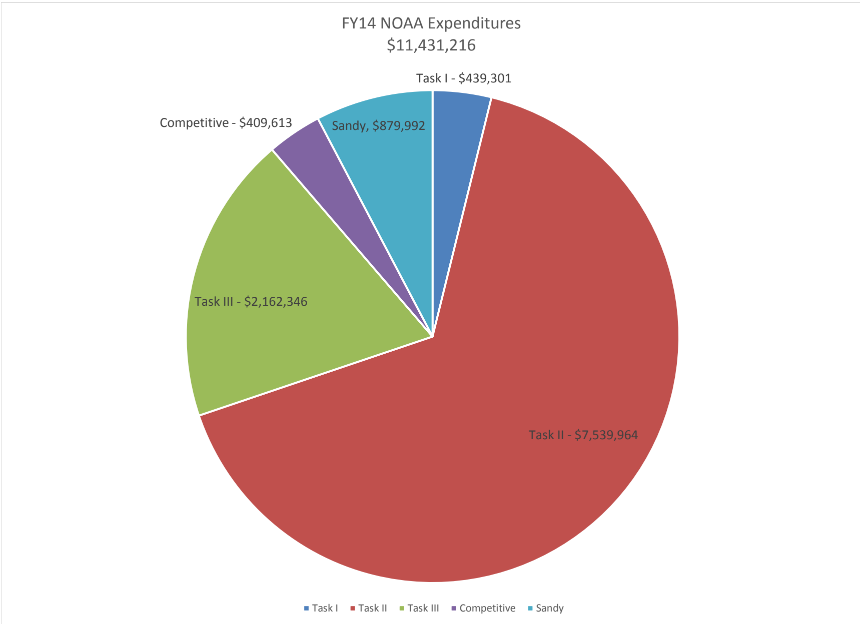
- Dr. Jeffrey B. Basara, Director of Research, OCS, and Associate Professor of Meteorology, OU
- Dr. William H. Beasley, Professor of Meteorology, OU
- Dr. Michael I. Biggerstaff, Associate Professor of Meteorology, OU
- Dr. Howard B. Bluestein, George Lynn Cross Research Professor of Meteorology, OU
- 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, Emeritus Professor of Electrical and Computer Engineering, OU
- Dr. Kirsten de Beurs, Assistant Professor of Geography and Environmental Sustainability, OU
- Dr. David Dowell, Research Meteorologist, Global Systems Division, NOAA Earth Systems Research Laboratory
- Dr. Michael W. Douglas, Research Meteorologist, Mesoscale Applications Group and Models and Assimilation Team, NSSL
- Dr. Richard J. Doviak, Senior Engineer, Doppler Radar and Remote Sensing Research Group, NSSL, and Affiliate Professor of Meteorology and of Electrical and Computer Engineering, OU
- Dr. Kelvin K. Droegemeier, Vice President for Research and Regents' Professor, OU
- Dr. Claude E. Duchon, Emeritus Professor of Meteorology, OU

- Dr. Imke Durre, Scientist, NOAA National Climatic Data Center (NCDC)
- Dr. David R. Easterling, Scientist, NCDC
- Dr. Evegeni Fedorovich, Professor of Meteorology, OU
- Dr. Chris Fiebrich, Associate Director, OCS
- Dr. Caleb Fulton, Assistant Professor of Electrical and Computer Engineering, OU
- Dr. Jidong Gao, Research Scientist, NSSL
- 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
- Dr. Hank Jenkins-Smith, Professor of Political Science, and Research Scientist, CASR, OU
- Dr. David P. Jorgensen, Chief, Warning Research & Development Division, NSSL
- Dr. Youngsun Jung, Research Scientist, CAPS, OU
- Dr. Jack Kain, Chief, Forecasting Research & Development Division, NSSL
- Dr. Petra Klein, E. K. Gaylord Presidential Professor and Associate Professor of Meteorology, OU
- Mr. Kevin E. Kelleher, Director, Global Systems Division, ESRL
- Mr. Redmond Kelley, Radar Engineer, ARRC, OU
- Dr. James F. Kimpel, Director, Emeritus NSSL, and Emeritus Professor of Meteorology, OU
- Mr. Paul Kirkwood, Scientist, NWS Southern Region Headquarters
- Dr. Kevin Kloesel, Director, OCS, and Associate Professor of Meteorology, OU
- Dr. Steven Koch, Director, NSSL
- Dr. Fanyou Kong, Research Scientist, CAPS, OU
- Dr. Matthew Kumjian, NCAR Post-Doctoral Research Associate
- Dr. Daphne LaDue, Research Scientist, CAPS, OU
- Dr. S. Lakshmivarahan, George Lynn Cross Research Professor of Computer Science, OU
- Dr. Lance M. Leslie, Robert E. Lowry Chair and George Lynn Cross Professor of Meteorology, OU
- Dr. Donald R. MacGorman, Research Physicist, Convective Weather Research Group, NSSL, and Affiliate Professor of Meteorology and of Physics and Astronomy, OU
- Mr. Ed Mahoney, Chief, WDTB
- Dr. Edward Mansell, Research Scientist, NSSL
- Dr. Renee McPherson, Director of Research, South Central Climate Science Center, and Associate Professor of Geography and Environmental Sustainability, OU
- Mr. John Meier, Radar Engineer, ARRC, OU
- Dr. James W. Mjelde, Professor of Agricultural Economics, Texas A&M University
- Dr. Berrien Moore III, Vice President for Weather and Climate Programs, Dean, College of Atmospheric and Geographic Sciences, Director, National Weather Center, and Chesapeake Professor of Meteorology, OU
- 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
- 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
- Dr. Jessica Ruyle, Assistant Professor of Electrical and Computer Engineering, OU
- Dr. Russell Schneider, Director, SPC
- Dr. Mark Shafer, Director of Climate Services, OCS, and 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
- Dr. John T. Snow, Emeritus Professor of Meteorology, OU
- Dr. Paul Spicer, Professor of Anthropology, OU
- Dr. David J. Stensrud, Head, Department of Meteorology, Pennsylvania State University
- 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
- Dr. Xuguang Wang, Assistant Professor of Meteorology, and CAPS, OU
- Dr. Neil Ward, Former Director, IRI, Decision Systems Research, Columbia University
- Mr. Steven J. Weiss, Chief, Science Support Branch, SPC
- Dr. Louis J. Wicker, Research Meteorologist, Convective Weather Research Group, NSSL, and Affiliate Associate Professor of Meteorology, OU
- Dr. Kimberly Winton, Director, South Central Climate Science Center, USGS
- Dr. Qin Xu, Research Meteorologist, Models and Assimilation Team, NSSL, and Affiliate Professor of Meteorology, OU
- Dr. Ming Xue, Director, CAPS, and Professor of Meteorology, OU
- 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
- 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
- Dr. Conrad Ziegler, Research Meteorologist, Models and Assimilation Team, NSSL
- 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 and All NOAA 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

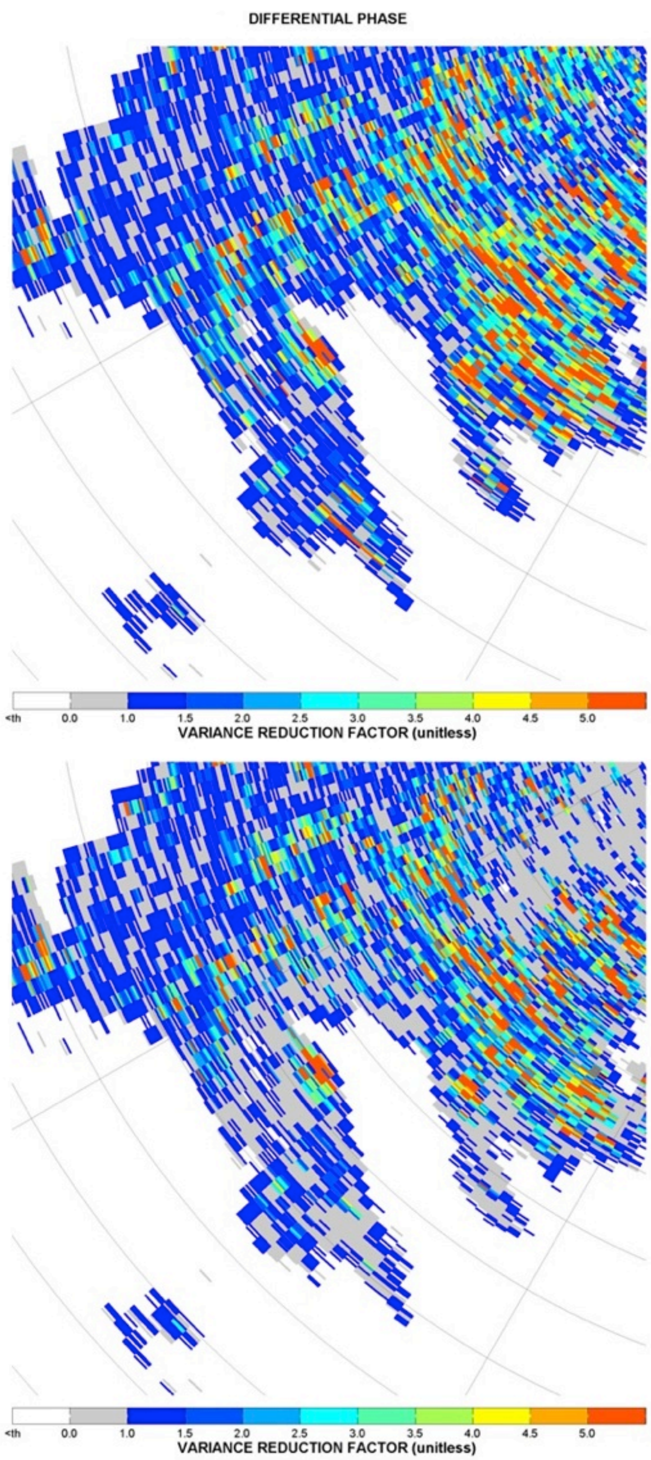
Overall Objectives
Conduct research and development to provide improvements to the NWS operational radar (WSR-88D). This research explores ways to improve the detection of hazardous weather and improve the weather radar data quality.

Accomplishments

a. Range Oversampling Techniques

Christopher 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. When increasing data rates, the conventional trade-off 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 FY14, we continued our research on the new adaptive pseudowhitening algorithm for dual polarization. A paper was submitted in October 2013 and was accepted for publication in 2014. Additional work was done on quantifying the improvements from adaptive pseudowhitening compared to whitening as shown in in the figure below. We also studied the effects of whitening on the detection of tornado vortices. Using a novel simulation technique, we can capture the effects of antenna rotation, windowing, and range oversampling processing on the difference between the maximum and minimum radial velocities. This work is ongoing.



Comparison of the variance reduction factor between adaptive pseudowhitening (top) and whitening (bottom) for differential phase. Adaptive pseudowhitening performs like whitening at high SNR (orange and red areas) and like a digital matched filter at low SNR (fewer gray areas).

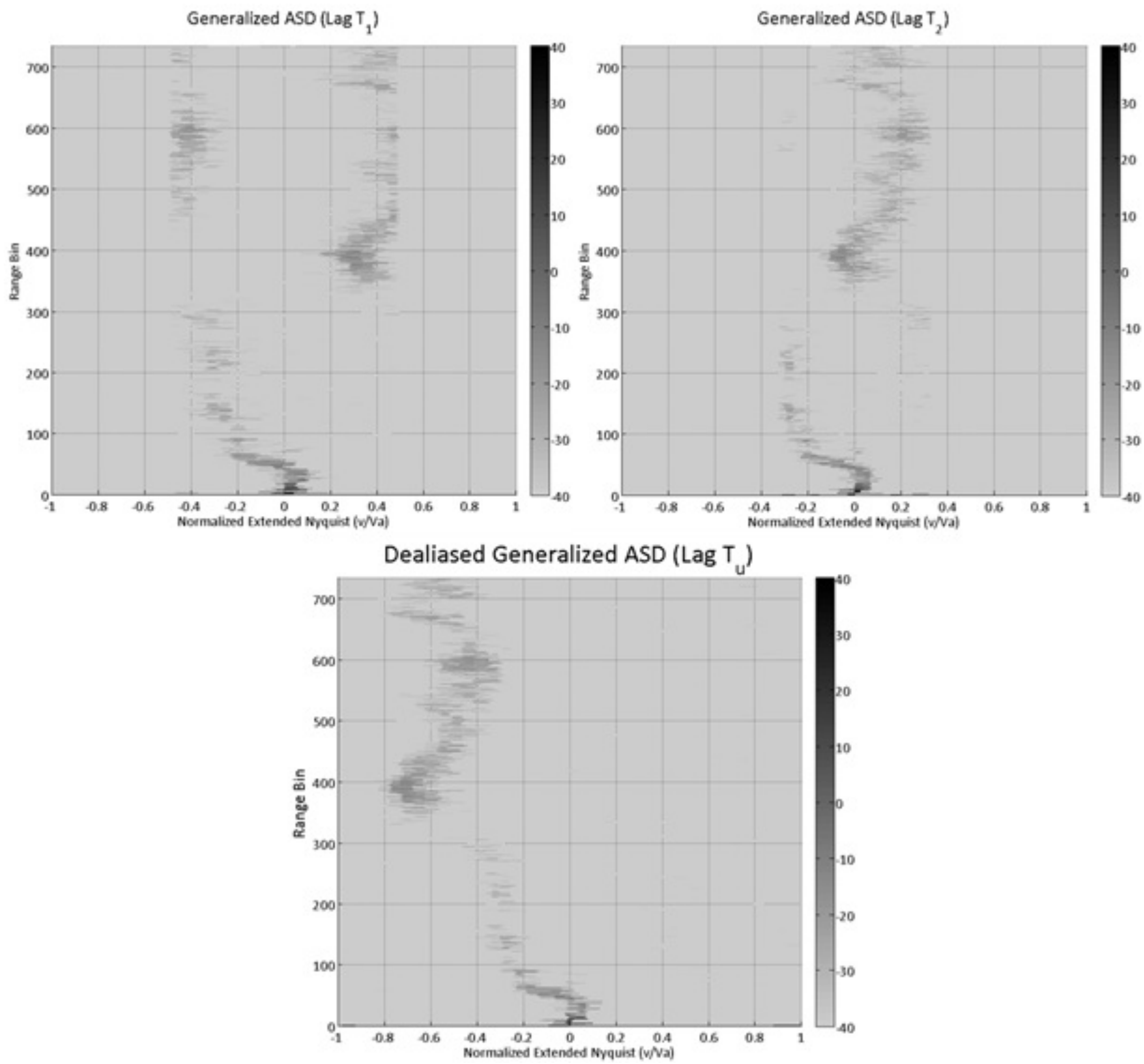
b. Range-and-Velocity Ambiguity Mitigation

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 efficient observation of severe weather. Efforts in this area are expected to culminate in significantly improved WSR-88D data quality when implemented on the Radar Data Acquisition sub-system. 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 in the WSR-88D thus reducing the amount of purple haze obscuration currently encountered during the observation of severe phenomena. These are: systematic phase coding (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 volume coverage pattern (VCP). The first stage of upgrades is now complete and has been operational with great success for a number of years. The second stage of NEXRAD upgrades dealing with range and velocity ambiguities involves the operational implementation of staggered PRT. We developed a novel spectral processing SPRT algorithm that incorporates the mature CLEAN-AP filter, range-overlaid recovery, dual polarization, and a generalized PRT ratio. In FY12, we had delivered the improved staggered PRT algorithmic description to the NWS Radar Operations Center (ROC) for inclusion into the NEXRAD software update cycle. In FY13 and FY14, we held several technical interchange meetings with and provide continual scientific support to the ROC to ease software implementation of Staggered PRT into the NEXRAD software update cycle. Also in FY14, we completed an extensive evaluation of the new staggered PRT algorithm in terms of its ability to mitigate ground clutter contamination. We developed optimum acquisition parameters for operational VCPs that use staggered PRT in place of the Batch waveforms. Improvements in clutter suppression using CLEAN-AP were leveraged to provide similar dwell times as current operational VCPs. The largest improvements from staggered PRT are seen in the mid-levels of the VCPs where replacement of batch waveforms with staggered PRT results in reduced error of estimates for reflectivity, differential reflectivity, differential phase, and correlation coefficient, higher maximum unambiguous velocities, reduced range-overlay obscuration, and increased dual-polarization coverage. Three VCPs were identified for incorporation of staggered PRT in place of batch waveforms: VCP 211, VCP 212, and VCP 221. These VCPs were delivered to the ROC for engineering testing of their staggered PRT algorithm implementation.

A novel spectral representation, the generalized autocorrelation spectral density (ASD) was formulated for staggered PRT waveforms to assist with ground clutter mitigation. Dealiasing techniques were applied to these generalized ASDs to assist in extending the Nyquist co-interval. These new spectral techniques to dealias velocities were computationally complex and only marginally successful; therefore, they were not

recommended for inclusion into the NEXRAD staggered PRT algorithm. With the recommended changes, we have provided a robust staggered PRT solution with enhanced ground clutter mitigation technology capable of meeting NEXRAD operational needs in the dual-polarization era. This work is ongoing.

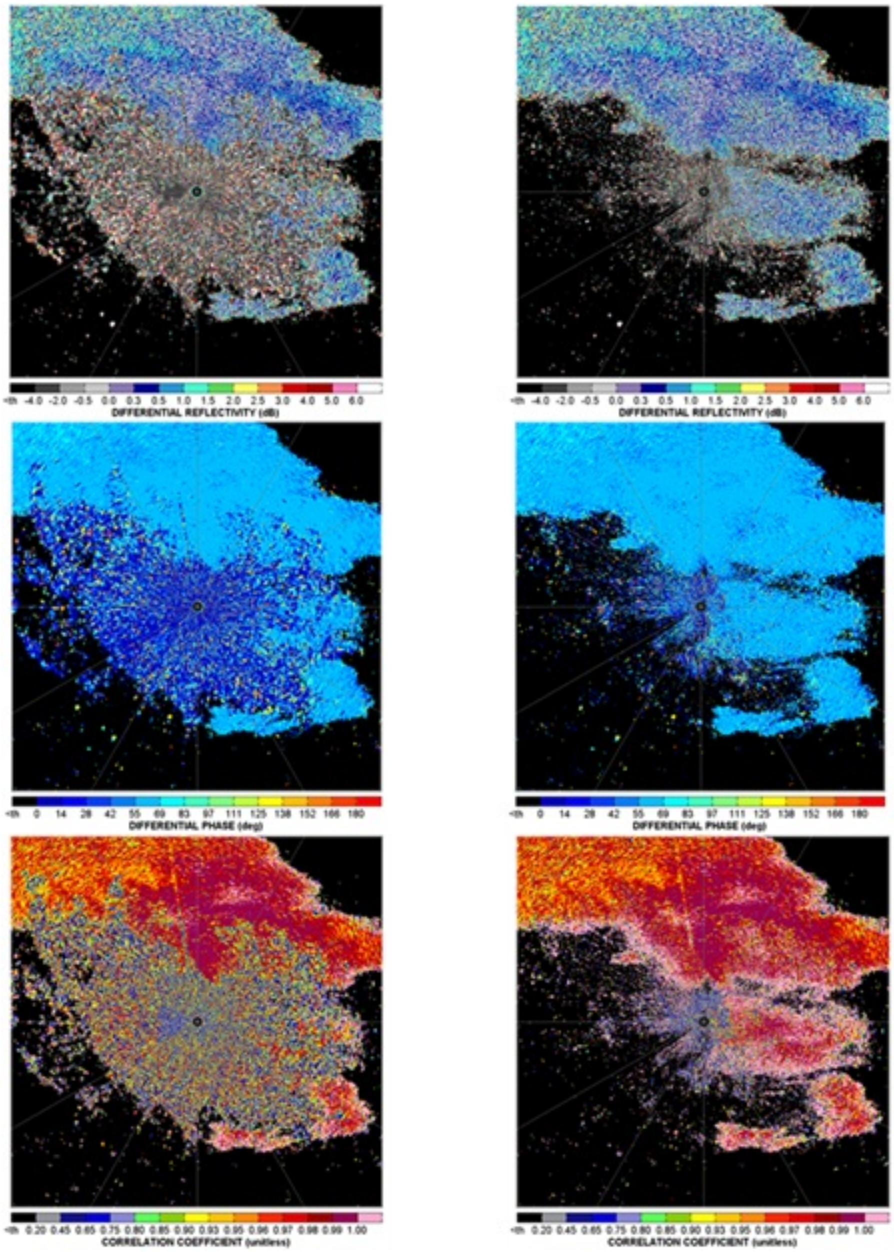


Example of real data from a WSR-88D radar processed using the generalized autocorrelation spectral density (ASD) with a 2/3 Staggered PRT ratio (i.e., $T_1/T_2 = 2/3$). The generalized ASD at lag T_1 (top left) and lag T_2 (top right) show aliased velocities beyond range bin 280 that cannot be resolved with either PRT. Combining the two ASDs (bottom) places the weather signals at the proper velocity locations within the spectrum of the extended unambiguous velocity co-interval as if sampled at a faster rate (i.e., shorter PRT, $T_u = T_1/2 = T_2/3$).

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 Clutter Environment Analysis using Adaptive Processing (CLEAN-AP) filter 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 WSR-88D radars, the dual-polarized (DP) KOUN and OUPrime radars, and the NWRT PAR. In 2011, the NEXRAD Technical Advisory Committee (TAC) recommended the CLEAN-AP filter be transitioned into the WSR-88D system for further engineering evaluation and operational use. During FY12, we had provided complete performance analysis of the CLEAN-AP filter comparing it alongside WSR-88D current ground clutter mitigation techniques. Additionally, 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 FY14, we continued working on improvements to CLEAN-AP and identified a notch width interpolation method that improves the recovery of near-zero, narrow-spectrum weather signals in clutter contaminated regions. We also completed an extensive ground clutter filter analysis of CLEAN-AP in staggered PRT waveforms. In addition, we have begun investigating the use of dual-polarization information to identify weather-only regions in which the filter could be safely bypassed. 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 work is ongoing.



Unfiltered (left) and CLEAN-AP filtered (right) PPI displays of differential reflectivity (top), differential phase (middle), and correlation coefficient (bottom) fields illustrate the automated recovery of polarimetric-variable estimates from weather signals with varying degrees of ground clutter contamination. The data was collected with a WSR-88D radar at an elevation angle of 0.5° with uniform sampling using 17 samples and a PRT of 3.107 ms.

d. Radio-Frequency Interference

Christopher Curtis and Brad Isom (both CIMMS at NSSL)

Expanding use of wireless technology has prompted a dialogue concerning the reallocation of several bands within the radio frequency (RF) spectrum. Included in the discussion is the 2.7 to 3.0 GHz band, where many meteorological and aircraft surveillance radars reside. Reducing the width of the allotted band or opening the band to additional transmitters will undoubtedly generate more instances of unwanted RF interference between radars. In an effort to quantify the potential impact, a simulation-based study was conducted to explore the extent of the corruption through statistical means. RF interference can appear in three primary forms: pulsed, continuous wave, and noise-like. This study determined realistic interference power limits based on generally accepted thresholds for each interference type and explored the impacts on the quality of the meteorological variables for specific volume coverage patterns on the WSR-88D. The interference-to-noise (INR) thresholds were compiled for several derived limits and delivered in a report to the ROC. The results of the study were also presented to the commissioning body and the NEXRAD TAC. This work is ongoing.

e. Dual-Polarization Signal-Processing Improvements

Brad Isom, David Warde, Christopher Curtis, Igor Ivić, Eddie Forren, and Sebastian Torres (all CIMMS at NSSL)

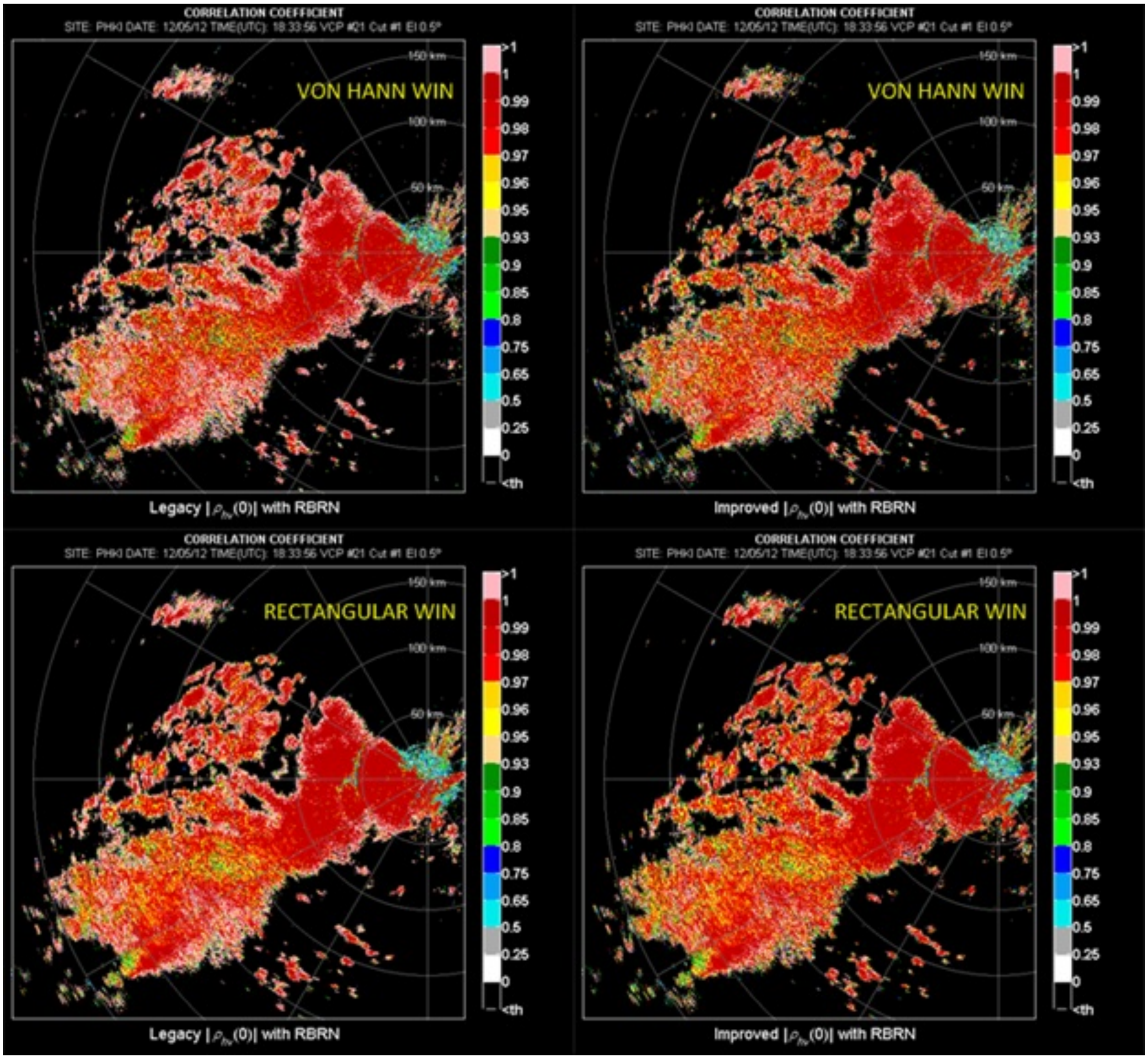
The NWS has just completed a multi-year dual-polarization hardware upgrade to the WSR-88D national network of weather radars. The dual-polarization enhancement provides complete characterization of weather type (i.e., rain, snow, hail, etc.) and non-meteorological targets (i.e., tornado debris, ground 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 updated the signal processing software on the National Weather Radar Testbed (NWRT) to include dual polarization processing. The new signal processor was generalized to process source data from any single- or dual-polarization weather radar system (e.g., WSR-88D, OU Prime, NWRT PAR, or mobile C-, X-, S-band radars). Included in the signal processing are enhancements that take advantage of dual polarization such as clutter rejection by combining horizontal- and vertical-channel notchwidth selection, noise estimates using radial-by-radial noise (RBRN), and reduced meteorological estimate variance using automated range correlation estimates. Additionally, an innovation to spectral analysis developed by CIMMS called the autocorrelation spectral density provides the framework for dual-polarization (co- and cross-polar) unbiased spectral and covariance estimates. FY14 saw continued development in the dual-polarization signal processing enhancements through improved radial velocity measurements by combining autocovariance estimates from horizontal and vertical channels, and polarimetric estimates by combining information from multiple PRTs while developing criteria for overlaid scenarios. Additionally, we improved on the range-folding algorithm, added a

dual-polarization simulator, and added Staggered PRT modules. We continue to support the real time implementation and update the signal processing.

f. Correlation Coefficient Estimation

Igor Ivić (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 (SNR). 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 SNR 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 the 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. During FY14, the novel estimator was further developed and applied to real data sets. The results were presented to the NEXRAD Technical Advisory Committee (TAC). Additionally, a replacement of the von Hann window with the rectangular one (for super-resolution scans) was proposed to further enhance the fields of CC. This prompted the same window replacement proposal to be extended to other polarimetric variables as well. To further reduce the number of cases with CC > 1, a simple algorithm that combines the outputs of lag-0 and lag-1 estimators has been studied. The results were presented at the annual AMS meeting in Atlanta, GA. This work is ongoing.



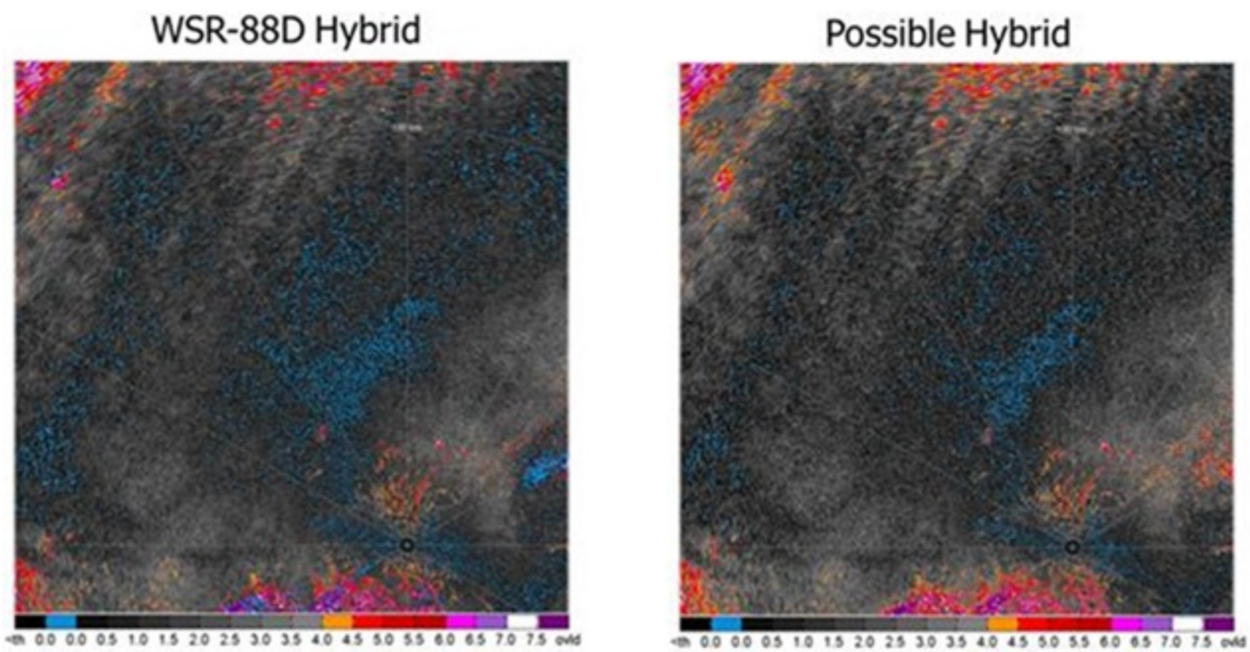
Comparison between CC fields produced by the legacy (left) and the improved estimator (right). Upper (lower) images were obtained using the von Hann (rectangular) window.

g. Spectrum Width Estimation

David Warde and Sebastian Torres (both CIMMS at NSSL)

Improved quality of spectrum width estimates has the potential to enhance radar data assimilation into numerical weather prediction models, storm feature identification (e.g., rear flank downdrafts, boundaries, tornado genesis, and hail spikes), and downstream algorithms (e.g., NEXRAD Turbulence Detection Algorithm, range oversampling processing, correction for non-uniform beam filling, and Bragg scatter identification). On Doppler weather radars, the spectrum width is commonly estimated from a ratio of

autocorrelation estimates at two different lags. These estimators have been used for decades on operational weather radars and have well known properties. For example, the R0/R1 estimator, which is based on the ratio of lag-0 to lag-1 autocorrelations, performs the best for wide spectrum widths but has poor performance for narrow spectrum widths and relies on accurate noise measurements. The R1/R2, which is based on the ratio of lag-1 to lag-2 autocorrelations, and other estimators based on higher-lag autocorrelations provide better narrow spectrum-width estimates than the R0/R1 estimator and improve performance when accurate noise measurements are not available, but they are severely biased for wide spectrum widths. Thus, to provide better estimates over a wide range of spectrum widths, a few estimators can be suitably combined. This so-called hybrid spectrum-width estimator can take advantage of the best characteristics of each estimator for different regimes. During FY14, we developed and formalized improvements to spectrum width estimation by combining the autocorrelation spectral density (ASD) and Welch processing to create “matched” autocorrelations. The new estimators based on “matched” autocorrelations provide a larger range of unbiased estimates for narrow spectrum widths at lower sample sizes and with less variance than standard methods. The performance at wide spectrum widths is comparable to that of the standard estimators. The results were presented to the NEXRAD Technical Advisory Committee and received favorable comments. The new estimators were combined into a simple hybrid spectrum width estimator that showed improve performance over the current NEXRAD WSR-88D hybrid spectrum width estimator. This work is ongoing.

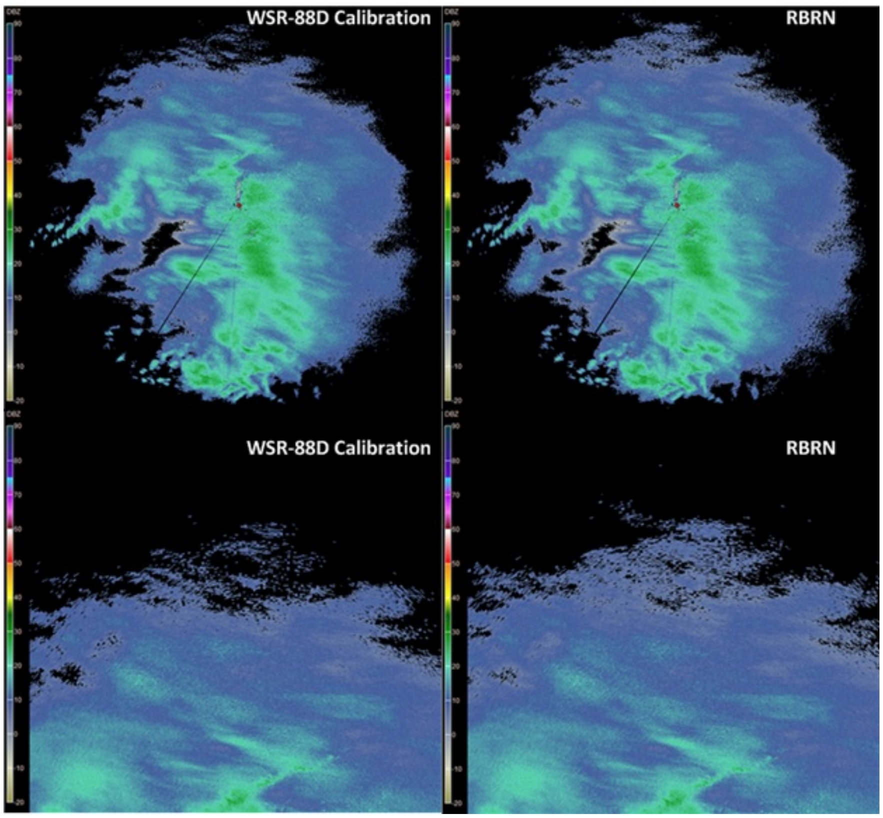


Spectrum width PPI displays of WSR-88D (left) and proposed hybrid spectrum width estimator (right) using ASD-based “matched” autocorrelations as inputs. The blue color where the estimates are set to 0 m s^{-1} shows reduced narrow spectrum width biases for the proposed estimator.

h. Noise Power Estimation

Igor Ivić (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 RBRN estimator 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 FY14, CIMMS staff provided extensive support to the ROC and successfully transferred the technique to operational use – this work is ongoing.



Plan-position-indicator (PPI) displays of the reflectivity generated using legacy calibration noise (left), and the radial-by-radial noise measurement technique (right). Gain in the coverage is evident (images courtesy of ROC).

i. Software Development for KOUN

Eddie Forren and John Thompson (both CIMMS at NSSL)

A tool to playback ORDA time series data files into the radar independent digital signal processor was developed. DSP control parameters functionality was extended to allow NEXRAD style VCP definitions and radar specific control parameters necessary for playback and/or real-time ingest of time series data. The playback tool included the design and implementation of a shared API to handle indexed radial grouping of pulses for ORDA batch, uniform, and FFT mode data collections. This shared API can be used in playback or real-time processing.

For real-time processing, two computers were installed to passively process udp broadcast IQ data from KOUN and an ingest application was written to take pulse data from the broadcast and publish pulses in an LB on one of the new computers. The full DSP processing stream has not been implemented or tested yet and it is likely that some additional ingest work will be needed to complete this work once the dual polarization DSP is fully implemented.

Work started on the dual polarization implementation of the radar independent DSP that can be used for processing KOUN or NWRT data. Because changes needed for dual polarization were fairly significant and because the real-time application infrastructure had improved since the NWRT DSP was developed, the real-time DSP was reorganized, streamlined, and many routines were being re-written as part of this effort. This includes possible processing speed gains from standardizing and extending vectorized processing routines built on top of the Intel Processing Primitives. This work is scheduled to be completed in the next calendar year.

j. Hardware Development and Maintenance for KOUN and Mobile Radars

Michael Schmidt and Matt McCord (both CIMMS at NSSL)

We wrote a utility program to enable changing the PRF based on the elevation angle for KOUN. This augments the sector-scan utility written last year; enabling NSSL/CIMMS scientists to use different PRF's for higher elevation angles while doing a sector scan. This allows the radar to better mimic operational configuration while performing sector scans with faster updates.

The RVP-900 Signal Processor Upgrade by the NWS Radar Operations Center in support of the NWS Service Life Extension Program (SLEP) is ongoing. We have started to receive some parts that have to be changed out before the upgrade will happen. The radar at this time is fully operational and is being utilized by NSSL/CIMMS staff for data collection and by ROC engineers for testing software upgrades. The mobile radar NOXP has been utilized quite a bit this past year collecting data. CIMMS technicians were called out to repair the radar when it was in North Carolina and had to work on the slip ring assembly. It was successfully repaired and continued to operate

with very few minor problems. At this time, NOXP is in Phoenix, Arizona and no issues have been reported to date. We are building new equipment that will be used to upgrade NOXP with the RVP-900 signal processor. This will be a major upgrade for this radar with much of the hardware having to be changed out.

k. WSR-88D Data Management

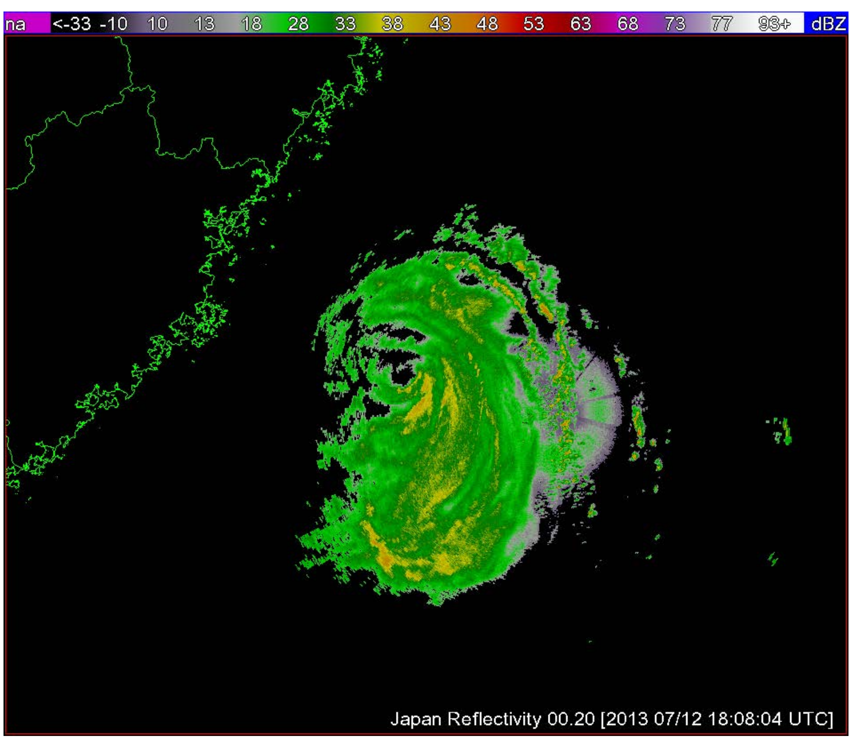
Richard Adams and Dan Suppes (both CIMMS at NSSL)

CIMMS staff continues to support the archiving and distribution of radar data for NSSL/CIMMS and the NWS Radar Operations Center. During FY14, data from KOUN, several operational WSR-88D radars, the 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 work is ongoing.

l. WDSS-II Ingest and Improvements

Jeff Brogden and Valliappa Lakshmanan (both CIMMS at NSSL)

WDSS-II was enhanced to ingest new data types including Canadian and Japanese radar data and High Resolution Rapid Refresh (HRRR) grids. This was required in order to support several other research activities within NSSL. The Canadian data was needed to support the Multi-Radar Multi-Sensor (MRMS) deployment at the National Weather Service. The Japanese radar was required to support precipitation research.



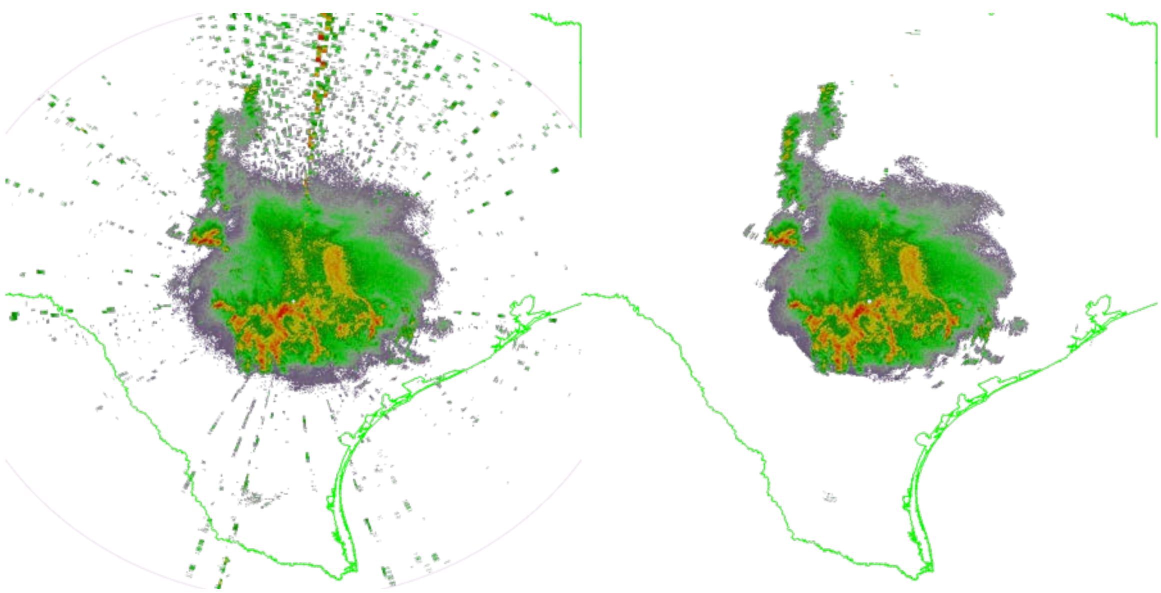
Japanese radar data in WDSS-II.

m. Radar Reflectivity Quality Control Algorithm

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

A quality control method has been developed to QC non-Doppler radar data using polarimetric variables. 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 ρHV 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, is also introduced in this paper and can be used if the full QC method cannot be applied. The simple classifier has a HSS of about 0.6 on the independent dataset.

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

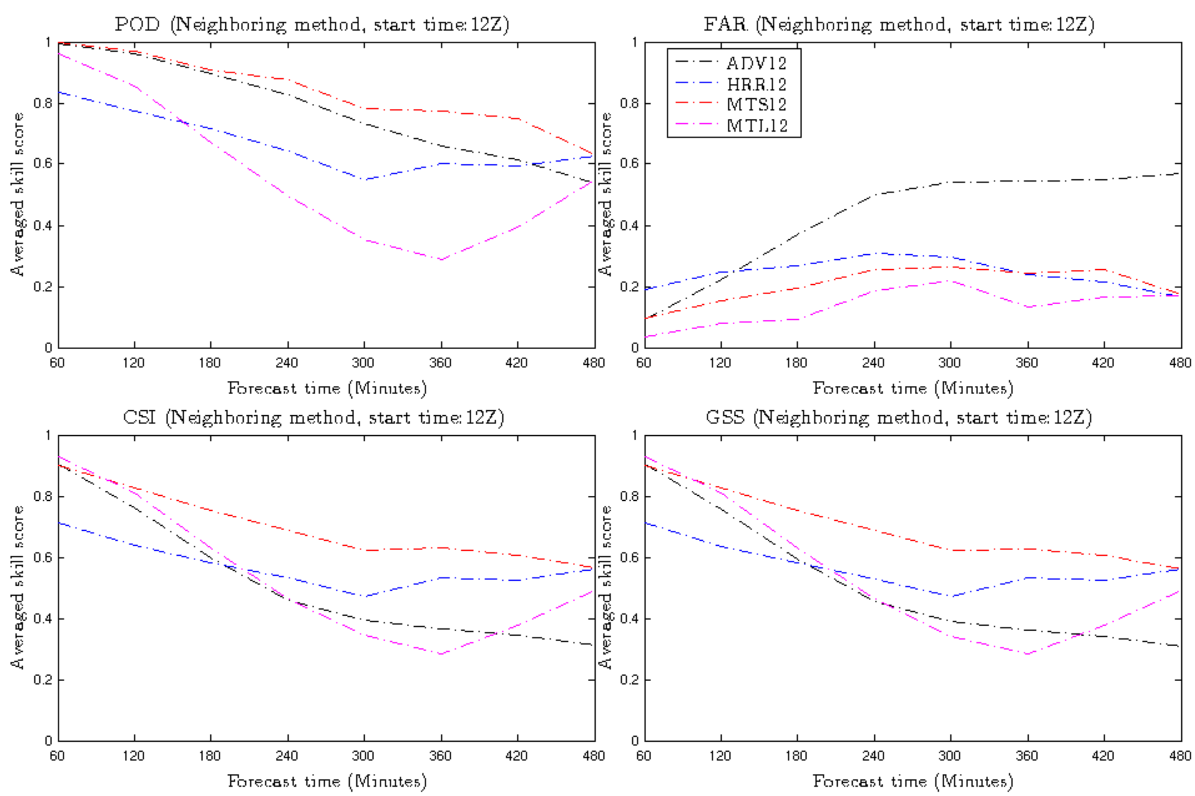


Left: Radar reflectivity data. Right: Radar reflectivity data with artifacts removed.

n. Improved Extrapolation Forecasts

Valliappa Lakshmanan, Yunsung Hwang, Adam Clark (all CIMMS at NSSL)

As numerical weather prediction models increase in skill and spatial and temporal resolution, it has become feasible to use them for short-term (0-8 hours) forecasts ("nowcasts"). However, extrapolation forecasts remain more skillful over the very short term (0-2 hours) and over the 2-8 hour time period, blending extrapolation and model forecasts provides improved skill over using only extrapolation or only numerical weather forecasts. An image processing method of morphing between extrapolation and model forecasts to create nowcasts was developed and the skill compared to extrapolation forecasts and forecasts from the High Resolution Rapid Refresh (HRRR) model. This algorithm improves nowcasting in the 0-8 hour time frame by applying image morphing to create imagery that is intermediate between that of plain extrapolation and the HRRR. These nowcasts are more skillful than either one. This algorithm is currently being tested, and a journal paper is being written.

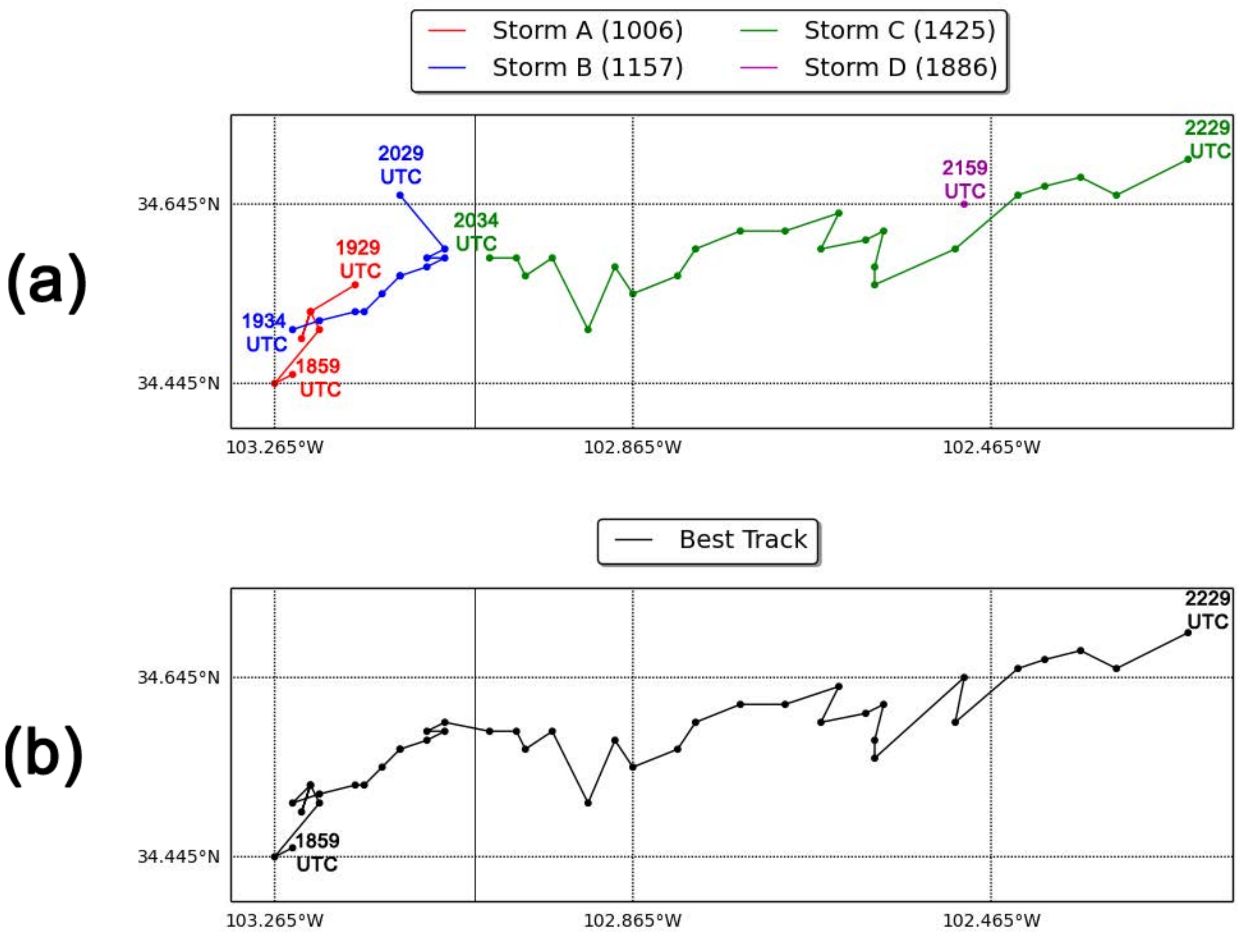


Morphing between an extrapolation forecast and a HRRR model forecast provides improved nowcasting skill. In the graphs above, the black line is advection, the blue HRRR, the pink line ("MTL") cross-fade image morphing (the usual approach) and the red line ("MTS") the image morphing approach developed at CIMMS.

o. Extracting Post-Event Storm Tracks

Valliappa Lakshmanan, Darrel Kingfield, and Benjamin Herzog (all CIMMS at NSSL)

Although existing storm tracking algorithms have been designed to operate in real-time, they are also commonly used to carry out post-event data analysis and research. Real-time algorithms cannot use information on the subsequent positions of a storm because it is not available at the time that associations between frames are carried out, but post-event analysis is not similarly constrained. Therefore, it should be possible to obtain better tracks for post-event analysis than what a real-time algorithm is capable of. A statistical procedure to determine storm tracks from a set of identified storm cells over time has been developed. We find that this procedure results in fewer, longer-lived tracks at all scales. This work is ongoing.

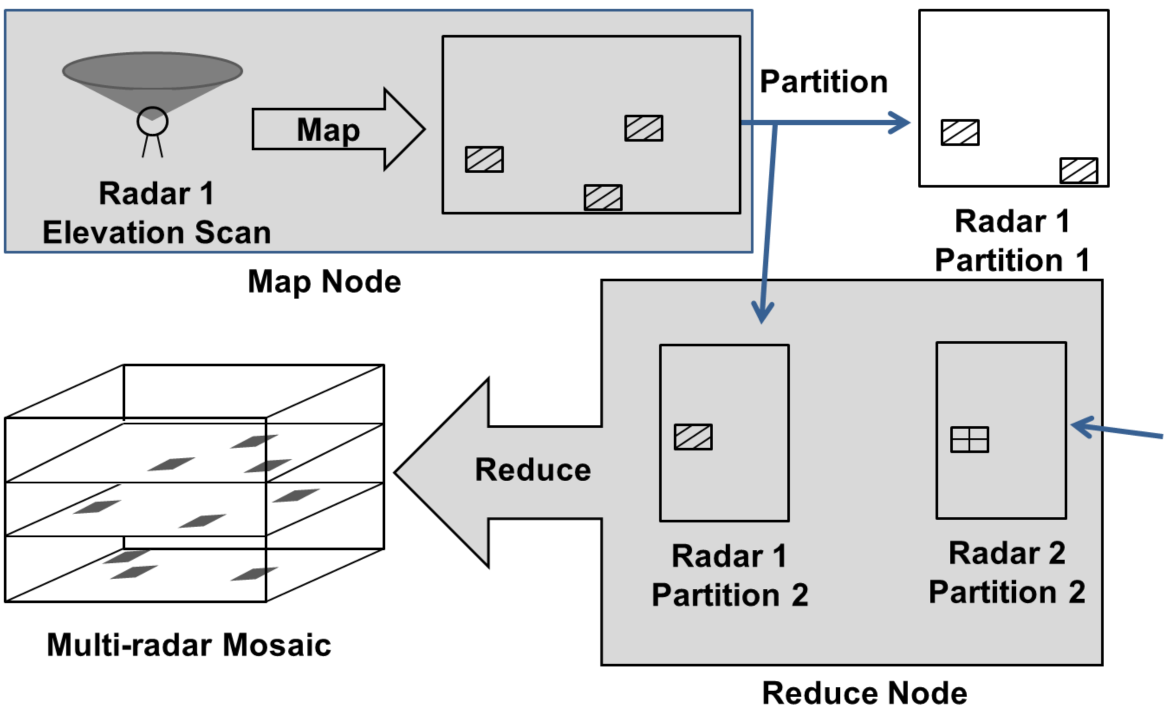


Spatiotemporal plot of storm centroids across object lifetime for the (a) w2segmotion real-time storm-tracking algorithm and (b) post-event track extraction algorithm. Note that the post-event storm track is unbroken.

p. MapReduce Mosaic Method

Valliappa Lakshmanan (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. A MapReduce approach to computing radar mosaics on a distributed cluster of compute nodes has been formulated. The approach is massively scalable, and is able to create high-resolution 3D radar mosaics over the Continental United States in real-time. This work is ongoing.



The MapReduce method of creating continental-scale radar mosaics.

q. Detailed Survey of the 20 May 2013 Moore, OK Tornado

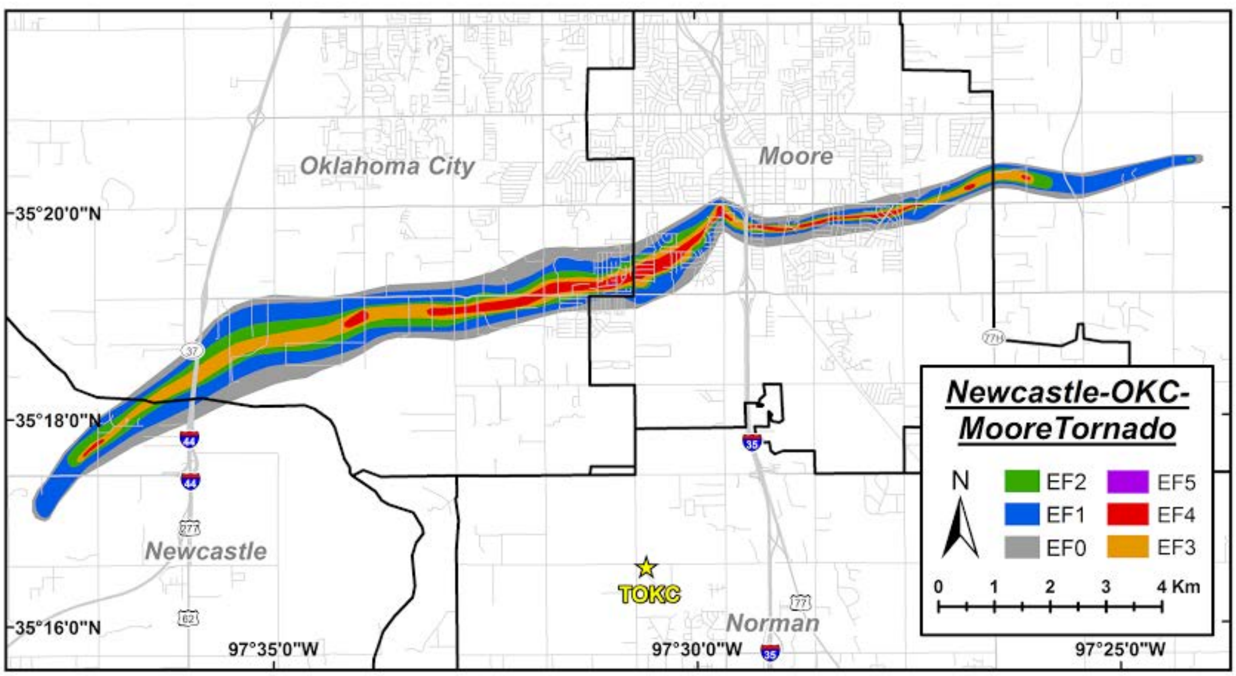
Don Burgess, Kiel Ortega, Chris Karstens, and Brandon Smith (all CIMMS at NSSL), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB in Norman, OK), Gabriel Garfield (CIMMS at OUN), and Tiffany Meyer (CIMMS at WDTB)

Utilizing ground and aerial surveys, a detailed damage survey was performed for the Moore tornado. Ground surveying began by CIMMS employees and partners on the morning of 21 May 2013 and continued for several days, using the Enhanced Fujita Scale (EF-Scale) to estimate damage magnitude at individual points. Aerial surveys

and additional ground surveys were used over ensuing weeks to fill in missing points and clear up points of confusion.

The tornado traveled 23 km and damage width was up to 1.7 km wide. In total, the survey documented 4,253 damaged structures, of which 4,222 were Damage Indicators within the EF-Scale. Of the total, approximately one-half of the structures were associated with EF0 damage (the weakest damage rating). Of the more seriously damaged structures (EF1 and greater), 38% were EF1, 24% were EF2, 21% were EF3, 17% were EF4, and only 0.4% were rated EF5 (the strongest damage rating). EF5 damage was limited to 9 residential homes. Other homes were completely destroyed, but were judged not well enough built to justify an EF5 damage rating. One destroyed school was initially rated EF5, but subsequent engineering analysis revealed construction flaws that reduced the rating to EF4. The percentages of damaged and destroyed structures are generally in line with recent violent tornado events (e.g. May 1999 Moore OK, Greensburg, KS, and Joplin, MO).

In completing the survey, the survey team established certain definitions (such as the definition of EF5 residential damage appropriate for Oklahoma construction practice), and listed recommendations for improvements to future surveys. The recommendations included improvements to the EF-Scale (addition of new Damage Indicators, and reduction in variability in rating practices), ways to organize and complete detailed damage surveys, and use of digital aids (such as the new NWS Damage Assessment Toolkit).



Path of the 20 May 2013 Moore tornado. EF-Scale areas are color-coded.

r. NOAA/NWS Radar Functional Requirements: Present through 2030

Don Burgess (CIMMS at NSSL)

Don Burgess served as a member of the Integrated Work Team that developed the NOAA/National Weather Service Radar Functional Requirements. The team met at 2-week intervals from July 2013 until June 2014, considering 1) NOAA/NWS current mission and strategic goals for the future; 2) evolving weather radar observational needs in warnings, forecasts, and numerical modeling; and 3) support to other government agency and private sector partners.

The document informs NOAA/NWS management on the substance and rationale for radar functional requirements, providing a basis for evaluating the role of radar improvements in meeting agency performance goals. The document also supports radar acquisition programs, including those of the NWS and the NWS engaged with the Federal Aviation Administration (FAA) in the FAA Next Generation Surveillance and Weather Radar Program.

The draft document is currently in NOAA review. It should be finalized within the next few months, and the final version will appear on a NWS web site.

s. Improving Data Quality of Polarimetric WSR-88D Radar

Valery Melnikov (CIMMS at NSSL)

Various calibration procedures for differential reflectivity Z_{DR} have been examined and their uncertainties have been quantified using measurements from three WSR-88D radars. The problem of overestimation of the cross-correlation coefficient ρ_{hv} by the operational WSR-88D radars was addressed and a methodology for its mitigation is suggested. The results of these studies are presented in three conference papers. A new parameter, the differential Doppler velocity, has been introduced to distinguish between weather and bird/insect echoes. The results are published in a journal article.

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. Refinement of the New Polarimetric QPE Algorithm Based on Specific Attenuation

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

The R(A) methodology has been modified via optimization of the net ratio of specific attenuation and specific differential phase along the propagation path using the estimate of Z_{DR} slope. An automatic routine for robust estimation of the Z_{DR} slope has been developed and tested for several WSR-88D radars and large number of rain events, which allowed us to glean an idea about the climatology of the Z_{DR} slope that characterizes rain type (more continental vs. more tropical). It was confirmed that on average the Z_{DR} slope is lower for the East Coast WSR-88D radars compared to the Great Plains radars as expected but within-the-storm variability greatly exceeds average climatological dependence.

Our study shows that the R(A) algorithm performs very well in terms of overall bias (R/G or radar / gauge ratio) with default value of the factor $\alpha = A/K_{DP}$ equal to 0.015 dB/deg in central part of the continent but tends to underestimate rain in the eastern part where rain regime is more tropical. Using adaptive factor α obtained from the Z_{DR} slope dZ_{DR}/dZ in rain dramatically improves the performance in the eastern US. The table below summarizes the results of the R(A) performance for nine notable flash flood events in the US using fixed and adaptable parameter α (number of R/G in parenthesis).

Another way to improve the performance of the R(A) algorithm is to optimize the factor α using comparison with attenuation measurements in rain via commercial cellphone communication links. The feasibility test has been conducted in Germany in collaboration with our German partners.

	Date	Storm	Radar	Duration, hr	$\alpha = A/K_{DP}$, dB/deg	Bias ratio R/G
1.	14 June 2010	OKC flash flood	KTLX	3	0.015	1.08
2.	20 May 2011	MCS in Oklahoma	KVNX	6	0.015	0.96
3.	26 – 28 August 2011	Hurricane Irene	KMHX	45	0.015 (adaptive)	0.53 (1.16)
4.	30 – 31 May 2012	Severe hailstorm	KICT	6	0.015	0.98
5.	30 June 2012	Duluth flash flood	KDLX	24	0.015	1.09
6.	28 – 29 October 2012	Hurricane Sandy	KDOX	24	0.015 (adaptive)	0.81 (0.95)
7.	4 -5 July 2013	Nashville flash flood	KOHX	12	0.015 (adaptive)	0.86 (1.01)
8.	11 – 12 September 2013	Boulder flash flood	KFTG	24	0.015 (adaptive)	0.43 (0.96)
9.	26 November 2013	Florida	KJAX	24	0.015 (adaptive)	0.47 (0.93)

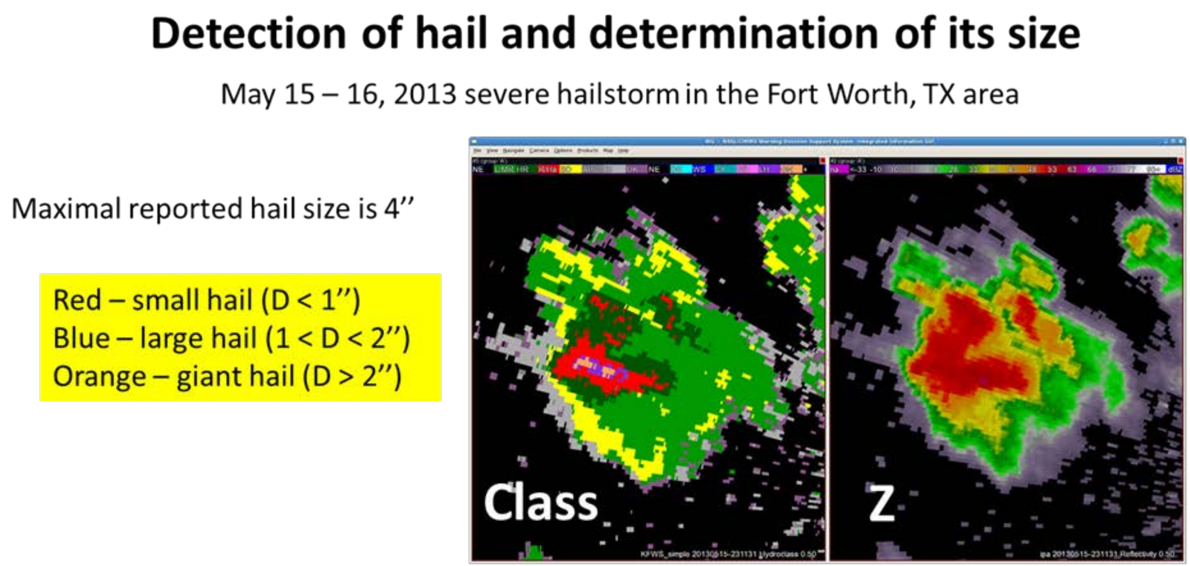
Performance of the R(A) algorithm implemented at WSR-88D radars for several flash flood events in the US. Numbers in parenthesis indicate the estimates with adaptive factor α.

b. Development of the Hail Size Detection Algorithm (HSDA) that Distinguishes Between Small, Large, and Giant Hail

Kiel Ortega, John Krause, Alexander Ryzhkov, and Pengfei Zhang (all CIMMS at NSSL)

Initial operational version of HSDA has been developed which distinguishes between small ($D < 2.5$ cm), large ($2.5 \text{ cm} < D < 5.0$ cm), and giant ($D > 5.0$ cm) hail. The HSDA

prototype was tested through the Severe Hazards Analysis and Verification Experiment (SHAVE) during warm seasons of 2013 and 2014. The HSDA membership functions have been tuned to obtain better match with the SHAVE verification results and certain conditions were imposed to mitigate possible contamination associated with differential attenuation and non-uniform beam filling. It is proven that Z steadily increases with hail size, whereas Z_{DR} and ρ_{hv} decrease with hail size. However, the value of Z_{DR} and ρ_{hv} diminishes at the heights approaching the freezing level. The radar reflectivity factor is a primary discriminator for hail size above the freezing level, although such additional signatures as bounded weak echo regions (BWER), Z_{DR} columns, and ρ_{hv} "holes" can also be very informative at higher levels. This work is ongoing.



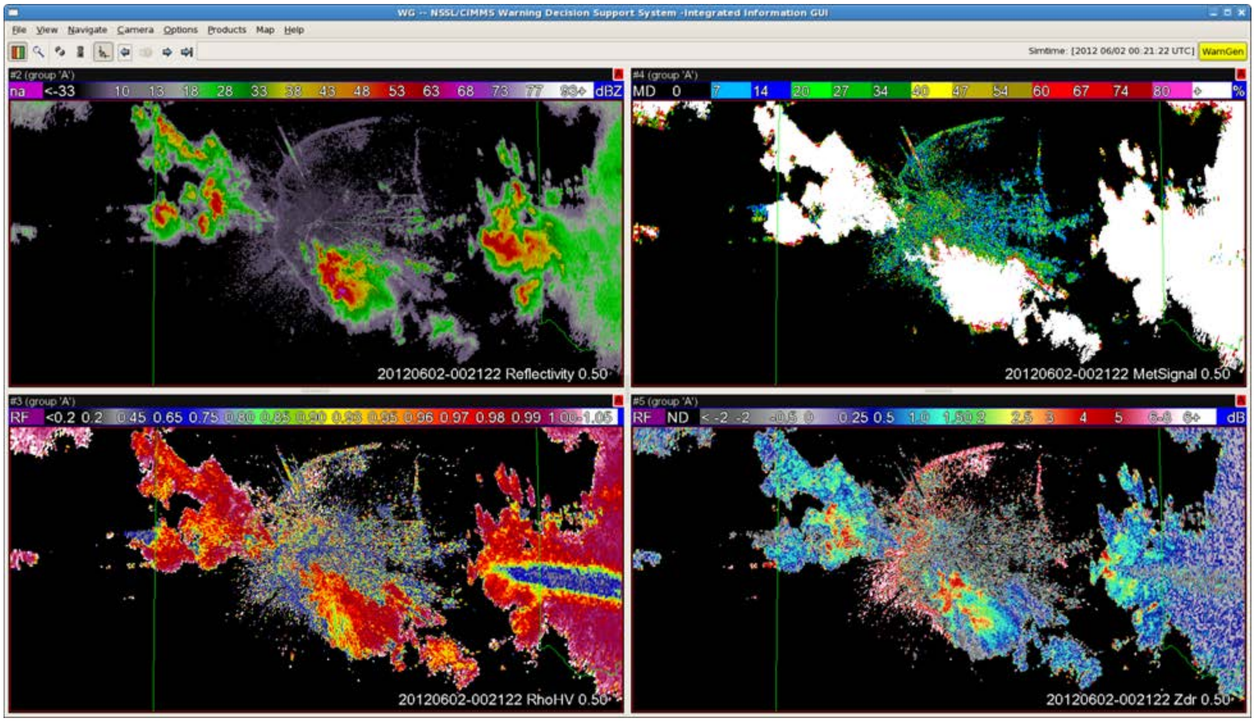
Example of HSDA classification along with the Z map for the case of giant hail.

c. Developing a Robust Algorithm for Discriminating Between Weather and Non-Weather Radar Echoes ("MetSignal" Algorithm)

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

Development of the MetSignal algorithm was completed in 2013. The project consisted of identifying the locations where meteorological signal was present and developing a fuzzy logic algorithm that identifies these regions. Using the information in recent CIMMS/NSSL works by Lakshmanan, the variables chosen for the fuzzy logic routine are radar reflectivity, Doppler velocity, cross-correlation coefficient, and the texture parameters of differential phase, differential reflectivity, and the cross-correlation coefficient. Applying a CAPPI of reflectivity as a check against missed detections in areas where non-uniform beam filling or highly variable melting layers is present further enhances the performance of the fuzzy logic routine. Results show that use of MetSignal improves the performance of the ORPG preprocessor in the computations of specific differential phase K_{DP} and in the identification of ground clutter for rainfall

estimation. A design approach review for the algorithm has been completed and development of the operation code is nearly complete.



Four views of data from the KAMA WSR-88D radar on 2 June 2012 during an outbreak of severe weather. Upper left: reflectivity showing strong storms and contamination from bugs, fine lines, wind farms and AP. Lower left: cross-correlation coefficient showing hail signatures and strong NBF in the right side of the frame. Upper right: Metsignal, white areas designate signal, non-white areas designate clutter and contamination. Note the performance in regions of NBF (right) and large hail (middle and left). Lower right: Differential reflectivity

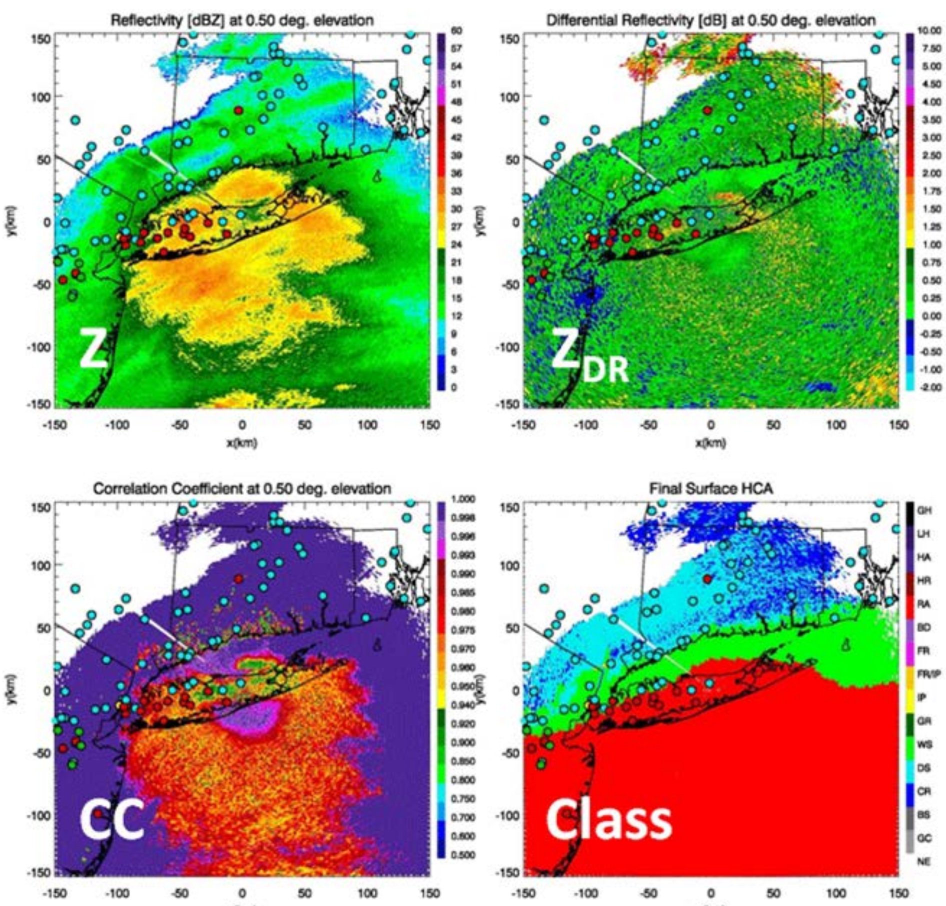
d. Recent Modifications to a New Surface-Based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network

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

A new, surface-based polarimetric Hydrometeor Classification Algorithm (HCA) that uses thermodynamic output from the High Resolution Rapid Refresh model has undergone continued development and testing. The 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 and rain, big drops, or hail for warm season events. For intermediate conditions typical of transitional winter weather events where the precipitation type is largely determined by microphysical processes that occur in shallow layers above the surface, however, the algorithm uses thermodynamic output

from numerical models to provide a background precipitation classification type that is then either accepted or rejected based on polarimetric radar observations.

In addition to continued work to improve both the model-based background classification and radar-based modification component of the algorithm, the algorithm's performance has been tested for several winter weather events through a comparison of algorithm results against surface observations of precipitation type collected by the Meteorological Phenomena Identification Near the Ground (mPING) project. An example of an evaluation of the algorithm performance for the historic 8-9 February 2013 Northeastern blizzard is shown below. The figure shows Z, Z_{DR}, and ρ_{hv} measured by the KOKX (New York City National Weather Service Office, located on Long Island at Upton, NY) WSR-88D radar and results from the new surface-based HCA at 1504 UTC on 8 February 2013. Precipitation type reports (overlaid on top of the Z, Z_{DR}, ρ_{hv} and surface-based HCA) at this time show good overall agreement with rain over much of Long Island and snow to the north. The project is ongoing.



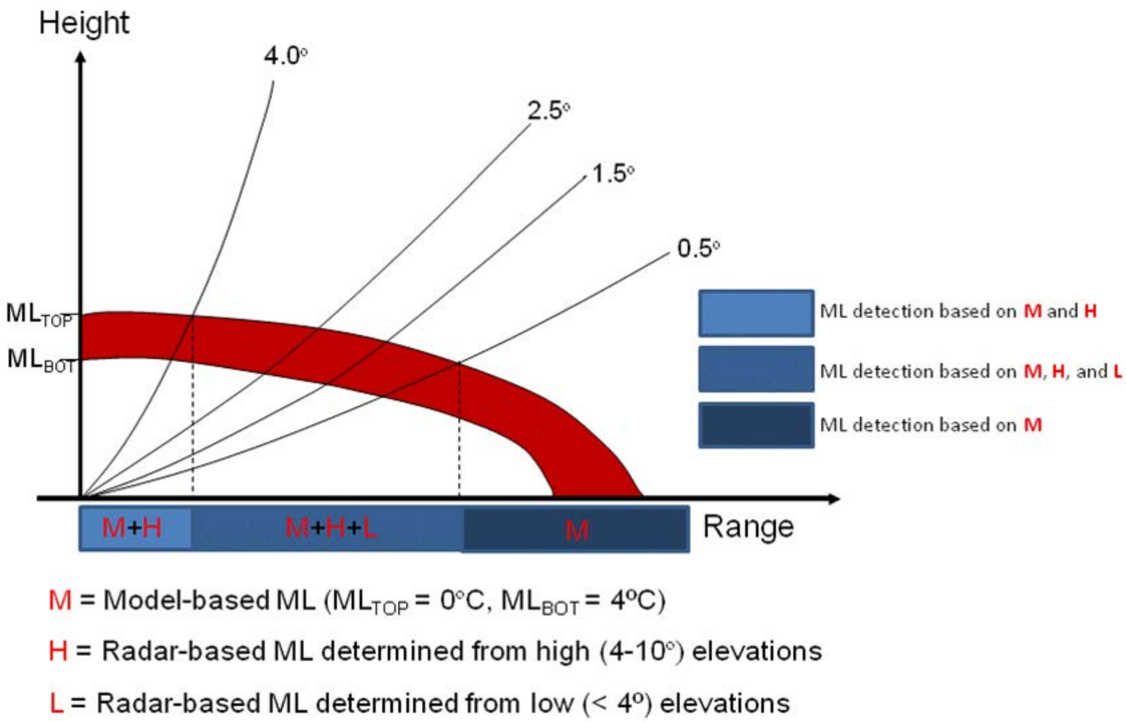
Radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (CC), and surface HCA for the KOKX (Upton, NY) radar at 1504 UTC on 8 February 2013. Overlaid mPING surface observations (shown by colored circles) follow the same color scheme as that of the surface HCA.

e. Development of a New Melting Layer Detection Algorithm that Combines Polarimetric Radar-Based Detection with Numerical Model Output

Terry Schuur, Alexander Ryzhkov, and John Krause (all CIMMS at NSSL)

The accurate detection of the presence/absence of an elevated warm layer is a fundamental requirement of the development of a surface-based Hydrometeor Classification Algorithm for transitional winter events. Polarimetric radar, through careful examination of radar reflectivity (Z), differential reflectivity (Z_{DR}), and correlation coefficient (r_{HV}) at high elevation scans (4-10º elevation) has been shown to provide accurate estimation of melting layer (ML) top and bottom at locations close to the radar, but the azimuthal projection of those heights to more distant locations have proven to be unrealistic for most meteorological situations. Similarly, while polarimetric variables at lower elevation angles (<4º elevation) can provide ML designations at more distant ranges; their interpretation is often complicated by the effects of beam broadening. These complicating factors point out a need for a ML detection method that can 1) be applied over the entire radar domain, and 2) also capitalize on additional information provided by thermodynamic output from numerical models, which are increasingly being used as part of the classification process.

In this project, a new ML detection algorithm that combines radar observations with thermodynamic output from the High Resolution Rapid Refresh (HRRR) model is developed in order to provide a hybrid ML designation over the entire radar domain. Radar-based, range-dependent Gaussian weighting functions for both high- and low-elevation ML designations, which take into account inherent errors known to each technique, are combined with a model-based Gaussian weighting function that depends on horizontal gradients in wet-bulb temperatures to create a “blended” map of ML detections. A separate, time-dependent weighting function is used to account for time lag in the model analyses by de-emphasizing the contribution from the numerical model as the Dt from the radar volume and the most recent model analysis becomes large. Aggregate values from the combined weighting functions are then compared to surface observations of known precipitation types to come up with a final ML product.

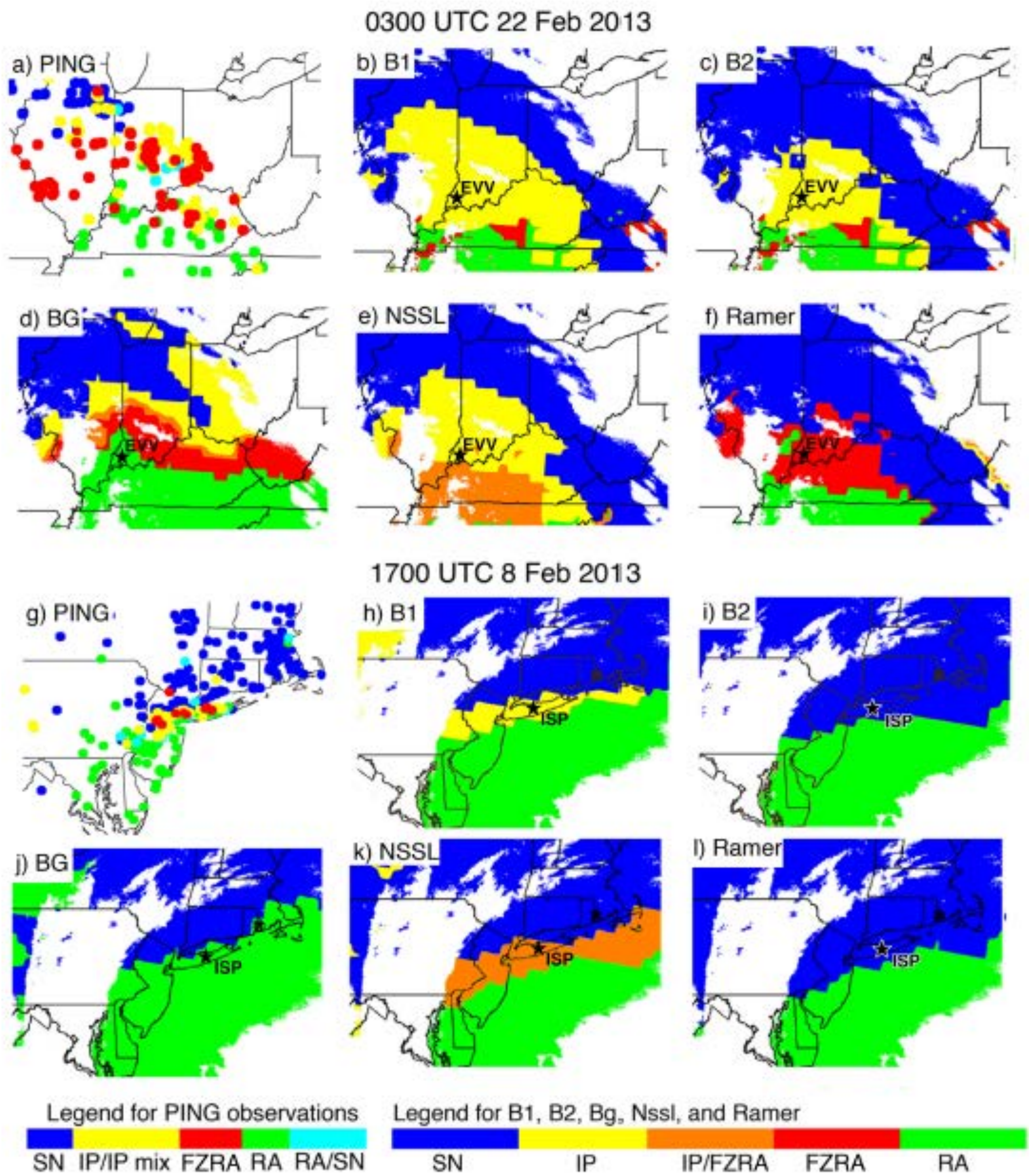


Schematic showing contributions, with range, of each method of ML detection to the overall hybrid product.

f. Sources of Uncertainty in Precipitation Type Forecasting

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

Five implicit precipitation type algorithms were assessed using observed and model-forecast sounding data in order to measure their accuracy and to gauge the effects of model uncertainty on algorithm performance. The effects of model uncertainty were also considered. All algorithms provided reliable guidance on snow and rain, but were much less effective for ice pellets and freezing rain. Deeper investigation shows that a five-category approach that isolates more horizontally uniform long-duration freezing rain and ice pellet events may yield improved results. This work is ongoing.



The (a,g) mPING observations for a 2-hour window surrounding the time indicated in each example and (b-f;h-l) the diagnosed precipitation type from each algorithm.

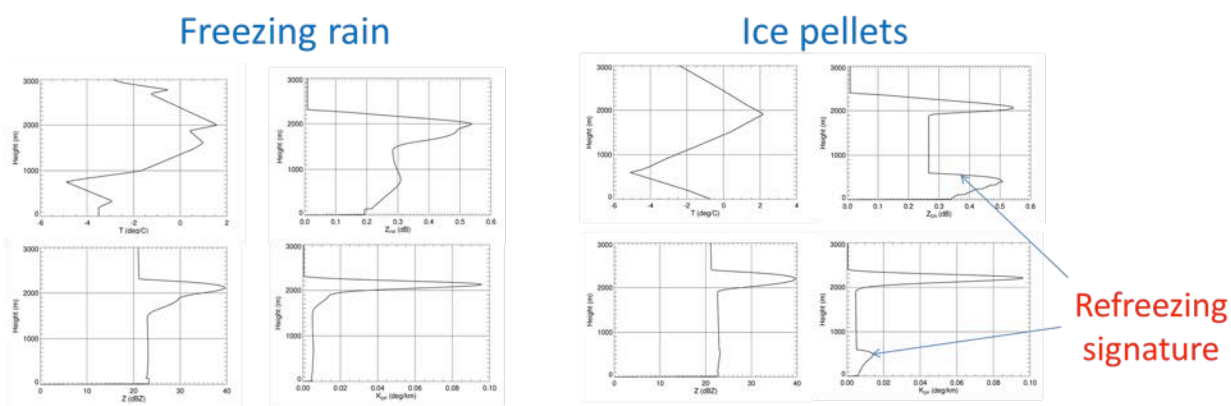
g. Discrimination Between Winter Precipitation Types Based on Explicit Microphysical Modeling of Melting and Refreezing in the Polarimetric Hydrometeor Classification Algorithm

Alexander Ryzhkov, Heather Reeves, John Krause, and Hoyt Burcham (all CIMMS at NSSL)

The winter weather Hydrometeor Classification Algorithm (HCA) recently developed at NSSL (Schuur et al. 2012) combines the polarimetric radar data with thermodynamic

output from numerical weather prediction models to enhance classification capabilities. The “background classifier” which is based on vertical profiles of temperature and humidity is essential part of HCA.

A principally new “background classifier” based on a 1D model of melting/refreezing with spectral microphysics has been developed and validated on a 10-year dataset of soundings and ASOS observations. The classifier distinguishes between rain, snow, freezing rain, and ice pellets. The new algorithm clearly outperforms the previous ones examined by Reeves et al. (2014). In addition to its classification capability, the method quantifies liquid and solid parts of precipitation rate at the surface. The suggested 1D model is capable to adequately reproduce the refreezing signature associated with the transition from freezing rain to ice pellets and marked by the increase of differential reflectivity Z_{DR}. This work is ongoing.



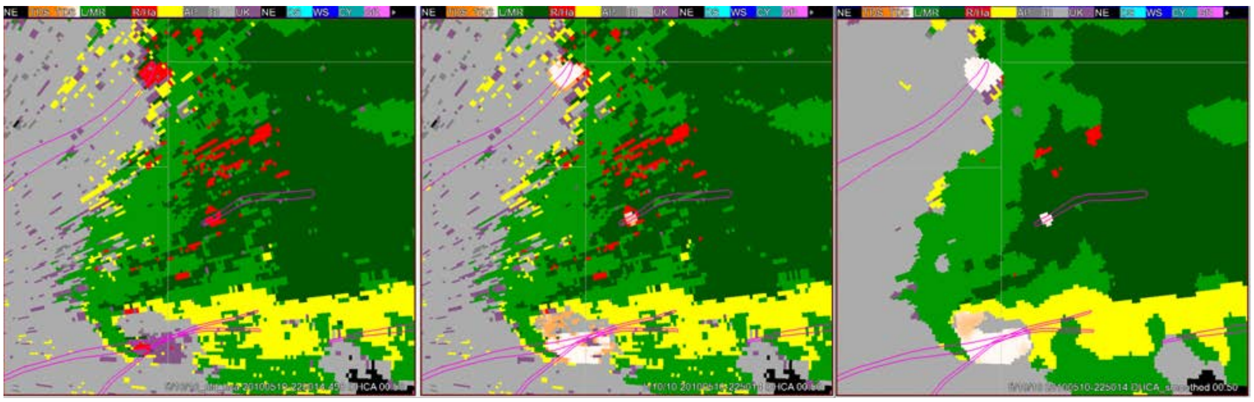
Vertical profiles of temperature and simulated radar variables in the cases of freezing rain and ice pellets.

h. An Automated Method for Polarimetric Tornado Debris Detection

Jeff Snyder (NRC Postdoc) and Alexander Ryzhkov (CIMMS at NSSL)

There are at least two ways by which a polarimetric tornado debris signature (PTDS) can be detected and displayed to the end user – in a detailed geospatial manner by modifying the existing hydrometeor classification algorithm (HCA) or in a more binary manner by denoting PTDS events by a single icon or marker (similar to the tornado vortex signature icon). At this time, the modification of the existing HCA for a PTDS category is seen as the best path forward since the PTDS can often readily detected in the raw radar data and knowingly continuing to allow for the misclassification of debris in the current HCA (most often as hail or “unknown”) is suboptimal. Preliminary membership functions for the PTDS classifier were established using TDS characteristics available in the literature, and the existing HCA as implemented in WDSSII was modified to include the new PTDS category. More than a dozen datasets have been analyzed by comparing the PTDS tracks from the modified HCA output with GIS-based tornado tracks and subjectively determined PTDS events. Refinements to the membership functions and other algorithm components are ongoing as additional

cases are tested. Particular attention is being given to measures that mitigate false positives (i.e., classifying PTDS events where one can be confident that a PTDS does not exist), which are currently occurring most frequently in areas of severe non-uniform beam filling and clutter-related reductions in the co-polar cross-correlation coefficient. Several strategies -- for example, increasing the aggregation value threshold to reject PTDS classification when radar parameters are not very closely matching the membership functions -- have resulted in a significant reduction in misclassification. This work is ongoing.



A comparison of the results from the (left) existing HCA, (center) modified HCA with TDS "uncertainty" ranging from orange (aggregation value of 0.8) to white (aggregation value of 1.0), and (right), modified HCA processed through a 5x5 neighborhood mode filter.

i. Using the Z_{DR} Column Product to Detect Convective Storm Development and Track Updraft Position

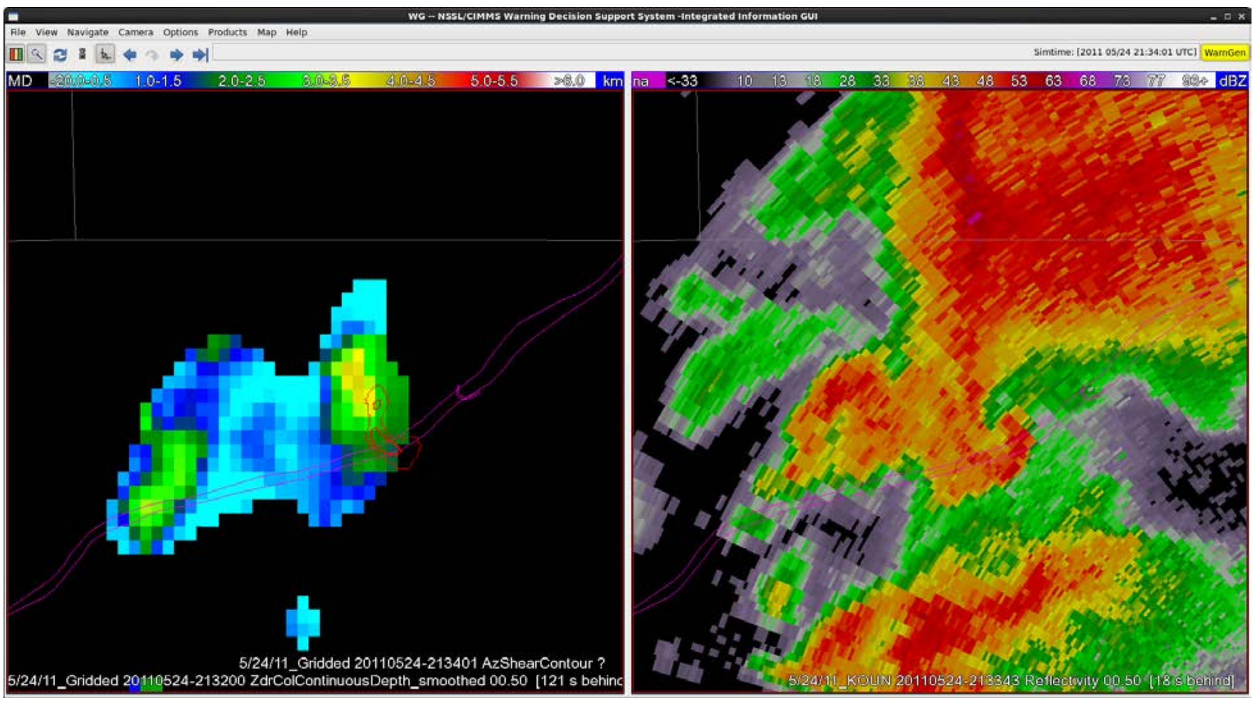
Jeff Snyder (NRC Postdoc) and Alexander Ryzhkov (CIMMS at NSSL)

Upward extensions of positive differential reflectivity (Z_{DR}) above the freezing level have been observed to occur within convective updrafts owing largely to the combined effects of an upward perturbation of the freezing level within the updraft (itself the result of latent heating) and the non-instantaneous nature of drop freezing. Additionally, as a result of differential sedimentation, enhanced Z_{DR} has been observed to occur under convective updrafts even where positive Z_{DR} may not extend much above the freezing level. High-resolution numerical simulations with a sophisticated spectral bin microphysics scheme corroborate such observations and provide strong evidence for the potential utility of these so-called "Z_{DR} Columns" as diagnostic and prognostic tools for monitoring the evolution of convective storm updrafts.

At this time, the Z_{DR} column algorithm detects the presence and assesses the intensity of Z_{DR} columns by measuring the total volume of Z_{DR} > 1 dB above the freezing level (where the freezing level is determined from near-real-time RAP analyses). Although there are several significant limitations imposed in the use of existing WSR-88D datasets (e.g., typically a lack of spatially-dense observations within 1-2 kilometers of

the freezing level owing to current volume scan strategies and the effects of beam spreading), the Z_{DR} column product has demonstrated some success in highlighting the initiation of convective storms and allowing one to examine the evolution of the updraft when compared with the use of radar reflectivity factor alone. The Z_{DR} column algorithm has been coded into WDSSII to allow for batch processing of additional datasets for future algorithm assessment. Modifications of the algorithm continue as we attempt to mitigate some of the data resolution and coverage issues present in the operational WSR88D data.

Theoretical modeling of Z_{DR} columns using the Hebrew University of Jerusalem cloud model indicates their sensitivity to the aerosol concentration so that taller Z_{DR} columns are associated with higher concentration of CCN. This work is ongoing.



Data from KOUN valid 2134 UTC on 24 May 2011 showing (left) Z_{DR} column depth above the freezing level (km) and (right) radar reflectivity factor at horizontal polarization (dBZ) on the 0.5 deg elevation angle. The red contours represent 0.005 and 0.010 s-1 azimuthal shear, and the magenta contours represent the tornado's path as determined by the Norman NWSFO.

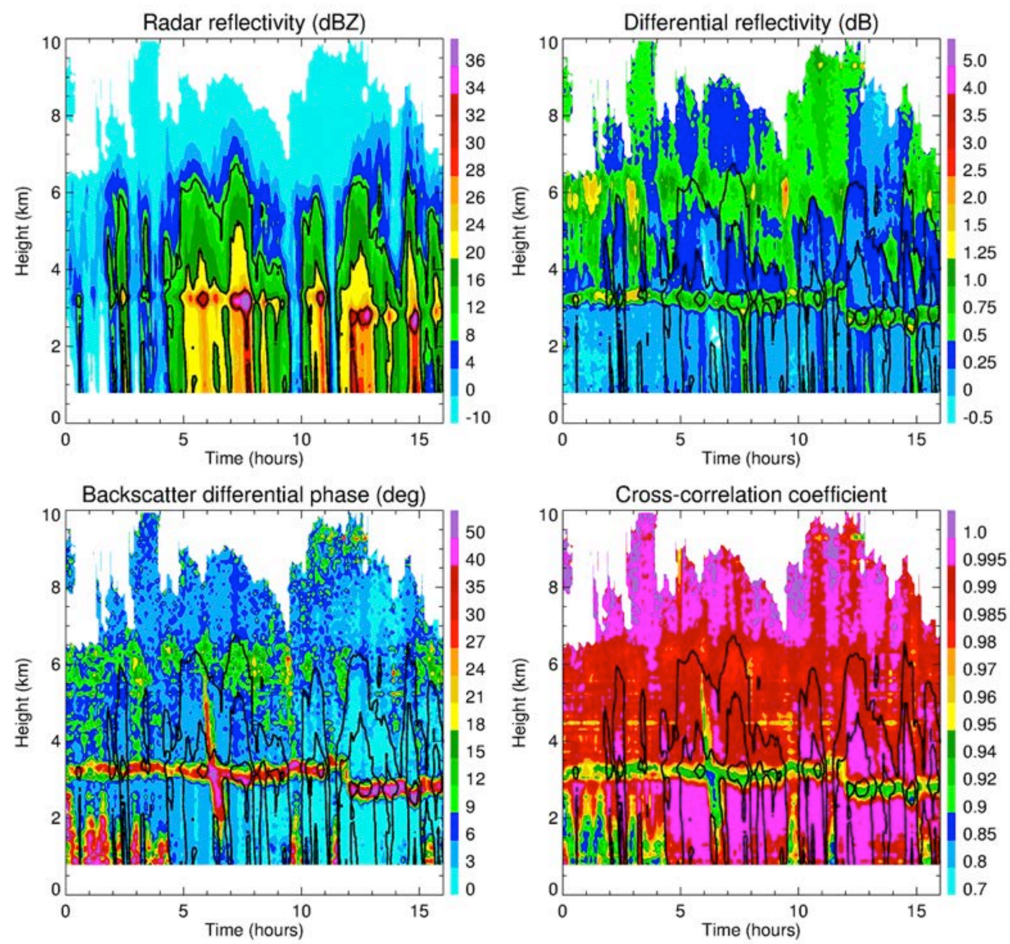
j. Introducing the Concept of Quasi-Vertical Profiles of Polarimetric Radar Variables for Analysis of Microphysical Processes in Clouds and Precipitation

Alexander Ryzhkov and Pengfei Zhang (both CIMMS at NSSL)

Operational weather radars scan the atmosphere in a sequence of PPIs at conical surfaces which are not conducive for capturing important features of vertical structure of clouds and precipitation because the vertical cross-sections retrieved from the series of

PPIs usually lack adequate vertical resolution. In order to alleviate such a deficiency, it is suggested to construct the so-called "quasi-vertical profiles" of polarimetric radar variables by azimuthal averaging of the radar data collected in a standard conical scan at sufficiently large antenna elevation angle (usually about 20°) which are represented in a time – height format. Using higher elevations ensures high vertical resolution of the radar data. Azimuthal averaging reduces statistical errors of the radar estimates. Such azimuthal averaging was first utilized to reduce the noisiness of differential phase within the melting layer to obtain reliable vertical profiles of the backscatter differential phase δ – an important polarimetric variable that was underutilized so far.

Using this technique, the data from ground-based weather surveillance polarimetric radars can be represented in a time-height format which is instrumental to examine temporal evolution of the vertical profiles and is fully compatible with a standard representation of the data collected with cloud radars, wind profilers, lidars, radiometers, and spaceborne active and passive sensors traditionally used for analysis of microphysical processes in clouds and precipitation. This work is ongoing.



Composite time – height plot of Z, Z_{DR}, δ, and ρ_{hv} for rain event on 12 December 2012 observed by the KTLX WSR-88D radar in North Carolina.

k. Microphysical Retrievals Using Polarimetric Radar Data

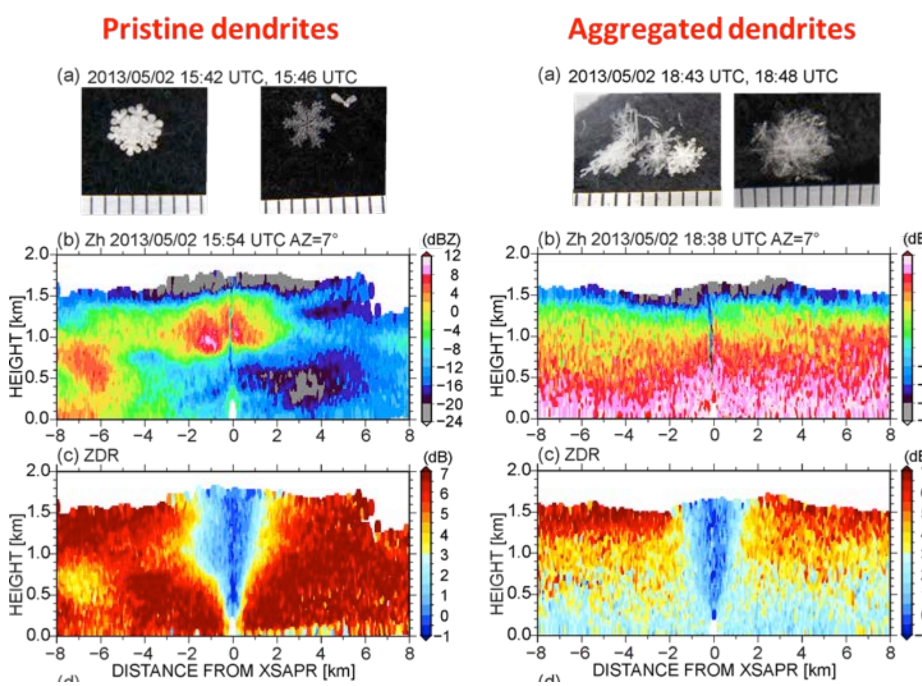
Jacob Carlin (OU School of Meteorology) and Alexander Ryzhkov (CIMMS at NSSL)

Novel methods for retrievals of the mixing ratios of rain and hail (q_r and q_h) have been developed from the polarimetric radar measurements as opposed to the traditional techniques based on the exclusive use of the radar reflectivity factor Z. It is shown that utilization of specific differential phase K_{DP} and specific attenuation A combined with Z and the results of polarimetric hydrometeor classification yields more accurate estimates of q_r and q_h, especially if rain is mixed with melting hail. Newly derived retrieval relations are potentially valuable for assimilation of polarimetric radar data into numerical weather prediction models. This work is ongoing.

l. Analysis of Polarimetric Radar Measurements in Polar Clouds

Alexander Ryzhkov (CIMMS at NSSL) and Partners at Pennsylvania State University

For the first time polarimetric radar observations of polar clouds at the North Slope of Alaska have been conducted with scanning X-band radar in partnership with the researchers at the Penn State. It is demonstrated that differential reflectivity Z_{DR} and cross-correlation coefficient ρ_{hv} provide important information about microphysical habits of hydrometeors in mixed-phase polar clouds. The processes of dendritic growth by vapor deposition, aggregation and riming of ice crystals can be well identified. The polarimetric measurements were complemented by Doppler velocity measurements from the vertically pointing Ka-band radar. This work is ongoing.



Examples of hemispheric vertical cross-sections of Z and Z_{DR} in polar cloud for pristine dendrites and dendrites undergoing aggregation as they fall to the surface.

m. Investigation of Microphysical Processes in Mixed-Phase Clouds Using Data Collected by Polarimetric Surveillance Radars, Cloud Radars, Wind Profilers, and Aircraft Probes During the MC3E Field Campaign

Subhashree Mishra, Pengfei Zhang, and Alexander Ryzhkov (all CIMMS at NSSL)

Comprehensive analysis of two prominent storms observed during the MC3E campaign on April 27, 2011 and May 20, 2011 has been performed using the data collected with S-band and C-band polarimetric radars, 915 MHz ARM wind profiler, 35 GHz vertically looking Doppler radar, and in situ aircraft probes. The focus of the study was to explore the impact of riming and aggregation of ice particles on various radar signatures in the melting layer and aloft. It is demonstrated that weak riming tends to increase differential reflectivity Z_{DR} above the freezing level due ice multiplication, whereas heavy riming producing larger amounts of graupel is associated with the decrease of Z_{DR} above the freezing level and downward shift of the melting layer clearly recognized in the fields of Z_{DR}, ρ_{hv}, and backscatter differential phase δ.

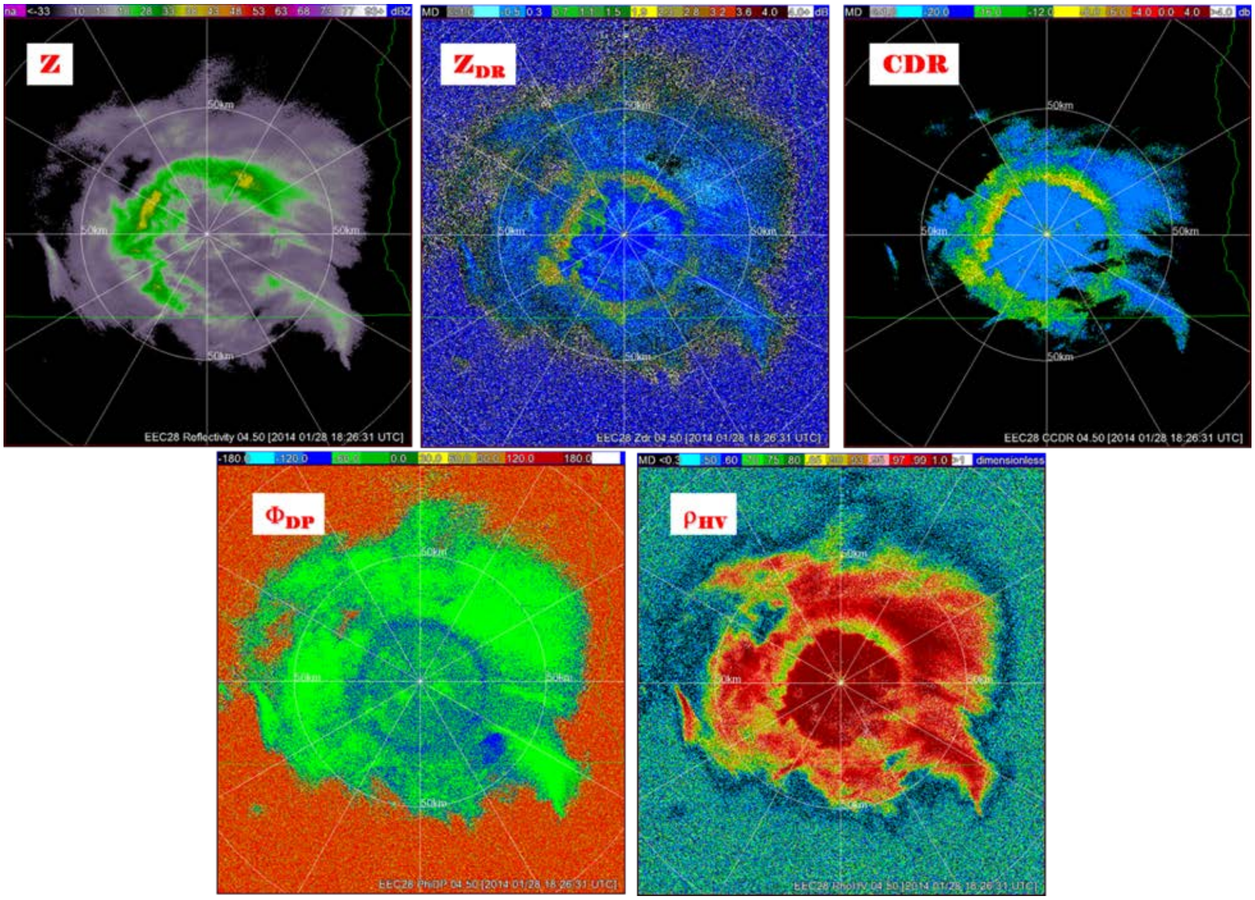
n. Measurements of Circular Depolarization Ratio (CDR) with the Radar with Simultaneous Transmission/Reception

Alexander Ryzhkov, Valery Melnikov, and Pengfei Zhang (all CIMMS at NSSL)

Circular depolarization ratio (CDR) is a polarimetric variable which was historically among the first measured by dual-polarization weather radars transmitting and receiving waves with circular polarization. One of its advantages is that it is primarily determined by the shape and phase composition of atmospheric particles and weakly depends on particle orientation. CDR can be effectively used for determination of hail size above the freezing level, discrimination between various ice habits, and quantification of the effects of riming.

One of the drawbacks of the “classical” CDR is that it is heavily biased by propagation effects and differential phase in particular which precluded its operational utilization so far. This was one of the reasons why the choice of operational polarimetric radar was made in favor of the radar with simultaneous transmission / reception which measures differential reflectivity Z_{DR}, differential phase Φ_{DP}, cross-correlation coefficient ρ_{hv} but not CDR.

We suggest the method which allows measuring CDR by the radar with simultaneous transmission/reception along with traditionally measured Z_{DR}, Φ_{DP}, and ρ_{hv} without slowing down or compromising the standard mode of operation. Moreover, the method automatically eliminates the impact of propagation effects on CDR at the signal processor level. This work is ongoing.



Composite PPI of Z, Z_{DR}, CDR, Φ_{DP}, and ρ_{hv} at El = 4.5° simultaneously measured by C-band radar at Enterprise, AL on 28 January 2014.

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 in a multifunction environment. The NWRT PAR test bed in Norman, OK 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). Other 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 and adaptive scanning techniques, beamforming techniques, and advanced digital signal processing techniques.

Accomplishments

a. NWRT PAR Software Upgrades (MPARSUP)

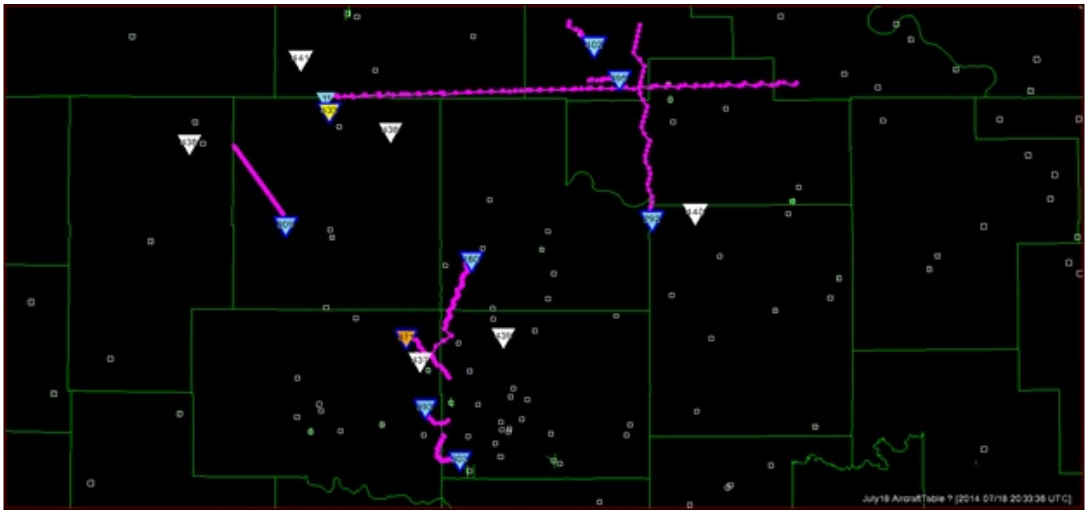
Sebastian Torres, Richard Adams, Christopher Curtis, Eddie Forren, Doug Forsyth, Igor Ivić, David Priegnitz, John Thompson, and David Warde (all CIMMS at NSSL), and Pam Heinselman and Michael Jain (both NSSL)

The goal of this project is to use the National Weather Radar Testbed Phased-Array Radar (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 FY14, 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. This work, reported below, is ongoing.

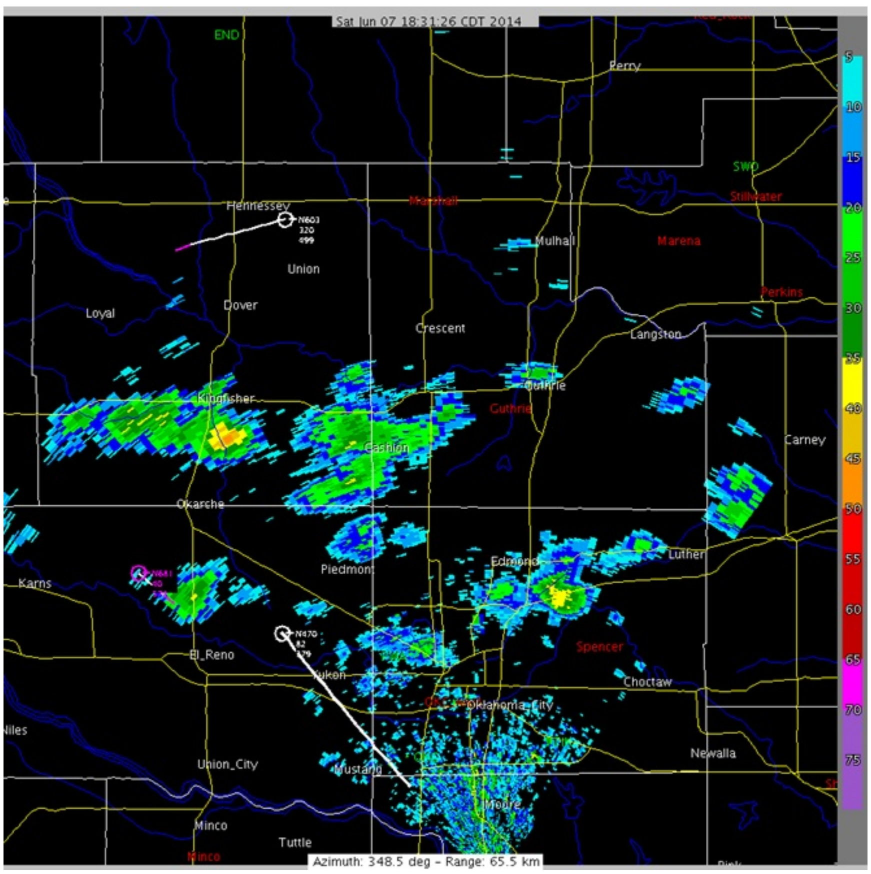
Multifunction (Priegnitz and Forren)*:* The offline MATLAB implementation of aircraft tracking was implemented in real-time on the NWRT environmental processor subsystem to demonstrate multifunction capabilities. Real-time radial data rates for aircraft tracking that were 10 times faster than weather data rates, which introduced some challenges for the real-time infrastructure that were overcome to complete the task. While the MATLAB implementation took at least 180 seconds to process a scan volume, the real-time implementation needed to process a volume approximately every 4.8 seconds. This required disabling some digital signal processing filters, optimization of some parts of the self-descriptive C product builder, vectorization of some functions using the Intel Processing Primitives, some other optimizations identified by the profiler, and threading of the signal processing preprocessor. Threading required additional modifications to the self-descriptive C product builder to make it thread-safe. The faster data rates also caused problems with inconsistent network data transfer speeds between application tasks running on different processing nodes. The result was that the preprocessor would fall behind because of sometimes-slow network data transfers. The solution was to isolate the preprocessor and the aircraft tracking algorithm from direct network transfers, but this caused some problems with the real-time I/Q data ingest which were eliminated by adjusting memory consumption and message queue sizes. This required some experimentation because ingest problems required less memory consumption/smaller queues and data transfer problems required more memory consumption/larger queues. Previously implemented conversion tools that automatically convert any self-descriptive C product into a MATLAB product made validation of real-time results against offline results easier. But, the lack of consistency of interfaces between the MATLAB implementation's interfaces and existing real-time interfaces caused some additional MATLAB conversion code to be needed for validating results. It should be noted that NWRT transmitter overheating problems slowed down development significantly. A brief description of the aircraft scan and its implementation can be found in the previous report. Some modifications to the aircraft

scan were made in order to resolve downstream processing problems. The main modification was to increase the pulse repetition time (PRT) and reduce the number of elevation angles in the scanning strategy. In addition, the efficiency of the main scan-processing loop was improved by eliminating idle time between scans. A number of modifications were made to the radar control interface (RCI) server and client to control aviation scanning. In addition, additional overlay options were added to the moment display window to support the display and capture of both aircraft tracks and weather data.

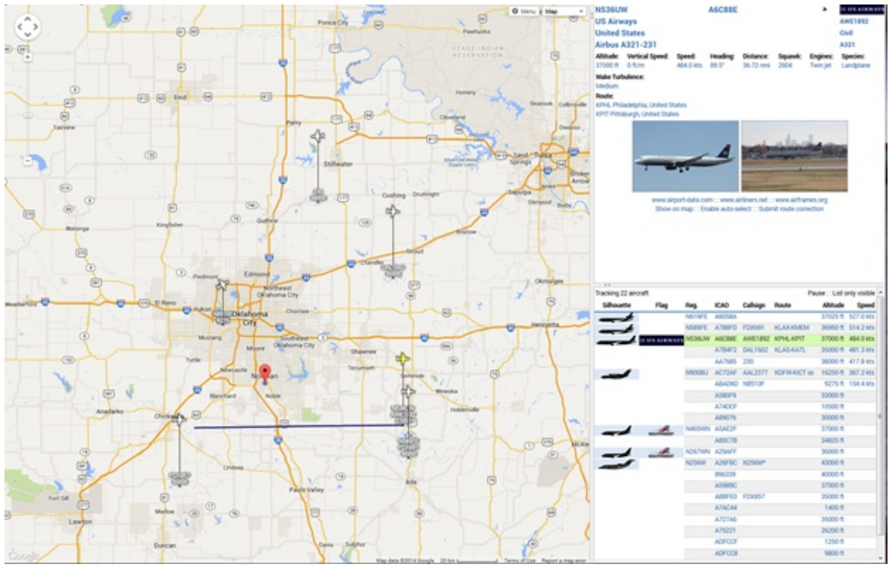
Aviation Function (Forsyth and Ivić): An aircraft detection & tracking algorithm was implemented on the NWRT PAR in real-time in order to show the multi-functional capabilities of a PAR system (see 2013 Annual Report). The aviation function was refined to improve correlations between aircraft targets and thus improve their tracking. In addition, the MATLAB code was run against a common data set to ensure the real-time implementation matched the original MATLAB code. MATLAB code was updated to provide for continuous tracking using more than one I/Q archive file (first figure below). During initial testing of the aviation function, it was established that the presence of weather signals (even weak ones) posed a serious issue. Left untreated, weather echoes undesirably trigger a large number of false aircraft detections, which overwhelm the tracker as it is incapable of handling a large number of detections. Since the goal was to demonstrate the aircraft detection & tracking in the presence of weather, solving this issue was critical. The problem was further exacerbated by the fact that the NWRT was not equipped with circular polarization that suppresses weather echoes and is routinely used on Airfield Surveillance Radars (ASR-9 and ASR-11). Consequently, in FY14 the weather detection capability was added to the aircraft detection algorithm in order to recognize regions where weather was present and adjust the moving target detection accordingly. This vastly decreased the spurious detections due to weather echoes and made aircraft tracking possible in the presence of weather. The system has been tested in real-time and the second figure below shows examples of weather and aircraft data collected in the same timeframe. In order to verify the tracks in real time, an Automatic Dependent Surveillance-Broadcast (ADS-B) downlink system was built. The system hardware is a Software Defined Radio (SDR) connected to a Universal Serial Bus (USB) port and a collinear antenna system. The system uses RTL1090 (started by using ADSB#, but tracks were delayed about 20-30 sec) to process and decode the ADS-B data and Virtual Radar Server (VRS) software to display the aircraft tracks. The system was installed on the roof of the National Weather Center. Real-time tracks are distributed over the Internet (172.16.26.254/VirtualRadar/) (third figure below) for comparison with the NWRT aircraft tracks. NWRT aircraft tracks are also compared to a web-based system called FlightRadar24.



Post Processing tracks from multiple I/Q files on July 18, 2014. Triangles are aircraft location and denote track status.

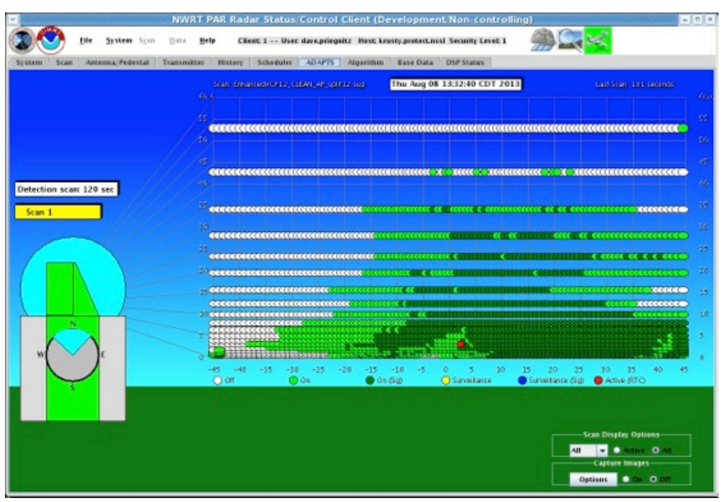


0.5° PPI reflectivity display from June 7, 2014 with aircraft tracks overlaid. Circles represent the current aircraft position. Lines emanating from the circles connect previous positions.



Display output from real-time ADS-B tracking system. X below Aircraft symbol denotes current location of aircraft beaconing ADS-B data.

<u>*ADAPTS*</u> (Priegnitz and Thompson): Improvements were made to the Adaptive Digital Signal Processing Algorithm for PAR Timely Scans (ADAPTS) to account for storm motion between detection scans. Prior to this change, two adjacent beams were activated on either side of a beam considered significant (containing weather). This resulted in "clipping" beams on the downstream side of storms moving across the array face; especially those located close to the radar. The overall effect of this modification is to improve tracking when storms are located near the radar (more than two neighborhood beams needed) and provide maximum time savings when storms are located far from the radar (one neighborhood beam needed instead of two).



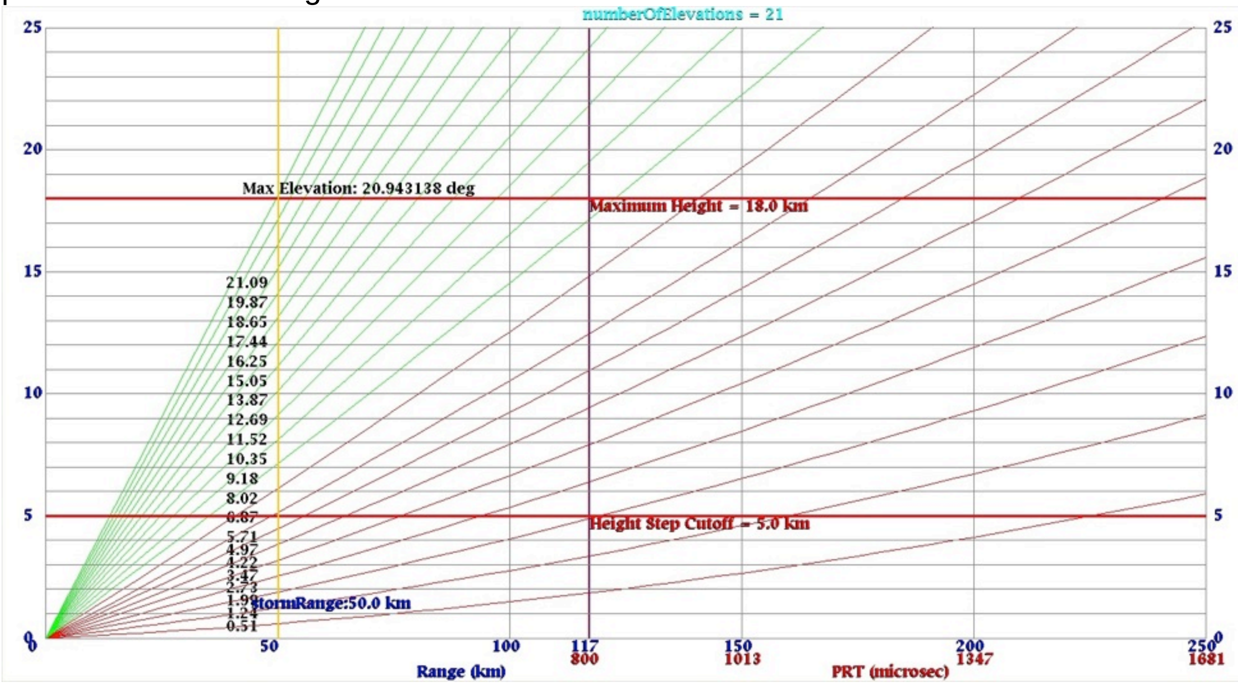
ADAPTS beam map with storm close to the radar. White circles are inactive beams (not containing weather); dark green beams are active (containing weather); light green beam are active (turned on by neighborhood rule); red beam represents current weather scan position.

Adaptive Scheduling (Priegnitz): An adaptive scheduling function was added to the radar control interface (RCI) client/server, allowing an operator to select a storm sector for focused scanning. The storm sector is defined based on the output from the cluster identification algorithm. When the storm is identified, a storm scanning strategy is created and inserted into the scan table at the first open position and sent to the Real Time Controller (RTC). When the storm scanning strategy is to be executed, it is first converted into a set of stimulus commands before execution. The storm scanning strategy is repeated until a user specified amount of time has elapsed. At that time the next scanning strategy in the scan table is executed. If no more scanning strategies follow the storm scanning strategy in the scan table, scanning reverts to the first scanning strategy in the scan table. If ADAPTS is active, the detection scanning strategy is executed before the start of a new scanning strategy after the detection timer expires. By default, the detection timer is set to 2 minutes. If the aviation function is active, the aviation scanning strategy will interrupt any active weather scanning strategy before a new pulse group is started.

Adaptive PRT Algorithm (Priegnitz and Thompson)*:* A new algorithm was developed that utilizes the maximum echo range information from the detection scan to change the pulse repetition time (PRT) dynamically in active scanning strategies. PRTs defined in typical scanning strategies are based on the unambiguous range for a given elevation angle at an expected maximum storm height. When weather is located closer to the radar, a shorter PRT can be used when there is no threat of contamination from more distant echoes. By preserving the dwell time, more pulses can be used, improving the quality of the radar data. The output from ADAPTS was modified to include a coded maximum echo range for each beam. This information is sent directly to the Real Time Controller (RTC) where the PRT for a maximum echo range is calculated (a new pulse count is also determined to preserve the original dwell time). The algorithm has two options: modify the PRT beam-by-beam, or modify the PRT by elevation cut using the maximum echo range from all beams in the cut. Only the latter option has been tested and demonstrated so far.

Adaptive Vertical Sampling Algorithm (Priegnitz)*:* Scanning strategies contain fixed sets of elevation angles to scan the vertical structure of weather. The exact height of a beam and its vertical separation from other beams is range dependent. When scanning storms, a given scanning strategy may be adequate to sample a storm at one range but not at another. Typically, using standard strategies, storms are undersampled at higher heights when they are located close to the radar. A new adaptive vertical-sampling algorithm has been developed to complement the existing storm identification, tracking, and scheduling function at the NWRT PAR. When a storm is selected for focused scanning by the operator, the algorithm creates a storm scanning strategy using storm location information generated by the cluster identification algorithm. This strategy contains a set of elevation angles that vertically samples the storm at intervals of 0.5 – 1 km, starting at the height corresponding to the lowest elevation angle (0.5 deg) and ending at a maximum storm height. If ADAPTS is active, the maximum storm height is determined from the detection scan, otherwise it is set to an operator-defined value. A

limited data set was collected in April and is currently being used to evaluate the performance of the algorithm.

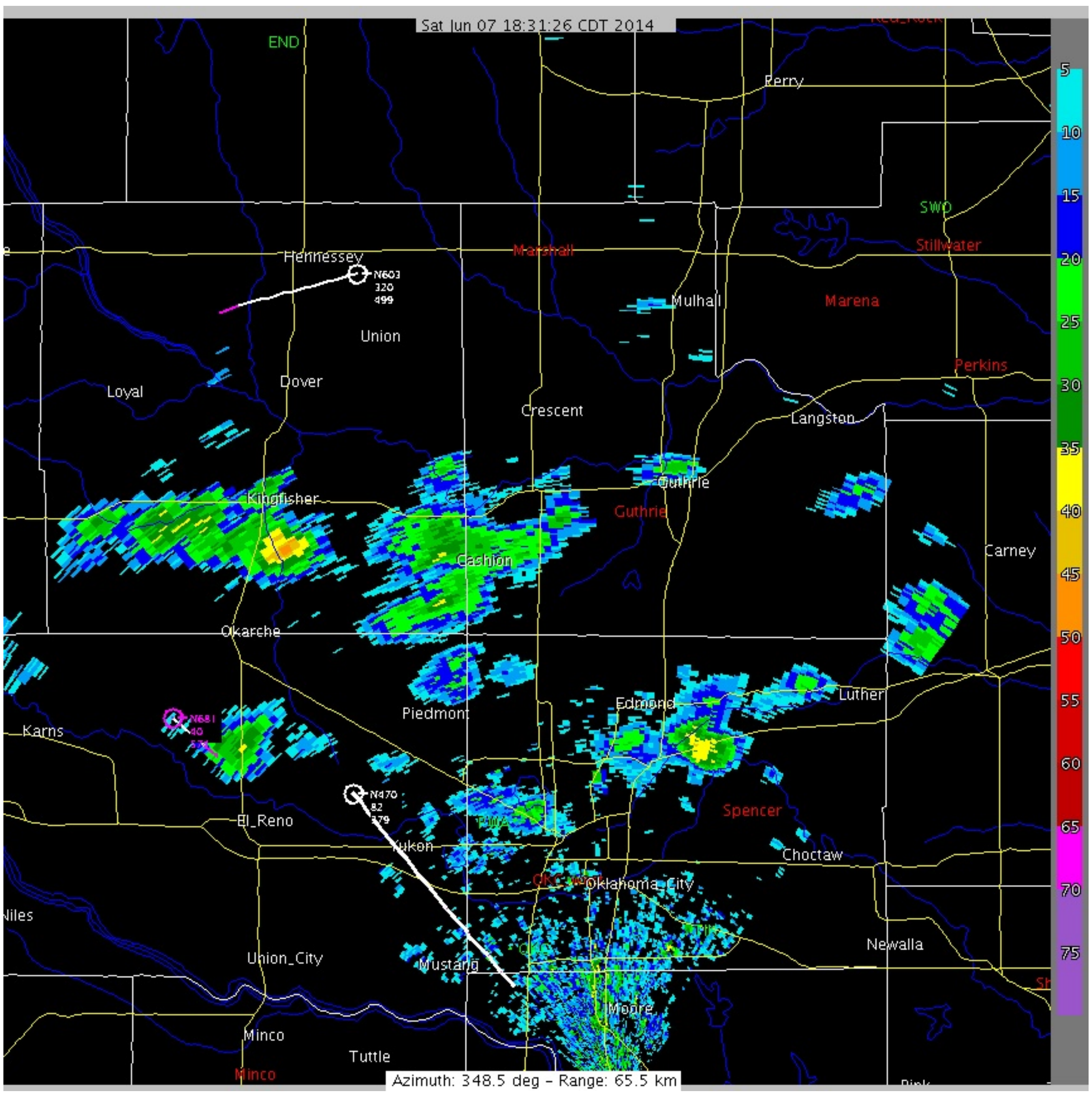


Graphical display of elevation angles defined by the adaptive vertical sampling algorithm for a storm located 50 km from the radar.

Signal Processing (Warde, Curtis, Ivić, and Torres): The NWRT DSP software provides a framework 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 at CIMMS 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 were demonstrated using the NWRT DSP have migrated into or are schedule for future DSP upgrades of the NEXRAD network (e.g., coherency-based thresholding, radial-by-radial noise estimation, CLEAN-AP, staggered PRT, and range oversampling). In FY13, the NWRT DSP was upgraded to include processing for either single- or dual-polarization systems. In FY14, we improved on the range folding algorithm and added an adaptive range correlation estimation routine to improve the performance of range-oversampling techniques. Evolution of ADAPTS has provided a few design challenges. In creating a completely autonomous detection mode in ADAPTS, flexibility in scheduling multiple scanning strategies are realized. However, to achieve a fast coverage of a large volume of space, short dwell times are needed. This in turn required design considerations to mitigate ground clutter. Creation of a new ground clutter filter that operates on small dwell times ultimately led to a decision to risk the loss of narrow-spectrum weather signals along the zero-isodop in the detection process. The risk was somewhat mitigated by existing neighborhood rules in the ADAPTS algorithm. The eventual goal of the upgrade was to achieve fast adaptive weather scanning thereby providing meteorologists with faster

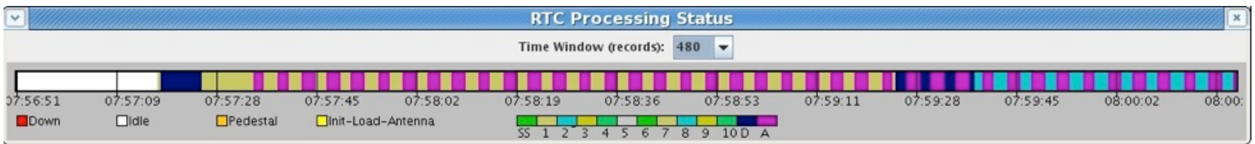
updates. A successful demonstration was realized when it was shown that the newly designed detection scan allowed observation of isolated storm initiation while maintaining fast update rates on mature storms.

__User Interface__ (Priegnitz): The Radar Control Interface (RCI) is being continually updated to support new functions and capabilities. During the reported period, a number of modifications were made to both the RCI server and client to support new capabilities. These include: ADAPTS control, aircraft tracking control and display, adaptive scheduling control (including adaptive vertical-sampling scan creation and display), range adjusted PRT control and display, improved scan status, and improved fault status display.



0.5° PPI reflectivity display from June 7, 2014 with aircraft tracks overlaid. Circles represent the current aircraft position.

Real Time Controller (Priegnitz): 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. Additional work was done to support the demonstration of simultaneous weather and aviation functions. The aviation scan was modified slightly to accommodate downstream processing limitations. In addition, the main scan processing loop was made more efficient to minimize idle time during active scanning. Modifications were made in the weather portion of the scan processing loop to decode maximum echo range information contained in ADAPTS status messages to support the new range adjusted PRT algorithm. Other maintenance related modifications were made to support troubleshooting transmitter issues.



Four-minute time slice of RTC scan activity during active weather and aircraft track scanning. The white region indicates idle time prior to scan initiation. The dark blue regions indicate time occupied by the weather detection scan; tan regions indicate time occupied by the weather enhanced VCP12; magenta regions indicate time occupied by the aviation scan; cyan regions indicate times occupied by the storm scan. NOTE: aircraft scanning was activated during enhanced VCP12 scan.

Software Infrastructure and Real-Time Signal Processor (Forren and Thompson): Data quality was improved by implementing a function to dynamically compute the correlation of range oversampled signals in real-time. This included feeding the correlation values from one volume into the data stream for the next volume so that eigenvectors needed for whitening of oversampled signals could be adjusted appropriately based on the latest correlation values. Support for automatic PRT selection and adjustable horizontal masking based on range was added to the infrastructure. This included having the DSP compute shortest significant range information for a radial and passing it to ADAPTS. ADAPTS then adjusts the width of its horizontal masking based on this range and determines the longest significant range for a radial. The width of the horizontal masking increases as range decreases. The longest significant range information is then passed along with the ADAPTS significant flag for each radial to the real time controller (RTC), which automatically determines the PRT based on the longest significant range for a radial. Fast detection scans were added, and ADAPTS was modified to apply significance from those scans to each independent weather scan based on closest elevation/azimuth match.

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.

b. NWRT PAR Operations

David Priegnitz and Richard Adams (both CIMMS at NSSL), and Allen Zahrai and Pam Heinselman (both 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 following table lists the formal data collection activities that were supported during the reported period along with the initials of the primary operator(s) (DP: David Priegnitz, PH: Pam Heinselman). Due to hardware issues and lack of active weather during the spring of 2014, the number of formal data collections was significantly reduced from the previous year. This work is ongoing.

Date	Operator(s)	Experiment	Event
04-13-14	DP & PH	PARISE	Multicellular convection
04-27-14	DP	PARISE	Ordinary convection
06-06-14	DP	PARISE	Early morning squall line
06-12-14	DP	PARISE	Hail/Wind

c. NWRT PAR Radar Data Management

Richard Adams and Dan Suppes (both CIMMS at NSSL)

We continue to support the archiving and distribution of NWRT PAR radar data for NSSL and other external users. During FY14, several data cases collected with the NWRT PAR 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.

d. Understanding Strength and Limitations of Scanning Strategies

Sebastian Torres (CIMMS at NSSL)

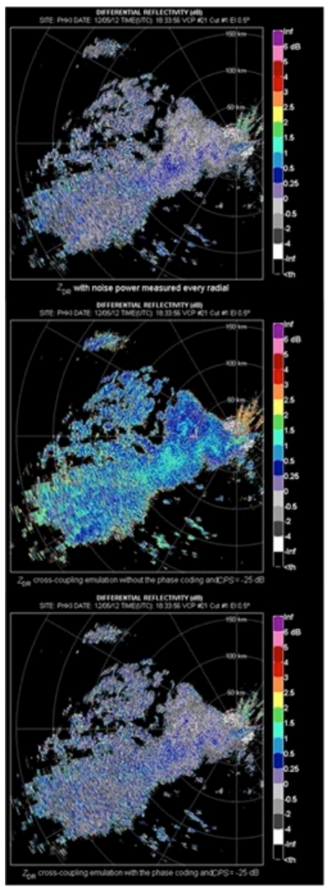
The Phased Array Radar Innovative Sensing Experiment (PARISE) of 2013 was held during six weeks in May, June, and July at the National Severe Storms Laboratory (NSSL) in Norman, OK. During PARISE 2013, NSSL scientists worked with twelve National Weather Service (NWS) forecasters to assess how the use of rapid-scan phased-array radar (PAR) data assists situational awareness and warning decisions during simulated severe-weather events. Another goal of this experiment was to understand the strengths and limitations of weather-radar scan strategies used by forecasters in their warning-decision process. The experiment was conducted in three phases over three days: orientation, case studies, and debriefing. Prior to working with the cases selected for this study, participants were briefed on the basic trade-offs that need to be considered when designing weather-radar scan strategies, and on the potential impacts of different scan-strategy characteristics to the quality, spatial resolution, and temporal resolution of the data. After working each case, participants were asked to assess the strengths and limitations of the associated scan strategy. At the end of each week, participants discussed the impacts of these scan strategies on their warning decision process. They also participated in interactive exercises conducted to assess the value of different scanning-strategy characteristics to their situational awareness and warning decisions. Questions were focused on two weather scenarios: supercells and microbursts. As the latter matched the phenomena observed in the simulated weather events, participants were able to draw from their experience with previous case studies. Forecasters' scan strategy choices and reasoning in response to these questionnaires and interviews were recorded, and the main common themes were identified from the analysis of this information. This was the first in a series of experiments with the overarching goal of understanding forecasters' needs to improve radar observations using adaptive scanning algorithms, which are best suited for the next generation of weather-surveillance radars based on PAR technology. This work is ongoing.

e. MPAR Dual Polarization

Igor Ivić (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 does the current WSR-88D system, allowing for improved rainfall estimation, hydrometeor classification, improved data quality, and enhanced 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) pulse-to-pulse (or interpulse) phase coding of the transmitted pulses in the horizontal and vertical channels, or (2) time-multiplexing (or Quasi-Simultaneous Horizontal and Vertical) in which the vertical transmitter port is immediately energized after energizing the horizontal port or vice versa. During FY14, phase coding and time multiplexing were further investigated using simulated and real time series and analytical derivations. The phase coding was shown to provide additional isolation with a small increase in the standard deviation of estimates. It was established that the time-multiplexing approach performs comparably to phase coding if the reflectivity spatial gradients are small but its performance declines as these gradients increase. It was observed that time-multiplexing approach also introduces significant increase in the standard deviation of estimates. In case of both approaches, it was concluded that the inherent cross-polar isolation from the hardware needs to be at least 25 dB. This work is ongoing.



Differential reflectivity field produced from unaltered real time-series (upper). Cross-coupling emulation of hardware cross-polar signal suppression of 25 dB with no phase coding (middle) and with phase coding (lower). Irrefutable resemblance of the upper most and lower most fields indicates the successful suppression of cross-polar signal contamination via phase coding.

f. PAR Dual-Polarization Demonstration

Brad Isom and Sebastian Torres (both CIMMS at NSSL), and Allen Zahrai and Kurt Hondl (both NSSL)

The NWRT PAR has served as a valuable platform to demonstrate unique capabilities of phased array technology for weather observations. Additionally, advancements in the use of polarimetric radars for meteorological observations have become a staple of weather forecasting. The future of weather radar lies in the combination of these two technologies. Current exploratory efforts have produced solutions that primarily focus on two designs: a conformal, cylindrical phased array and a four-sided planar phased array. Prior to the commitment to one of these designs, significant analysis must be completed for each geometry. The goal of this study is to evaluate the performance of polarimetric planar phased array technology with respect to the national weather mission. In FY13, NSSL approved the construction of a 10-panel mobile polarimetric phased array system by MIT Lincoln Laboratory. The demonstration system will serve as an evaluation platform for NSSL to ascertain the polarimetric performance of the planar phased array technology. A test plan was developed over the course of FY14 that exercises the capabilities of the demonstration system, which focuses on absolute and relative accuracy measurements. Absolute measurements resolve the system's capability to accurately identify hydrometeors, while relative measurements examine the correct calibration of the system as well as off-broadside cross-polarization impacts. Comparisons with legacy systems (KOUN) are also important in developing a good understanding of the system capabilities and are built into the test plan. An analysis of the performance will play an ongoing important role in the defining the expected performance of future systems, including an upgrade/replacement for the NWRT PAR.

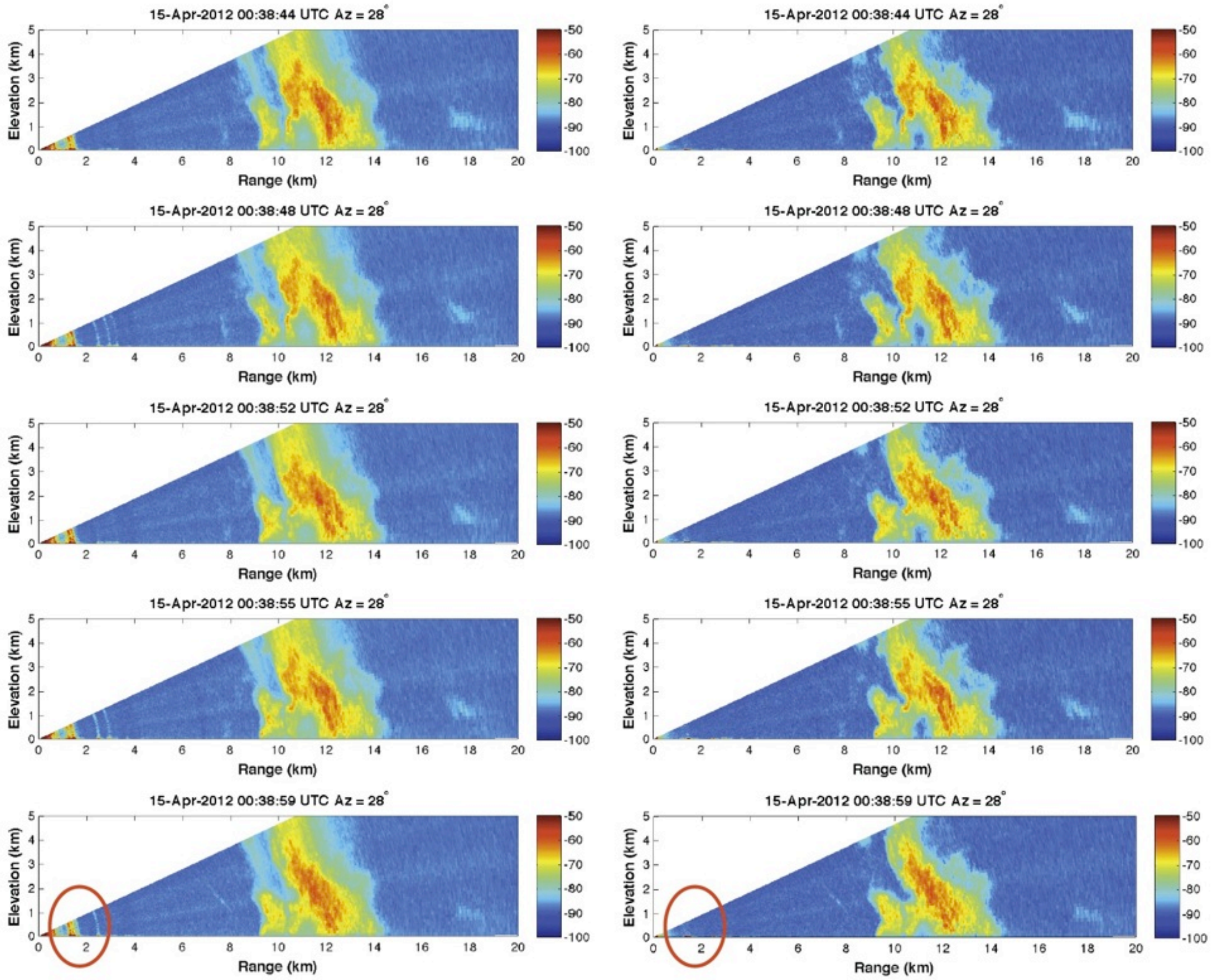
g. PAR Clutter Characterization and Mitigation

Christopher 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.

Another advantage of phased-array radars that has been suggested by other researchers is improved clutter filtering because of the ability to scan without antenna

rotation. The spectrum width of ground clutter could be narrower because of this lack of antenna rotation. Some initial research on this topic was presented at the American Meteorological Society Annual Meeting, which showed that the expected effects could be less significant than originally thought. Research is continuing including new techniques for simulating time series data for ground clutter targets.



RHI plots of cross-sections through a tornado using data collected with the ARRC Atmospheric Imaging Radar. Since data for the entire RHI is collected simultaneously, the observed vertical structure evolution has no artifacts due to storm motion. The left column shows power estimates by Fourier beamforming, and the right column shows power estimates by robust Capon beamforming. Notice the ground clutter leakage into higher elevations angles (circled in red) in the Fourier method is not present in the robust Capon method.

h. PAR Pulse Compression and Range Oversampling

Sebastian Torres and Brad Isom (both CIMMS at NSSL)

It is anticipated that a future MPAR system will rely on pulse compression to achieve the required sensitivity for the weather surveillance function. In addition, the use of range-oversampling techniques will be beneficial to meet the required update times. As demonstrated with the NWRT PAR, range oversampling allows reducing the dwell times without degrading the quality of the radar data. Because both pulse compression and range oversampling operate along range time, it is important to explore their relationship for potential symbiotic use on the MPAR. During FY14, we developed initial simulations to understand the interplay of pulse compression and range-oversampling processing. We determined that a straightforward application of both techniques would not lead to the desired performance. Thus, we began exploring alternate ways of combining these techniques and developed measures to characterize the different tradeoffs.

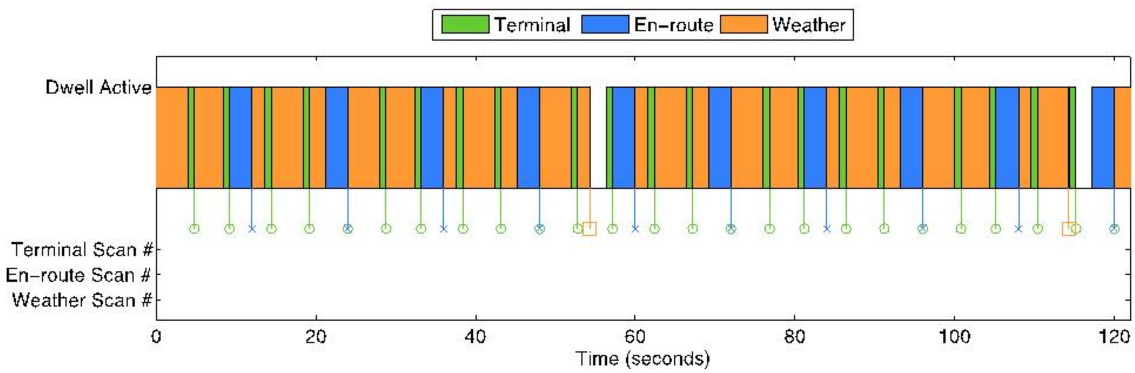
i. Cylindrical Polarimetric PAR (CPPAR)

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 Advanced Radar Research Center (ARRC) at OU 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 into the trailer and have worked on configuring the servers used for recording and processing all of the data. This work is ongoing.

The 2-m CPPAR demonstrator electronic enclosure and antenna.

CPPAR Design Study: CIMMS engineers participated in a CPPAR Design Study with NSSL and ARRC staff to investigate the feasibility of building a large-scale cylindrical phased array radar. While the study was focused on a cylindrical array, a significant portion of the discussion was also applicable to planar phased arrays. Many topics were investigated, including requirements according to the NFR, concept of operations, scanning strategies, backend architecture, and mechanical design. A lot of effort was spent defining an LRU to ensure that, with currently available parts, it is feasible and affordable. The LRU encompasses the electronics from the antenna ports to the digitized IQ data feeds. At the conclusion of the study, we wrote a report detailing our findings for the NSSL and OU administration. This work is ongoing.



Proposed multi-function timeline for CPPAR

j. MPAR Program Support

Sebastian Torres and Brad Isom (both 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 work is ongoing.

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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.
- 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 using dual-polarization parameters to filter non-hydrometeor signals.

- Evaluate possible improvements to radar based QPEs in complex terrain using satellite-based active and passive sensors.
- 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.
- Improve accuracy of QPEs in different storm environments using NWP analysis information
- Improve the quality of national rain gauge datasets for QPE and QPE verification
- Develop advanced web-based tools and displays for QPE comparisons, verification, and radar calibration

Accomplishments

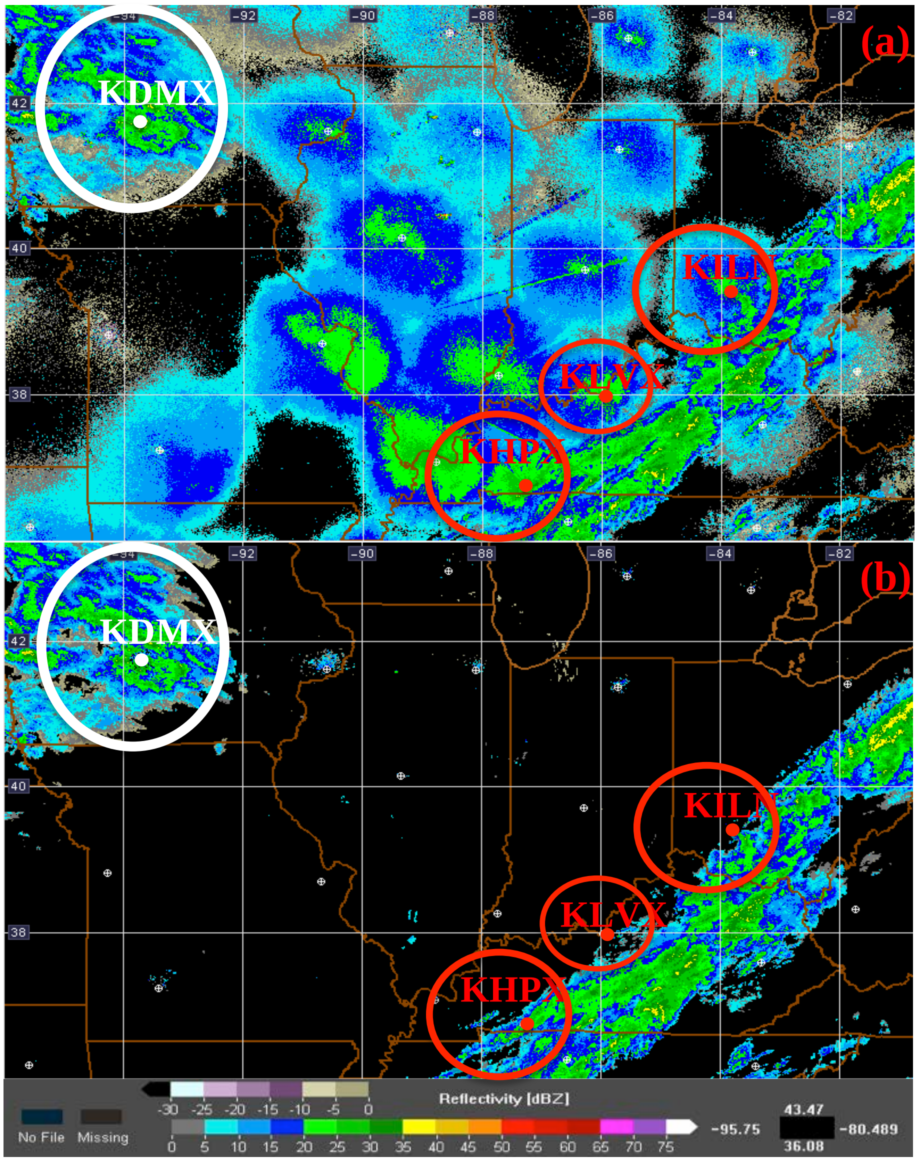
1. WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities

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

Polarimetric radar observations provide information regarding the shape and size of scatterers in the atmosphere, which help users to differentiate between precipitation and non-precipitation radar echoes. Identifying and removing non-precipitation echoes in radar reflectivity fields is one critical step in radar based quantitative precipitation estimation. An automated algorithm based on reflectivity, correlation coefficient, and temperature data is developed to perform reflectivity data quality control through a set of physically based rules. The algorithm applies a set of explicit meteorological principles according to ρ_{HV}, Z, and atmospheric thermodynamic fields. It combines a simple ρ_{HV} filter that separates precipitation (high ρ_{HV} values) and non-precipitation (low ρ_{HV} values) areas and a set of heuristic rules that handle exceptions to the based ρ_{HV} filter. Such exceptions include areas of hail, non-uniform beam filling (NBF), and a melting layer (ML) that have low ρ_{HV} values and random clutter and biological pixels with high ρ_{HV} values. The algorithm uses 3-D reflectivity structure and environmental data to protect hail, NBF and ML areas from the simple ρ_{HV} filter and it uses spatial filters and vertical and horizontal consistency checks to remove random NP pixels that exhibit high ρ_{HV} values.

This dual-polarization quality control (dpQC) algorithm was tested with a large number of real data cases across different geographical regions and seasons and showed a high accuracy (Heidke Skill Score of 0.83) in segregating precipitation and non-precipitation echoes by taking on average 3.15s of CPU time and 83MB of memory to process a volume scan on a workstation with four 2.27GHz processors and 12GB double data rate type three random access memory (DDR3 RAM). The dpQC was compared with two other operational and experimental reflectivity quality control methodologies and showed a more effective removal of non-precipitation echoes and a higher computational efficiency. The current methodology has been implemented in the

real-time national multi-radar and multi-sensor system (MRMS) to process 146 WSR-88D radars. While computationally efficient, the quality control scheme has been very effective in removing biological and other NP echoes and retaining precipitation information. The figure below provides an example of the mosaicked composite reflectivity field before (a) and after (b) the dpQC process. The dpQC algorithm is able to completely remove the non-precipitation clutter that heavily mixed with storms while keeping the precipitation echoes. This project is ongoing.



The real-time composite fields (a) before QC, and (b) after dpQC valid at 08:30 UTC on 10 Oct. 2013. The white circles indicate an area of light precipitation and red circles are the areas of blooms.

Publications

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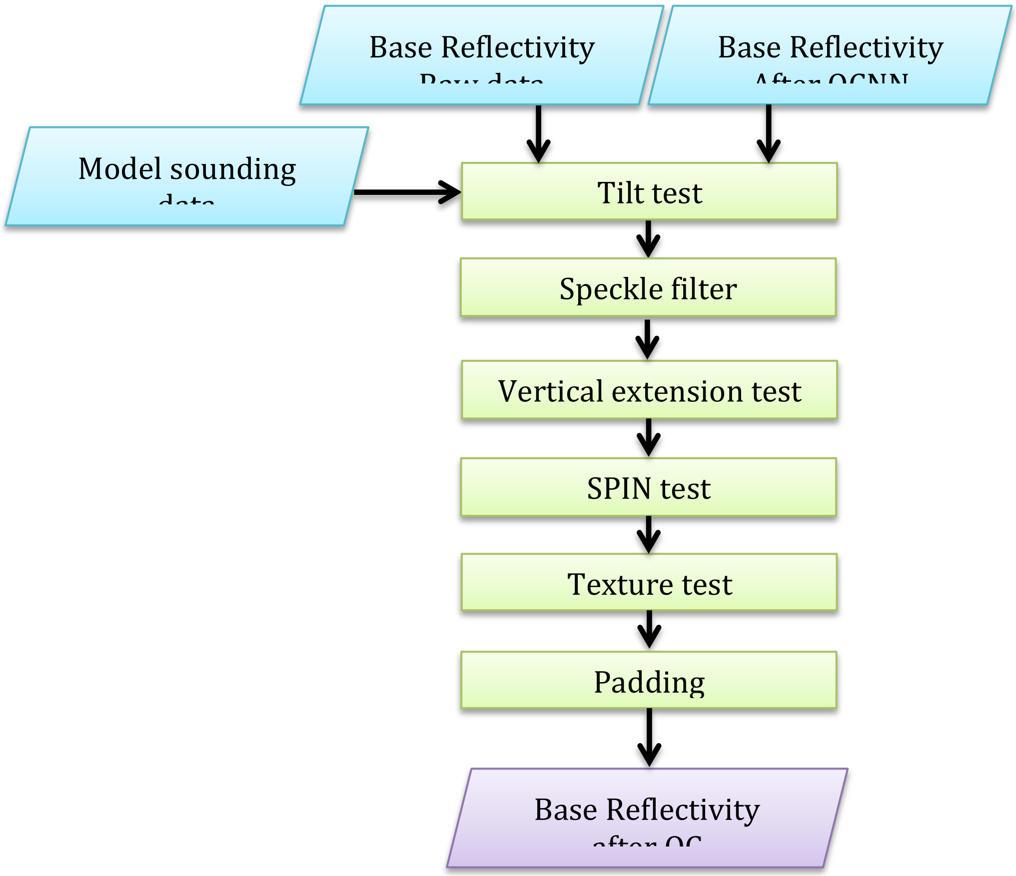
2. Reflectivity Quality Control for the Canadian Radar Network

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

The quality control (QC) of Canadian radar data in the real time Multi-Radar Multi-Sensor (MRMS) system has been focused on reducing contamination of ground clutter caused by abnormal propagation (AP) of radar beams. AP is a type of ground clutter caused by strong vertical temperature and moisture gradients or temperature inversions in the lower troposphere. In this situation, the propagation of the electromagnetic (EM) wave bends toward the ground instead of continuing straight upward. This “anomalous propagation” of EM wave causes part of the radar beam hitting the ground and results in ground clutter contaminations in radar data. Severe AP clutter is a major issue with the Canadian radar network. The full 3D volume scan (“CONVOL”) base level data for Canadian radars does not contain the information of velocity and spectrum width, nor is signal-to-noise data available. In this work, the effort is to develop an automated QC processing algorithm (APQC) to address AP clutter for Canadian radars that is limited to reflectivity field in comparison to WSR-88Ds in which all three moments are available.

The APQC scheme mainly relies on the texture and spatial variability of reflectivity, as well as the vertical extent of radar echoes to identify AP clutter. The figure below is a flowchart of the APQC algorithm process. The data flow starts from inputs of raw base reflectivity, after the QCNN process, and the model sounding data, and then goes through six steps: tilt test, speckle filter, vertical extension test, the SPIN test (spatial variability of reflectivity), texture test, and padding. The APQC has been tested on the cases from 26 radars, where the cases include weather conditions of pure AP clutter, precipitation events in winter and summer seasons and mixed AP with weather echoes. The testing results show that the complementary scheme of APQC is able to effectively remove pure AP clutter during clear-air weather conditions, and mitigate severe AP echoes close to the radar site. The QCNN, persistent ground clutter filter and APQC can identify ~80-90% (subjective assessment based on the case studies) of the non-precipitation echoes. The remaining 10-20% non-precipitation echoes, mainly AP clutter far away from the radar and/or during severe super refraction conditions in the atmosphere, are extremely difficult to identify unless additional information such as dual-polarization radar observations are available. This work is ongoing.



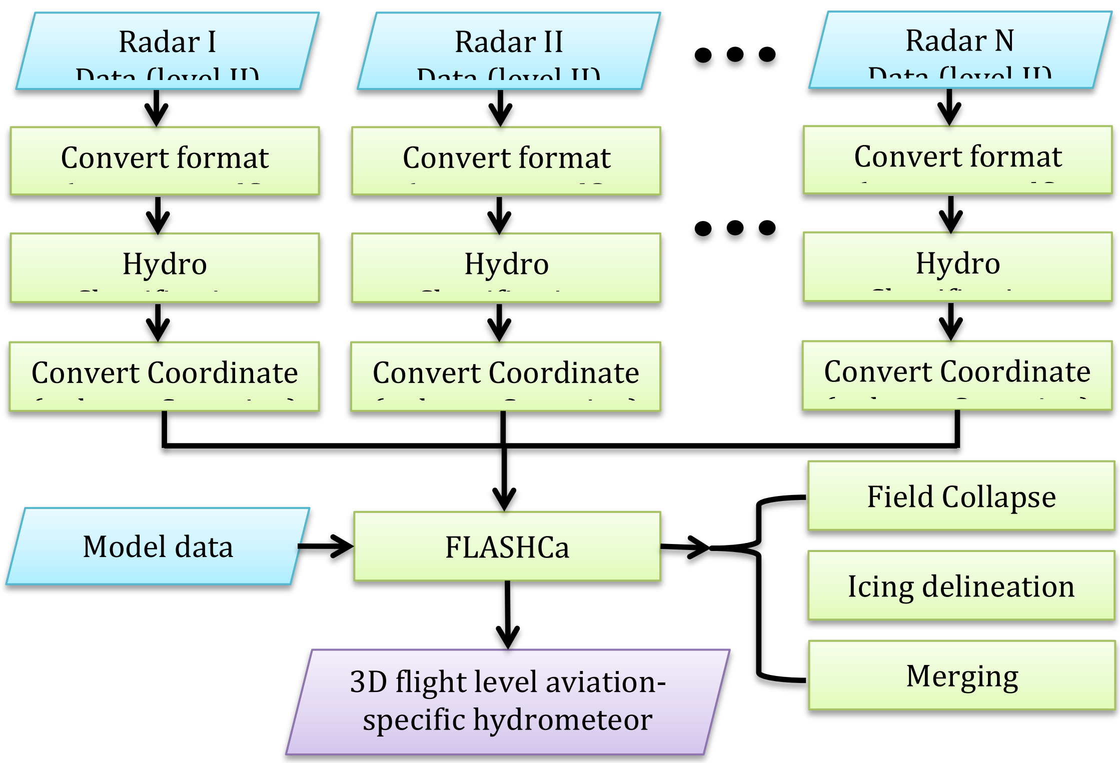
Flow chart of the APQC algorithm.

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

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

Polarimetric radar observations facilitate discrimination between different types of hydrometeors (e.g., hail vs. rain and liquid vs. frozen in winter). This will be useful for airport de-icing operations as well as for severe weather and in-flight icing hazard warnings. The Hydrometeor Classification Algorithm (HCA) developed by NSSL (Park et al. 2009) applies the fuzzy logic method with a suite of input parameters derived from dual-polarization radar variables to discriminate between 10 different classes (rain, heavy rain, rain/hail, big drop, wet snow, dry snow, graupel, crystal, biological scatterers, and ground clutter). Based on the HCA results from individual radars and the temperature model data, the flight level aviation-specific hydrometeor classification (FLASHC) is generated in a three-dimensional (3-D) coordinate for aviation weather warning purposes. This work is ongoing.

The figure below provides the flow chart of data process. Firstly the level II radar data are injected and converted format for the HCA algorithm that delivers a set of ten-category hydrometeor classification in polar coordinate for each of individual radars. After coordinate conversion from polar to Cartesian, all the single radar data inside the studied region are input into FLASHC for an output of mosaicked 3D aviation specific hydrometeor classification. The FLASHC algorithm includes three steps of collapsing the HC field, possible icing layer delineation, and merging the classification products. By applying the thermal model field of wet bulb temperature (WBT), the 10-category hydrometeor classification is collapsed into six categories: 1) No meteorological hazard; 2) Precipitation with possible visibility restriction; 3) Precipitation, possible icing, possible visibility restriction; 4) Precipitation, likely snow, possible visibility restriction; 5) Precipitation, possible icing hazard; and 6) Possible hail. Here WBT is used, instead of dry bulb temperature, to take considerations of relative humidity, pressure, dew point temperature and other properties. Then the classifications from individual radars are merged into a mosaicked field, where the categories in the overlapping region between the radars are determined by the observations from the closest radar. Because of the effects of radar beam broadening with range, artificial circular discontinuities can be observed in the mosaicked field at high elevation heights or at the locations far from radar sites. A median filter is applied in the merging step to smooth the FLASHC. This project is ongoing.

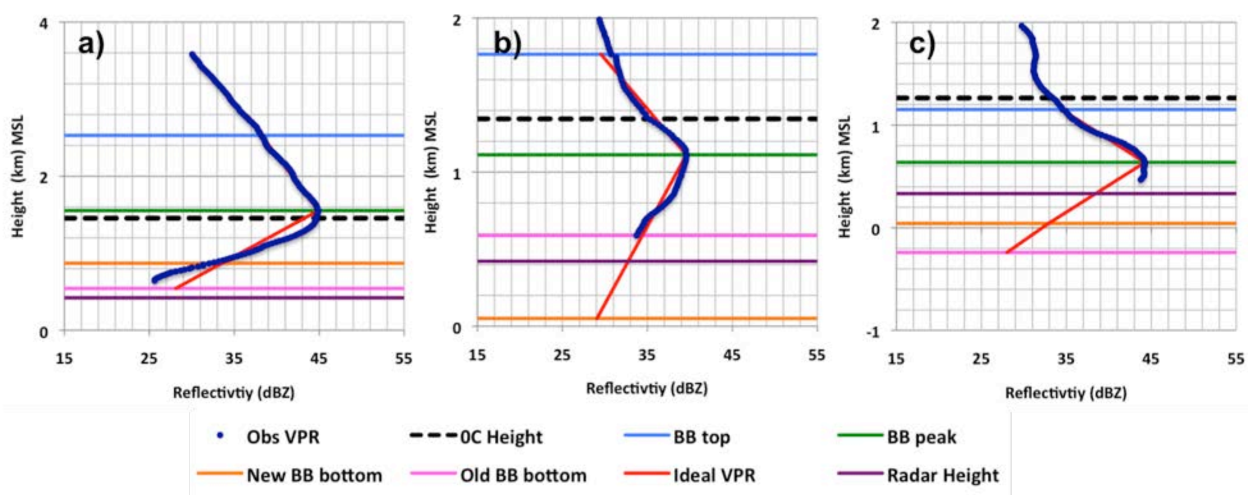


The flow chart of the FLASHC process.

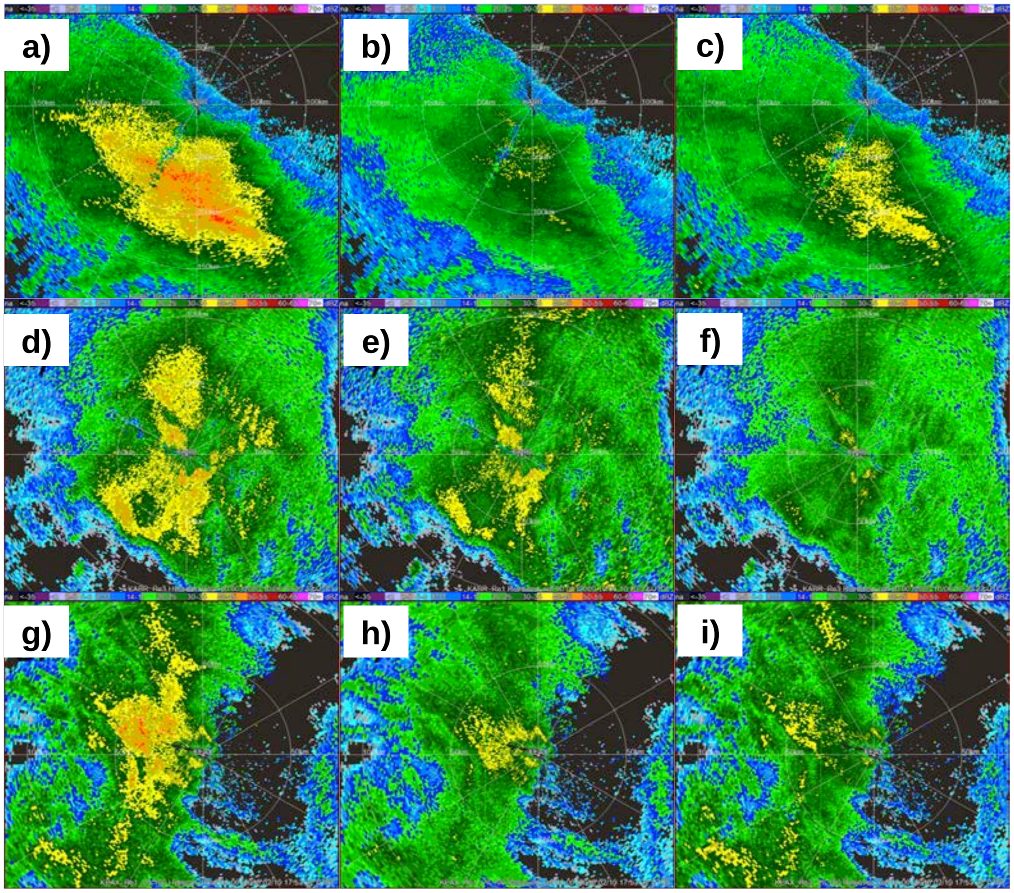
4. Correction of Radar QPE Errors Associated with Low and Partially Observed Brightband Layers

Youcun Qi (CIMMS at NSSL) and Jian Zhang (NSSL)

The melting of aggregated snow/crystals often results in an enhancement of the reflectivity observed by weather radars, and this is commonly referenced as the bright band (BB). The locally high reflectivity often causes overestimation in radar quantitative precipitation estimates (QPE) if no appropriate correction is applied. When the melting layer is high, a complete BB layer profile (including top, peak, and bottom) can be observed by the ground radar, and a vertical profile of reflectivity (VPR) correction can be made to reduce the BB impact. When a melting layer is near the ground and the bottom part of the bright band cannot be observed by the ground radar, a VPR correction cannot be made directly from the Weather Surveillance Radar-1988 Doppler (WSR-88D) radar observations. This paper presents a new VPR correction method under this situation. From high-resolution precipitation profiler data, an empirical relationship between BB peak and BB bottom is developed. The empirical relationship is combined with the apparent BB peak observed by volume scan radars and the BB bottom is found. Radar QPEs are then corrected based on the estimated BB bottom. The new method was tested on 13 radars during seven low brightband events over different areas in the United States. It is shown to be effective in reducing the radar QPE overestimation under low brightband situations. This work is ongoing.



Apparent VPRs (blue dots) and associated linear VPR model (red lines) for (a) KABR at 1200 UTC 5 October 2009, (b) KABR at 1100 UTC 6 October 2009, (c) KEAX at 1700 UTC 19 February 2010.



Reflectivities from 0.50^o elevation angle (left column: a, d, and g) before AVPR correction, (middle column: b, e, and h) after the AVPR correction with ZQ10, and (right column: c, f, and i) after the AVPR correction with New. The three rows are images from (row 1) KABR at 12:26 UTC 5 October 2009; (row 2) KABR at 10:29 UTC 6 October 2009; and (row 3) KEAX at 17:53 UTC 19 February 2010.

Publications

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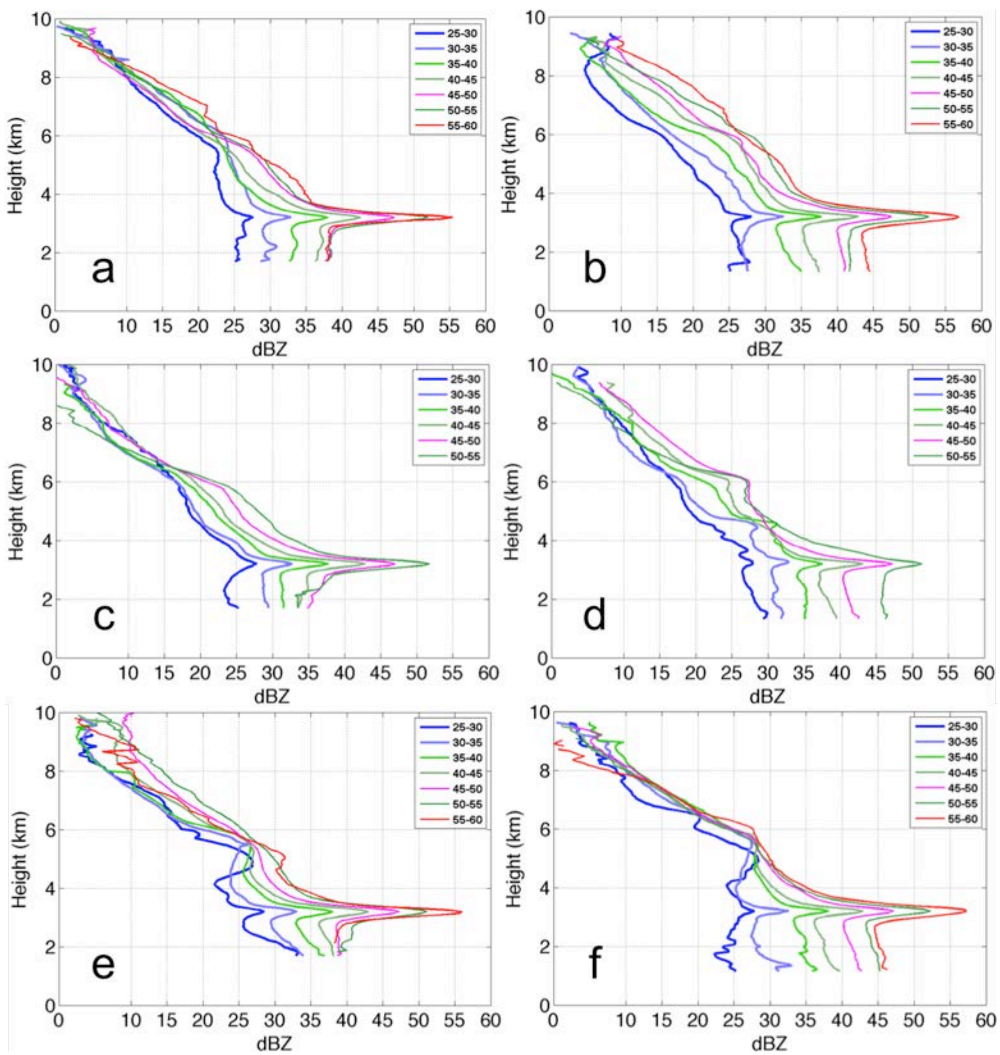
5. Improving WSR-88D Radar QPE for Orographic Precipitation Using Profiler Observations

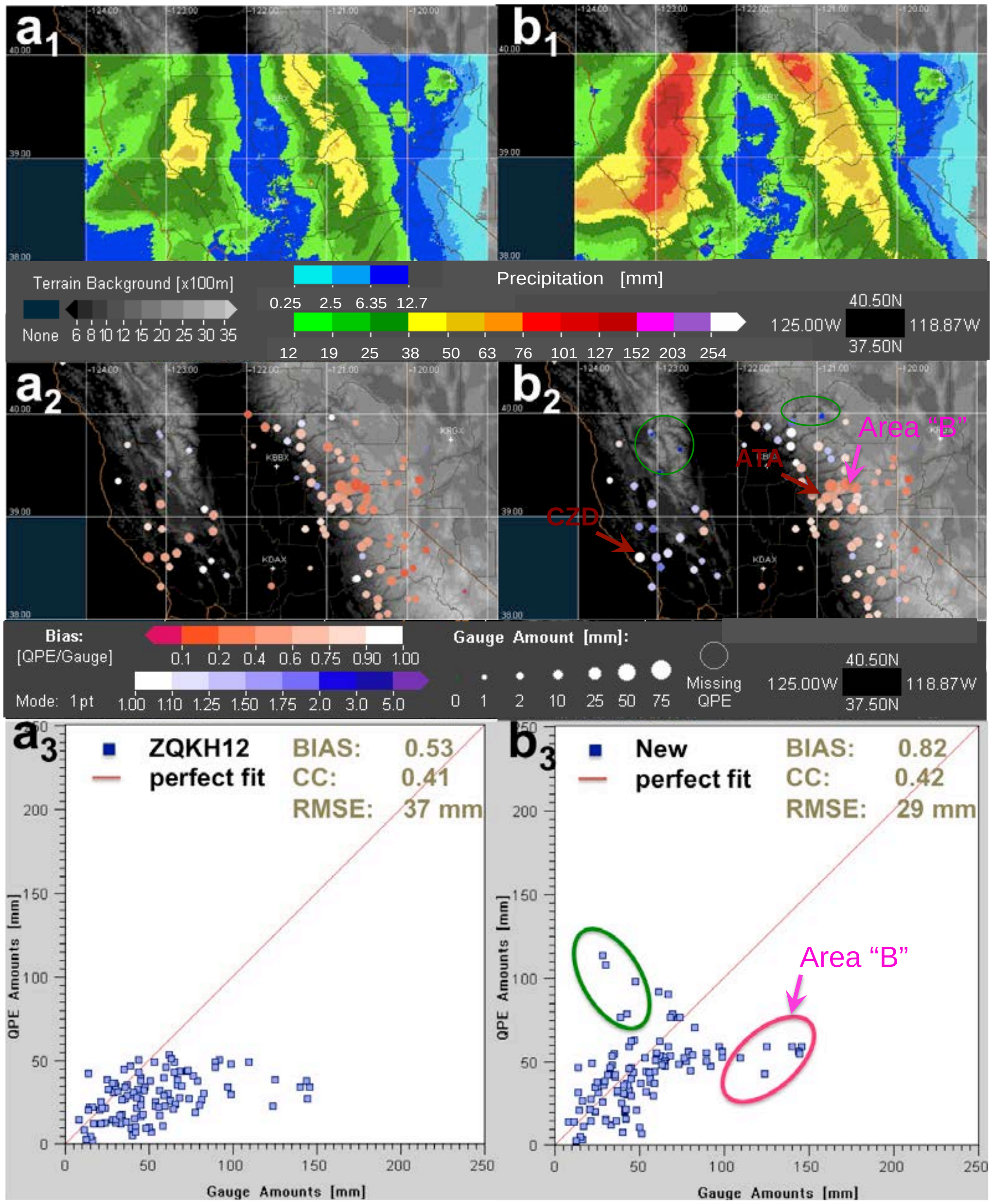
Youcun Qi, Brian Kaney, and Carrie Langston (all CIMMS at NSSL), and Jian Zhang and Kenneth Howard (both NSSL)

Quantitative precipitation estimation (QPE) in the West Coast region of the United States has been a big challenge for Weather Surveillance Radar-1988 Doppler (WSR-88D) because of severe blockages caused by the complex terrain. The majority of the heavy precipitation in the West Coast region is associated with strong moisture flux from the Pacific that interacts with the coastal mountains. Such orographic enhancement of precipitation occurs at low levels and cannot be observed well by WSR-88D because of

severe blockages. Specifically, the radar beam either samples too high above the ground or misses the orographic enhancement at lower levels, or the beam broadens with range and cannot adequately resolve vertical variations of the reflectivity structure. The current study developed an algorithm that uses S-band Precipitation Profiler (S-PROF) radar observations in northern California to improve WSR-88D QPEs in the area. The profiler data are used to calculate two sets of reference vertical profiles of reflectivity (RVPRs), one for the coastal mountains and another for the Sierra Nevada. The RVPRs are then used to correct the WSR-88D QPEs in the corresponding areas. The S-PROF–based VPR correction methodology (S-PROF-VPR) has taken into account orographic processes and radar beam broadenings with range. It is tested using three heavy rain events and is found to provide significant improvements over the operational radar QPE. This work is ongoing.



The mean VPRs are calculated from S-band profiler data (left column from ATA; right column from CZD) which are categorized from left to right by the intensity of BB peak (dBZ), 25, 30, 35, 40, 45, 50, 55, and 60 respectively. a) and b) IOP3 21-22 December 2005; c) and d) 27-28 December 2005; and e) and f) IOP4 30-31 December 2005.



24-hr radar rainfall accumulations ending at 23:00 UTC on 22 December 2005 with ZQKH2012 (a1) and New (b1), and the corresponding distribution of the bias of individual R-G pairs for 24-h accumulation are shown in (a2) and (b2) respectively. The color reflects the variation of the bias. The warm colors (orange/red) are for biases of less than 1 (radar underestimate). The cold colors (blue/purple) are for biases greater than 1 (radar overestimate). The white colors are for biases very close to 1; i.e., the radar agrees well with the gauge. The size of the circle represents the gauge amount. Scatter plot of radar vs. gauge results are shown in (a_3) and (b_3) respectively. The light-red line is the line of perfect correlation. The R-G pairs (data points) are all of the radar-gauge pairs in the current study domain. The bias, RMSE, and CCs are shown.

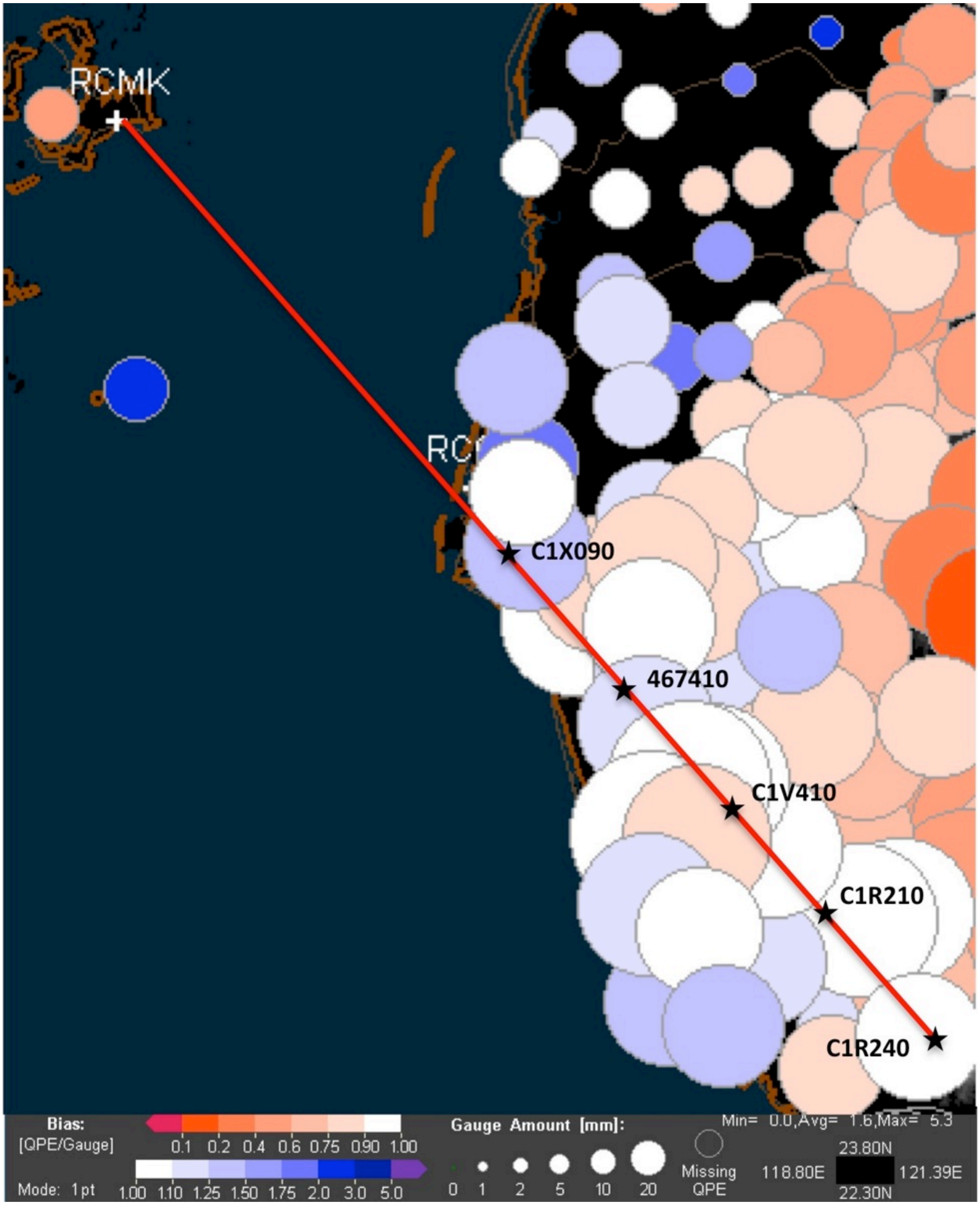
Publications

Qi, Y., J. Zhang, B. Kaney, C. Langston, and K. Howard, 2014: Improving WSR-88D radar QPE for orographic precipitation using profiler observations. *Journal of Hydrometeorology*, **15**, 1135-1151.

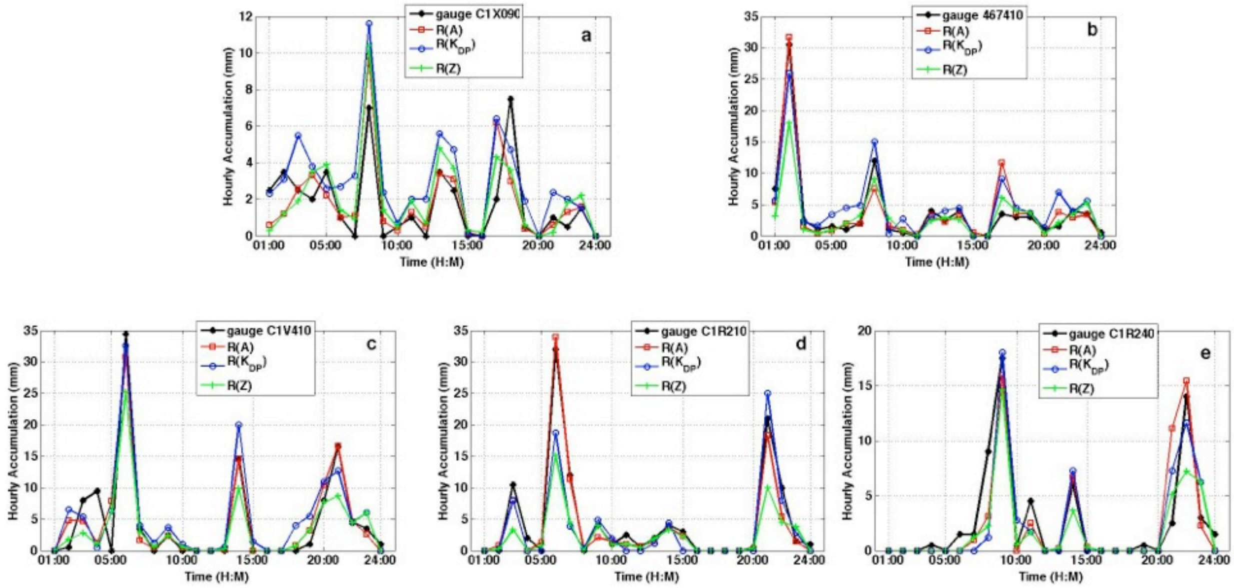
6. Development of a Novel Radar QPE Approach Using Specific Attenuation for Two C-Band Dual-Polarization Radars

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

To improve the accuracy of quantitative precipitation estimation (QPE) in complex terrain, a new rainfall rate estimation algorithm has been developed and applied on two C-band dual-polarization radars in Taiwan. In this algorithm, the specific attenuation (*A*) is utilized in the rainfall rate estimation, and the parameters used in the *R*(*A*) method were estimated using the local drop size distribution (DSD) and diameter shape relation (DSR) observations. In areas of complex terrain where the lowest antenna tilt is completely blocked, observations from higher tilts are used in radar QPE. Correction of vertical profile of rain rate estimated by the *R*(*A*) algorithm (VPRA) is applied to account for vertical variability of rain. It has been found that the VPRA correction improved the accuracy of estimated rainfall in severely blocked areas. The *R*(*A*)-VPRA scheme was tested for different precipitation cases including typhoon, stratiform, and convective rain. Compared to existing rainfall estimation algorithms such as *R*(*Z*) and $R(K_{DP})$, the new method is able to provide accurate and robust rainfall estimates when the radar reflectivity is miscalibrated, significantly biased by attenuation, and the lower tilt of the radar beam is significantly blocked. This work is ongoing.



The spatial distribution of gauge observations vs. radar based QPEs from 24 hours accumulation *(0000~2400 UTC, 18 July 2011). The relation of* $R=359A^{0.89}$ *is used in the rainfall rate estimation. The locations of these 5 gauges are indicated with black stars.*

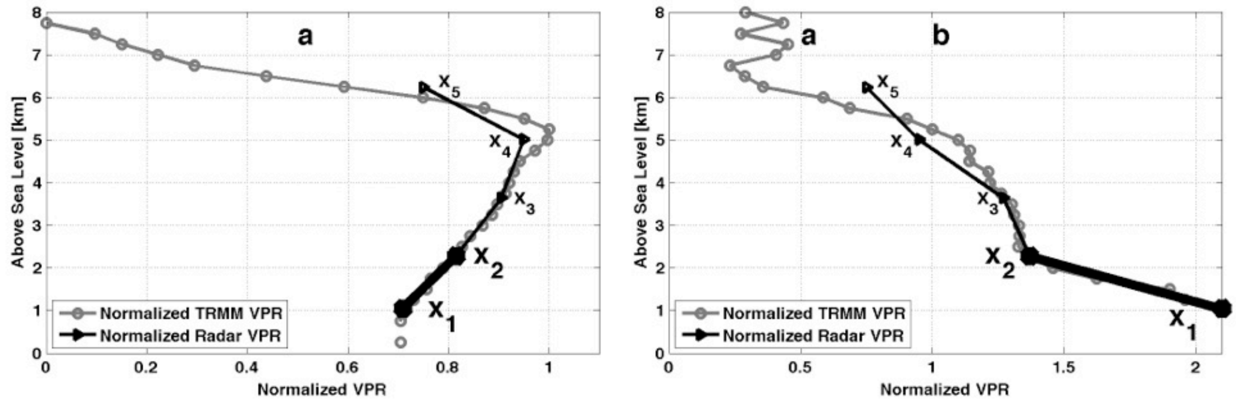


Hourly accumulation comparison between gauge observations and QPE using $R=359A^{0.89}$ (red line), $R=207Z^{1.45}$ (green line), and $R=35.4K_{DP}^{0.799}$ (blue line), respectively. The gauge observation is depicted with black line. 24 hours data from 0000~2400 UTC 18 July 2011 is used in this example.

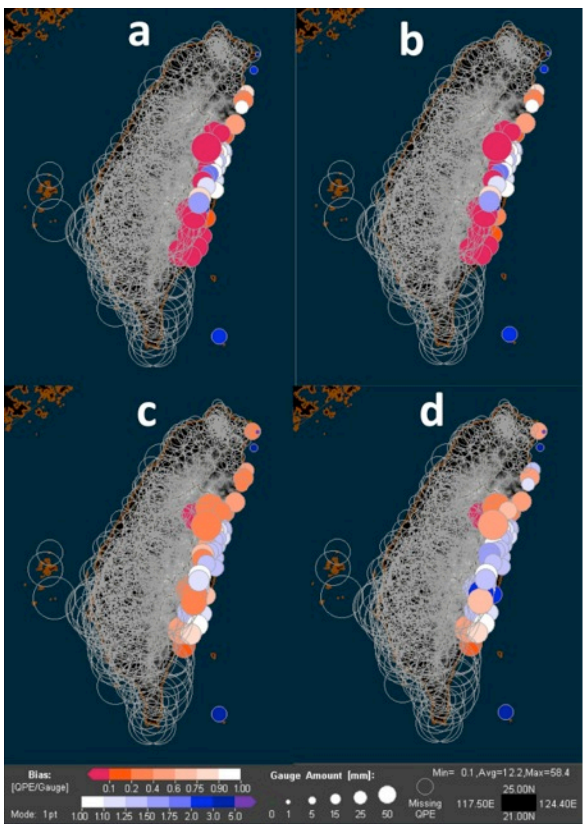
7. Radar Vertical Profile of Reflectivity Correction with Satellite Observations Using a Neural Network Approach

Yadong Wang (CIMMS at NSSL) and Jian Zhang (NSSL),

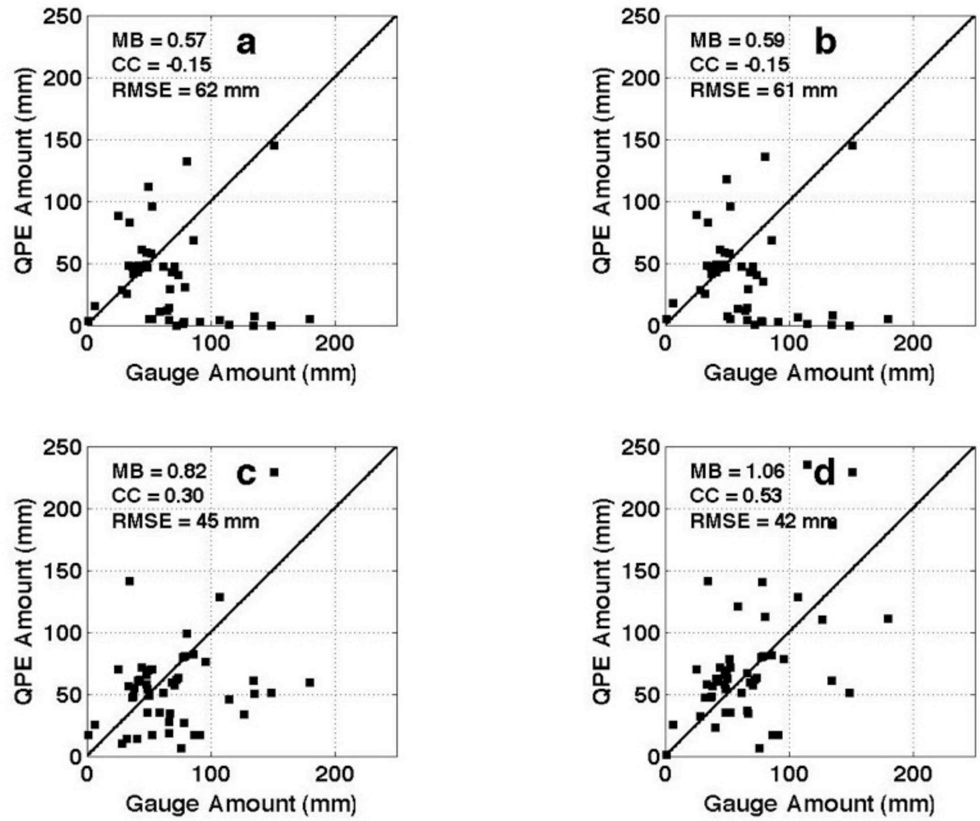
Complex terrain, which causes partial or total blockage on radar beams from the lower tilts, poses challenges to the ground based radar quantitative precipitation estimation (QPE). Although reflectivities from higher tilts could be used in the QPE instead, biases will be introduced because of vertical variations in the reflectivity field. Space-borne precipitation radar carried by Tropical Rainfall Measurement Mission satellite (TRMM-PR) can provide unblocked data close to the surface even in complex terrain, but the poor temporal resolution of TRMM-PR data limits its usefulness in real-time high resolution QPE. To combine the two observing systems for improved radar QPE in the complex terrain, an artificial neural network (ANN) based radar vertical profile of reflectivity (VPR) correction approach was developed in this work. In this approach, reflectivities from S-band Doppler weather radar located on the east coast of Taiwan and TRMM-PR are connected with an ANN, which is trained with typhoon precipitations. When mountains block the lower tilt reflectivity, higher tilt radar observation is corrected with the trained ANN, and the corrected reflectivity is then applied in the rainfall estimation. The proposed algorithm was evaluated with three typhoon precipitation events, and its performance was evaluated and analyzed. This project is ongoing.



The normalized VPR observed by RCHL (black lines) and TRMM-PR (gray lines). X_3 ~ X_5 are the RCHL observations from three higher continued elevation angles, and X_1 and X_2 are the retrieved reflectivities from two lowest elevation angles. The vertical reflectivity observed from stratiform and convective precipitations are shown in panels a and b, respectively.



The spatial distribution of the radar QPE vs. gauge observations without VPR correction (a), with VPR correction where the VPRs derived using mean VPR-RCHL (b), using mean VPR-TRMM (c), and using VPR-TRMM reconstructed from ANN. 24 hours accumulated precipitation from typhoon Morakot (0000 ~2400 UTC, 8 August 2009) is used in this experiment. The size of the circles represents gauge-observed accumulated amount, and the color of the circles indicates the bias (QPE/Gauge).



The scatterplots of radar QPE vs. gauge observations for Typhoon Morakot (0000 ~2400 UTC, 8 August 2009). The reflectivity fields used in the rainfall rate estimation are without VPR correction (a); with VPR correction using the VPR derived from mean VPR-RCHL (b), from mean VPR-TRMM (c), and from VPR-TRMM reconstructed from ANN (d). The evaluation results in terms of mean bias, correlation coefficient, and root mean square error are also included in each figure.

Publications

Wang, Y, P. Zhang, A. V. Ryzhkov, J. Zhang, and P.- L. Chang, 2014: Utilization of specific attenuation for tropical rainfall estimation in complex terrain. *Journal of Hydrometeorology,* **15**, in press. doi:10.1175/JHM-D-14-0003.1

8. Producing MRMS QPE Technical Documentation for VLAB

Steven Cocks and Steven Martinaitis (both CIMMS at NSSL)

As part of the transition to NWS operations, technical documentation was produced for key MRMS QPE processes and products that were posted on the National Weather Service Virtual Laboratory (VLAB). The documents can be found at http://nws.weather.gov/innovate/group/mrms/wiki/-/wiki/Main/MRMS-QPE+Products.

The documentation adhered to a previously agreed upon format and included charts and sample product images that help illustrate the processes and products. MRMS QPE documentation is organized into three sections: Quality Control, Key QPE Processes and Key Reflectivity and QPE Products. The following table shows the section and title of the technical documents produced. Periodic document updates will be required whenever a process/product is changed.

Section	***Process/Products Technical Document Titles***
Quality Control	Reflectivity Processing
	Radar Quality Index
	Gauge Influence Index
Key QPE Processes	MRMS QPE Mosaic Process
	Convective Stratiform Precipitation Separation
	Apparent Vertical Profile of Reflectivity Correction
	POWR
	Tropical Rain Identification
	Surface Precipitation Type
	Surface Precipitation Rate
Key Reflectivity and QPE Products	Bright Band Top and Bottom
	Seamless Hybrid Scan Reflectivity
	Seamless Hybrid Scan Reflectivity Height
	Q3 Radar Based Precipitation Accumulations
	Q3 Local Gauge Bias Corrected Radar QPE
	Mountain Mapper

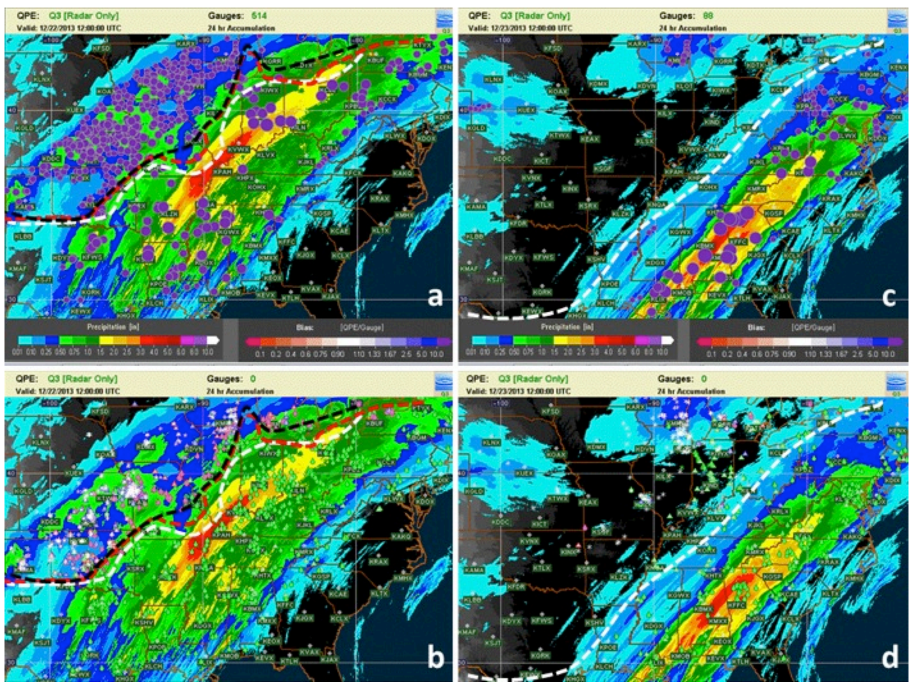
List of MRMS technical documents per VLAB section written this spring.

9. Evaluating MRMS Quantitative Precipitation, Dual-Polarization Precipitation and NCEP Stage II Estimates

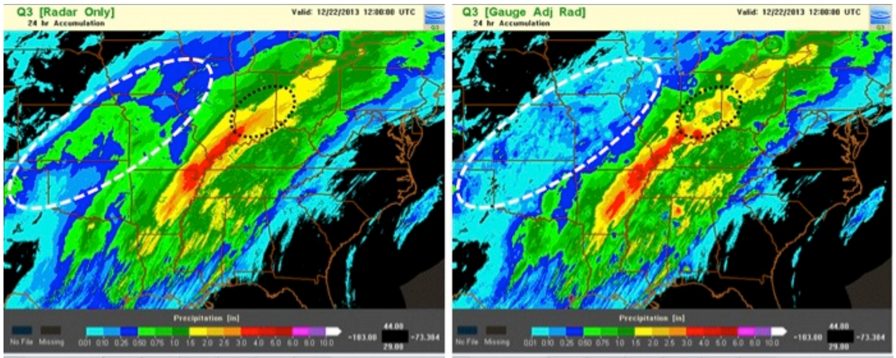
Steven Cocks and Steven Martinaitis (both CIMMS at NSSL)

MRMS QPE case study evaluations were conducted for eleven cool-season (December 2013 through March 2014) and a few warm season events (April 2014 to the present), all east of the continental divide. Cases evaluated were operationally significant weather events and had substantial, and sometimes near record, amounts of precipitation. The examination of the cool-season events indicated that a widespread problem existed with the automatic gauge sites, namely becoming stuck or clogged when freezing rain, sleet or snow was present. Hundreds of gauges (over 900 for one event) located within the sub-freezing air were indicating essentially no precipitation where radar, mPING and synoptic reports clearly showed it was occurring. While the occurrence of stuck and clogged gauges during winter weather is not a new finding, the magnitude of the problem found in these cases is surprising and one not fully realized

by some researchers. More importantly, the suspect gauges significantly affected the Q3 local gauge corrected products as these suspect gauges removed any radar detected precipitation areas over sub-freezing surface air. This spurred development of a new gauge quality control routine that incorporates hourly model wet-bulb temperature information to remove suspected stuck or clogged gauges (details of which are discussed in Martinaitis sub-topic and will be tested this fall/winter). The cool-season cases have been compiled into a distinct dataset currently being used to evaluate the MRMS QPE performance during this time of year and to compare its performance with other precipitation estimate products. Additionally, the spring and summer season suggests that specific synoptic and mesoscale environments can lead to MRMS QPE Radar Only precipitation over and under-estimates. This work is ongoing as results may help find ways to mitigate the errors in these types of events.



Q3 24 hour rainfall estimate ending at 12Z for the 22nd (1a and b) and 23rd (1c and d) of December 2014. Locations where gauge totals report ≤ 0.03 cm (0.01") and Q3 ≥ 0.64 cm (0.25") denoted by the filled purple bias circles. For 1 a) and 1b), black, red and white dashed lines denotes the surface 0 ^{o}C line from 18Z/21st, 00Z/22nd and 12Z/22nd RAP analyses. For 1c and 1d, only the 12Z/23rd (white dashed line) surface 0 ^{o}C line is shown.



Q3 24 hour rainfall estimate (left) and the Q3 gauge corrected estimate (right) ending at 12Z for 22 December 2014. White dashed ovals indicate the difference between the two products due to the use of suspected frozen gauges; black dotted ovals indicate effects caused by a few stuck gauges on the precipitation maximum over the Ohio Valley.

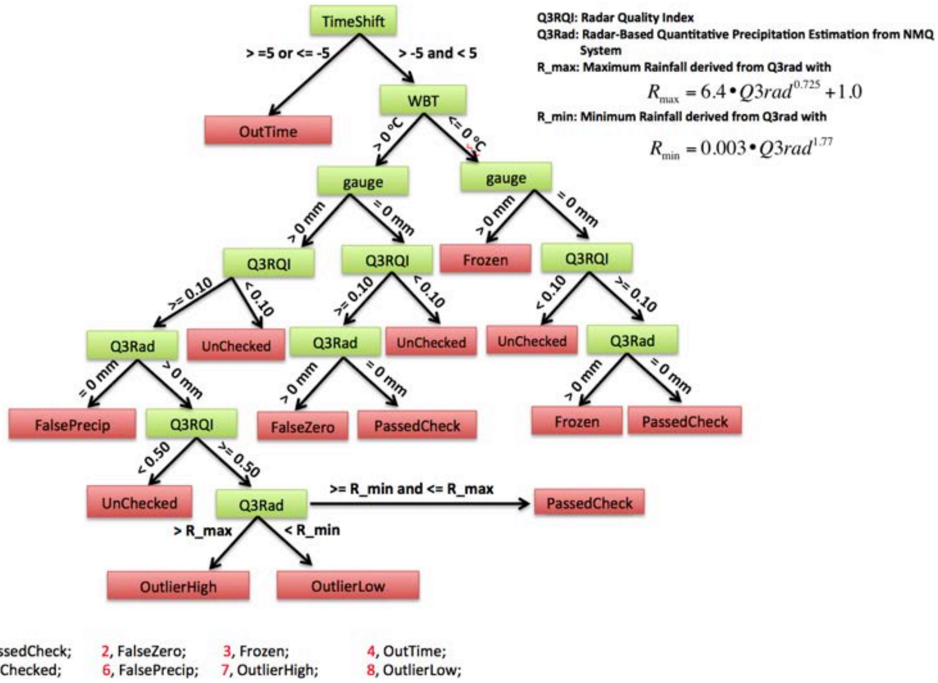
10. Quality Control Advancements of Hourly Rain Gauge Observations

Steven Martinaitis, Steven Cocks, Youcun Qi, and Brian Kaney (all CIMMS at NSSL), and Jian Zhang and Ken Howard (both NSSL)

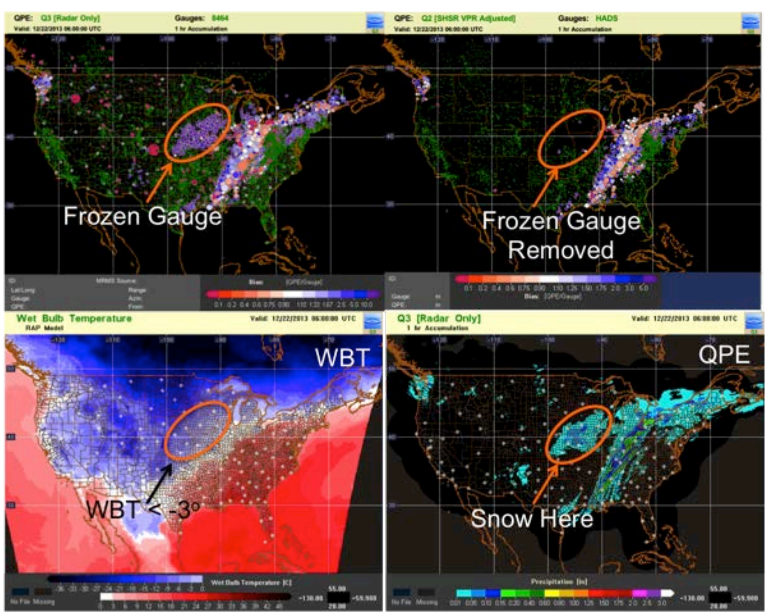
Surface rain gauge observations are regarded as “ground truth” when used to verify and calibrate radar-derived quantitative precipitation estimates (QPE). However, gauges not properly vetted by a quality control (QC) procedure can introduce erroneous statistical results and bias calibration. Advancements were made to the rain gauge QC algorithm to account for new logic for outlier values and impacts from winter weather events.

The 2014 version of the QC algorithm replaced the use of Z-R relationships to determine potentially outlier gauge values when compared to the radar-only QPE (hereinafter referred to as Q3Rad) with two power-law functions derived from approximately 9.5×10^4 hourly gauge vs. Q3Rad observations. Solid, winter precipitation was also found to impact up to 17% of the ingested gauge sites per hour due to undercatchment, blockage, or evaporative effects from heating elements. The quality of gauge observations were also found to degrade within three hours of becoming “stuck” due to partial impacts from winter precipitation. The QC algorithm accounts for this by removing gauges located in regimes defined by Rapid Refresh (RAP) model surface wet bulb temperature (WBT) ≤ 0°C.

Implementation of the new rain gauge QC algorithm included a series of QC flags to denote pass/fail classifications for each gauge site. An average of approximately 75-80% of ingested gauge sites per hour pass the QC algorithm for use in gauge-derived QPE products. Continuing longer-term collaboration between the National Severe Storms Laboratory (NSSL) and the National Operational Hydrologic Remote Sensing Center (NOHRSC) are assessing the QC of gauge metadata along with a reduction of ingest latency periods. This project is ongoing.



QC algorithm flow chart for hourly rain gauges to identify gauges that are flagged for being more than ±5 minutes of the top of the hour, frozen, false zero, false precipitation, outlier value, or unchecked.



Four-panel image demonstrating how the QC algorithm removes gauges that are potentially impacted by winter precipitation. The top-left panel shows the bias ratios between the 1-HR Q3Rad accumulation and gauge observations across the CONUS at 0400 UTC 22 December 2013 prior to the QC algorithm being applied. The size of each

circle represents the average of Q3Rad and gauge observed hourly precipitation amounts, and the color represents the bias ratio (Q3Rad/gauge). White color indicates a ratio of 1.0 (Q3Rad matches gauge), blue/purple indicates overestimation (bias > 1.0) and pink/red indicates underestimation (bias < 1.0). A large group of frozen gauges are highlighted by an orange oval. The bottom-left panel shows the frozen gauges in a region of WBT < -3°C while the bottom-right panel shows the Q3rad product depicting QPE over the region that was shown to be snow based on surface observations. The top-right panel shows the Q3Rad/gauge bias ratios after the QC algorithm removes the "frozen" gauges, as highlighted by the orange circle.

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

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

The MRMS Q3 precipitation type algorithm has been updated to include a new method for identifying where tropical rainfall rates should be delineated. The new tropical or warm rain identification method uses an environment-based probability of warm rain (POWR) that is derived from the hourly analysis of the 13-km Rapid Refresh (RAP) model (Grams et al. 2014). The updated precipitation type algorithm using POWR for warm rain identification will be included in the initial operating capabilities of the operational MRMS system at NCEP Central Operations.

Development and improvement of the POWR algorithm is ongoing. The operational debut of the HRRR model later this year will provide an opportunity to increase the spatial resolution of all the MRMS model-based products to 3-km, which is much closer to the 1-km grid spacing of all the radar-based MRMS products. The increased resolution will allow for detection of finer-scale features than was possible with the 13-km RAP and will require re-training of the POWR probabilities. Additionally, the POWR algorithm will be upgraded to include predictors sensitive to orographic enhancement of warm rain for improved precipitation types in complex terrain.

In anticipation of migrating the MRMS model-based processes from the RAP to the HRRR, a six-month archive of HRRR isobaric and native analysis grids has been compiled in order to derive new POWR probabilities. The MRMS model remapping algorithm has also been updated to successfully read and process HRRR grids.

Publications

Grams, H. M., J. Zhang, and K. L. Elmore, 2014: Automated identification of enhanced rainfall rates using the near-storm environment for radar precipitation estimates. *Journal of Hydrometeorology*, **15**, 1238-1254.

12. Multisensor Estimation of Intense Rainfall in Complex Terrain using GOES-R combined with Ground and Space-Based Radars

Heather Grams (CIMMS at NSSL), J.J. Gourley and Bob Rabin (both NSSL), and Pierre-Emmanuel Kirstetter (ARRC at OU)

While the WSR-88D network provides fairly good spatial coverage over the eastern United States, gaps remain in the western U.S. where complex terrain limits how well ground-based radars can observe precipitation at low-levels. This limitation makes flash flood detection a significant challenge. Satellite-based rainfall products can provide much better spatial coverage, but coarse spatial and temporal resolutions have limited their usefulness at flash flood scales.

The Advanced Baseline Imager (ABI) set to launch on the GOES-R satellite will provide improved spatial resolution over current IR imagers (up to 2-km for some products), and the geostationary platform will allow for full CONUS scans at as high as a 5-minute time step. A new CONUS probabilistic QPE product is under development that will use a Bayesian scheme to match probability distributions of ABI cloud-derived fields to MRMS Q3 vertical profiles of reflectivity and surface rainfall rates.

During 2014, a two-year database was compiled that consists of GOES-R ABI proxy products, MRMS rainfall rates, VPRs, precipitation types, and the radar quality index (RQI), and TRMM PR vertical profiles of reflectivity. This project is ongoing.

13. Development of Web-Based Tools and Displays for Real-Time QPE and Hydrologic Analysis

Brian Kaney and Carrie Langston (both CIMMS at NSSL)

Within the hydrometeorology group, a cornerstone of all research and development has always been the evaluation of experimental products in real-time across the entire CONUS. The primary interfaces for this evaluation are the QPE Verification System (QVS; http://mrms.ou.edu) and the Radar Reflectivity Comparison Tool (RRCT; http://rrct.nwc.ou.edu).

During 2014, several updates and improvements were made to both systems, and an entirely new interface was developed for comparisons between ground-based and satellite-based QPE. This work is ongoing.

a. QPE Verification System

The update from NMQ to MRMS in August 2013 consisted of some fundamental changes in the way products are tiled, product time resolution and grid point identification (NW corner versus cell center). A new ‘Application Launcher’ scheme was adopted for the highest level of the QVS webpages. The tools in the former legacy QVS were ‘cut apart’ and reorganized and many new capabilities were eventually added.

This was by far the most extensive redo of the QVS since about 2006 when the system went from local domains to CONUS coverage.

Additionally, a complete overhaul was made of the rain gauge ingest stream. In particular, the move was made away from keeping separate gauge files for each data source, but instead to forming a true merger (a MRMS gauge group). The transition required extensive quality control of the separate gauge lists to remove duplicates and to address discrepancies within the gauge metadata. Much of this was completed within the past year, but work is ongoing.

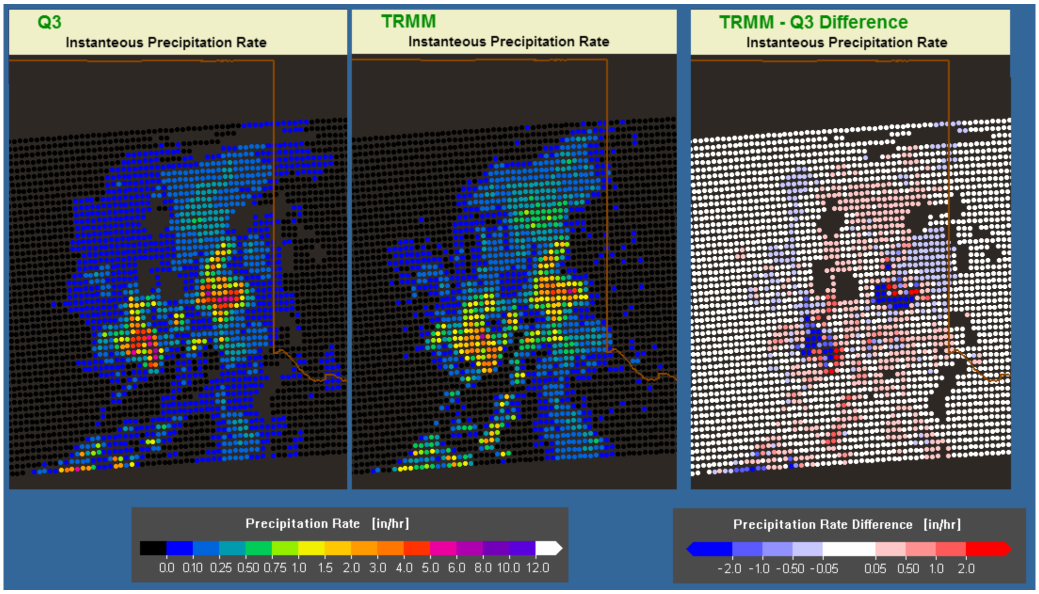
A significantly enhanced new version of the Gauge vs. QPE comparison tool was developed. New features include the ability to screen gauge/QPE pairs via extremes in G/R bias and the ability to open a window of end time 'mismatch' between the gauge and QPE report times. Other new features of the new QVS include new time series plotting options, real time ingest of mPING reports, and real-time display of dual-pol and legacy QPE coefficients used across the CONUS for all WSR-88Ds.

b. Differential Reflectivity Comparison Tool

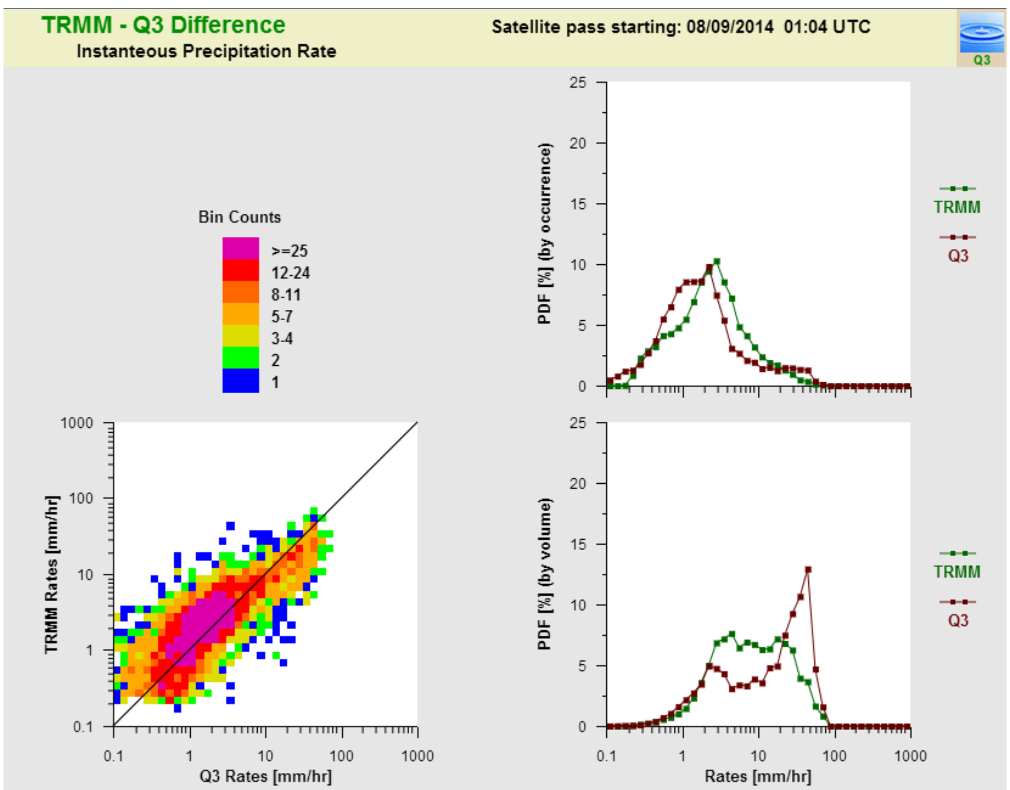
With support from the NWS Radar Operations Center, the RRCT display was updated to include relative comparisons of differential reflectivity, or ZDR, between radars. Accurate Z_{DR} retrievals are critical for dual polarization QPE algorithms, and knowing relative differences in collocated Z_{DR} values between adjacent radars can assist with evaluation of QPE performance. Work on the RRCT display is ongoing, with continued emphasis on assessment of radar calibration across the WSR-88D fleet.

c. TRMM vs. MRMS Q3 Comparison Tool

Created a web tool to display a precipitation rate map from TRMM satellite passes versus collocated (spatially and temporally) MRMS Q3 precipitation rates. Since the timing and location of a satellite pass is not a simple pattern, a small preview map quickly showing the location of many paths and levels of precipitation seen, was constructed. Maps of either of the two precipitation rates or a color-coded difference can be rapidly toggled (the first figure below). The same web tool also shows TRMM vs. Q3 precipitation rate comparisons in the form of scatterplots and dual probability density plots (second figure below). This project is ongoing.



Side-by-side comparison between Q3 and TRMM PR instantaneous precipitation rates (left, middle) and a difference plot between the two (right).



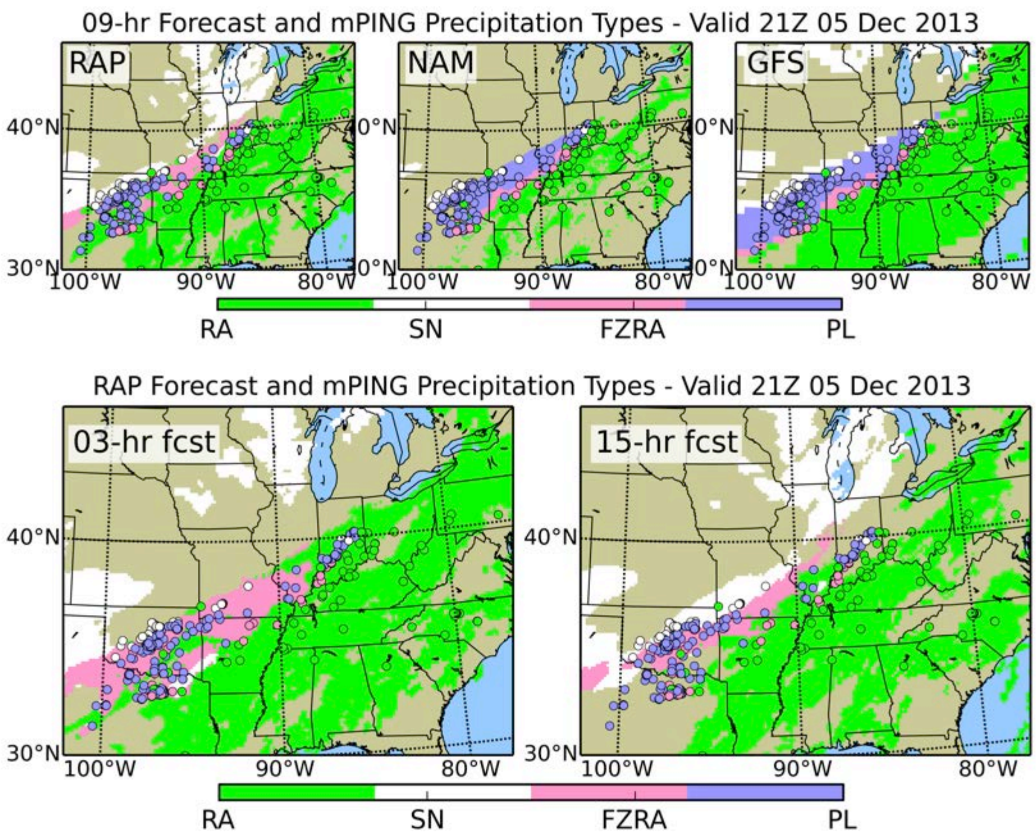
Statistical analysis of collocated Q3 and TRMM precipitation rates on the new TRMM-Q3 comparison tool. The lower left panel shows a scatterplot between the two rainfall products, and the two right panels show probability distribution functions on a log scale.

14. Crowd-sourcing Reports of Hydrometeor Type and Location Using mPING

Kim Elmore and Brian Kaney (both CIMMS at NSSL), and Zac Flamig (OU School of Meteorology)

The mPING (meteorological Phenomena Identification near the Ground) crowd-sourcing smart-phone app has continued to gain users (now approximately 65,000 download) and has generated over 635,000 report submissions. Recent work demonstrates that the reports are internally consistent. Internal consistency is a key to accuracy, since observations nearby in space and time should report similar or identical precipitation types. A BAMS paper describing the app has been accepted and appears in the September issue.

mPING reports have been used to verify numerical model forecast precipitation type from 03 to 24 h lead times for the NAM and GFS, 18 h for the RAP, in what constitutes a novel approach to precipitation type forecast verification. A paper summarizing these results is in review for *Weather and Forecasting*. This project is ongoing.



Model forecast precipitation type for 5 December 2013 valid at 2100Z (top). Forecasts precipitation type is shown by the filled contours while mPING observations are shown by the small colored dots, (color legend shown at bottom of plot). Images are for the 9 h forecast. Bottom panel shows 03 h (right image) and 09 h (left image) precipitation type forecasts for the RAP only, both valid at 2100Z.

15. 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.

A Random Forest classifier, described in the preceding year's report, has been developed and recently validated against several other methods. The random forest currently outperforms all other tested classifiers by a highly statistically significant margin. Unfortunately, the current coding technique, using within C++, is very inefficient and new methods need to be implemented to make the system operational. Fortunately, these problems have been resolved elsewhere; those methods will be implemented for the sake of efficiency in both CPU usage a memory usage.

This random forest is likely to benefit the current tasking for better quantitative precipitation estimation and so will be examined in a research capacity. This project is ongoing.

CIMMS Task III Projects – Next Generation Weather Radar Technology Research at OU *and* Multi-Mission Phased Array Radar Risk Reduction: A Collaborative Effort with the ARRC at the University of Oklahoma

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)

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

1. Effects of Transmit Schemes on Polarimetric Variables

Boon Leng Cheong (ARRC at OU) and Igor Ivić (CIMMS at NSSL)

Objectives

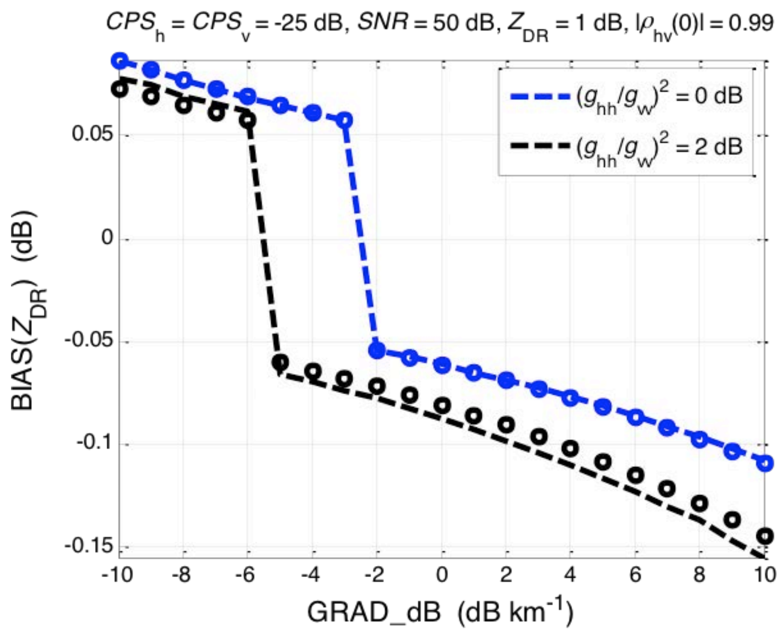
One of the key requirements of the MPAR is the collection of polarimetric variables. While traditional dish-like antennas can provide cross-polar isolation on the orders of 30 dB, patch antenna design is challenging to achieve similar isolation. A solution to improve this deficiency is by using a transmit scheme that can help improve the isolation/minimize the coupling. The primary objective of this project is to improve the polarimetric isolation through different pulsing scheme.

Accomplishments

A pulsing scheme called quasi-simultaneous was proposed as one of the solutions to improve the polarimetric isolation. Under this transmit scheme, the radar sends out the V-channel pulse immediately after the H-channel pulse. A pertinent trade-off is the doubling of end blind range of pulse compression technique since the total transmit cycle is now two times the pulse width plus the rest gap; although this transmit scheme can be applied independently with or without a pulse compression technique. However, the blind ranges may be potentially very short as the MPAR may have an excess of sensitivity due to the combined output power from multiple elements, in this case the pulse compression ratio may be very small. Of course, if no pulse compression is used, the quasi-simultaneous scheme introduces no blind range.

The primary test platform to validate this idea was the ARRC PX-1000, which is a solid-state X-band radar with arbitrary waveform generator. While most hardware were in place at the beginning of the project, significant effort was devoted into the development of digital transceiver to accommodate delayed transmit cycle and the timing block to synchronize the power amplifiers of the H and V channels. More work is underway but we anticipate data collection to be accomplished in the coming fiscal year.

Theoretical work was accomplished regarding the performance analysis of the proposed technique and it was determined that an additional isolation of -25 dB between H and V channels could be achieved with the proposed method. Through this work, it was also discovered that the transmit scheme is sensitive to the reflectivity gradient of the storm, particularly in range. Due to the non-simultaneous coverage / sampling of a volume, the leakage from one channel to the other could constructively interfere the sample on the other channel depending on the intrinsic differential phase of the sampling volume. The worst-case bias is up to 0.15 dB in differential reflectivity measurements if a reflectivity gradient of 10 dB km^{-1} is present. Of course, this is a rare case but does exist in nature.



This graph shows the maximum bias given a range of reflectivity gradient across range cells. At each gradient value, the differential phase that introduces the worst bias was selected to illustrate the maximum impact. Imbalanced gain of the H and V port also plays a non-negligible role in the bias of differential reflectivity estimates.

2. Optimal Pulse Compression Waveforms for MPAR

Robert Palmer and Boon Leng Cheong (ARRC at OU), and James Kurdzo (OU School of Meteorology)

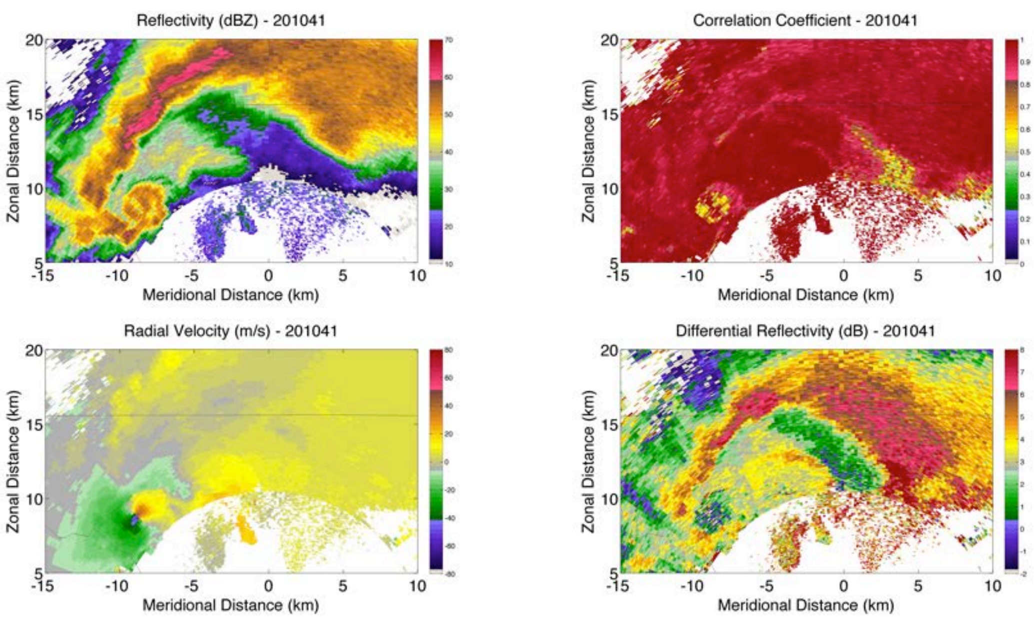
Objectives
The future of the MPAR program is dependent on numerous research thrusts that assume the use of individual transmit/receive elements in order to achieve fully digital design architecture. In order to alleviate excessive heat dissipation and cost concerns, it will be critical to utilize low power solid-state transmit elements and pulse compression techniques to achieve the necessary sensitivity and range resolution.

Accomplishments
The Advanced Radar Research Center at the University of Oklahoma has been developing novel waveform design techniques for weather radar platforms that provide excellent sidelobe performance while maintaining operational processing gains as high as 0.95 due to limited use of amplitude modulation. While directly applicable to weather observations, such waveforms are capable of lowering price points on all types of radar systems, ranging from military uses and aircraft detection to SAR applications. These waveforms have been implemented on the ARRC’s PX-1000 transportable, solid-state, polarimetric X-band weather radar, which operates at 100 Watts on each channel. Due to the very low peak transmit power, as well as a fully customizable waveform implementation and real-time signal processing architecture, PX-1000 serves as an excellent test bed for waveform research and development.

Exploration into Doppler tolerance correction, multi-lag calculation of polarization moments, blind-range mitigation, Nyquist mitigation, and volumetric scattering assumptions has been ongoing. Data collected using PX-1000 on 20 May 2013 during the Moore, OK EF5 tornado have led to the ability for unique meteorological analysis, as well as the ability to experiment with advanced waveform signal processing methods for extreme weather phenomena.

Waveforms have been designed and implemented on the Atmospheric Imaging Radar (AIR) and Cylindrical Polarimetric Phased Array Radar (CPPAR). The use of highly non-linear waveforms on the AIR, specifically, has allowed for increases of 9 dB in sensitivity and a factor of 5 in range resolution. These improvements have drastically increased the ability for the AIR to observe tornadic/supercellular phenomena at close range and in high detail for future analysis similar to that expected in future MPAR systems.

Additional work is well underway regarding the development of a series of waveform "families" for CPPAR; a concept that we believe will open numerous avenues for spectral flexibility in the MPAR concept. The future plans for this idea involve the ability to scan at high spatial and/or temporal resolutions, increase data quality, and offer new mitigation strategies for radio frequency interference.



From top left, clockwise: reflectivity, correlation coefficient, differential reflectivity, and dealiased radial velocity from the 20 March 2013 EF-5 tornado in Moore, Oklahoma at 2010:41 UTC, as observed by the ARRC's PX-1000 transportable radar platform. Despite only dual 100-W solid state transmitters, the radar is capable of seeing highly detailed aspects of the tornado and parent supercell at 100 meter range resolution (with a 10 km pulse).

3. Calibrated and Computationally Efficient Adaptive Beamforming

Robert Palmer and Feng Nai (ARRC at OU), and Sebastian Torres (CIMMS at NSSL)

Objectives

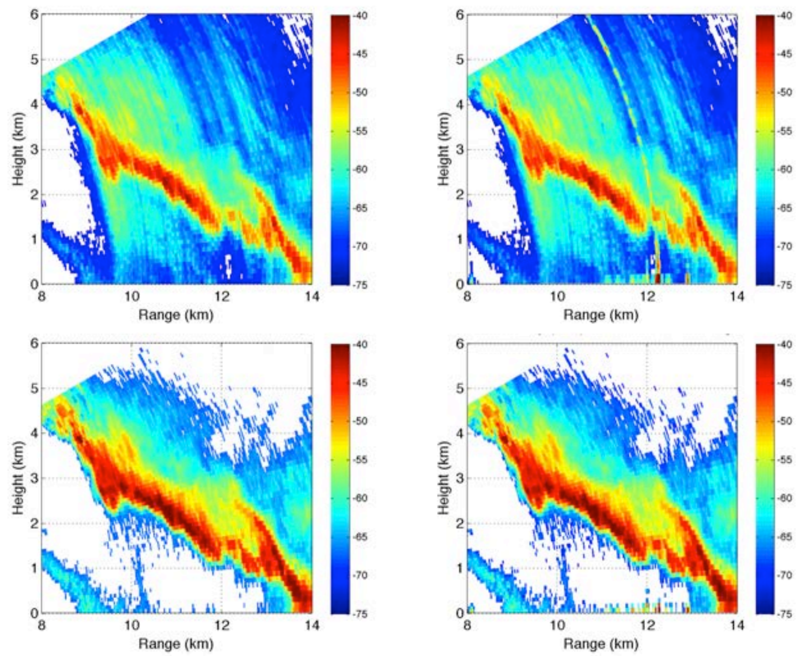
Active phased-array radars can adaptively change the beam pattern to mitigate the detrimental effects of interfering signals. Existing algorithms are computationally complex and cannot obtain accurate estimates of the meteorological variables. A calibrated and computationally efficient adaptive beamforming algorithm must be developed to achieve automatic interference nulling and to improve data quality.

Accomplishments

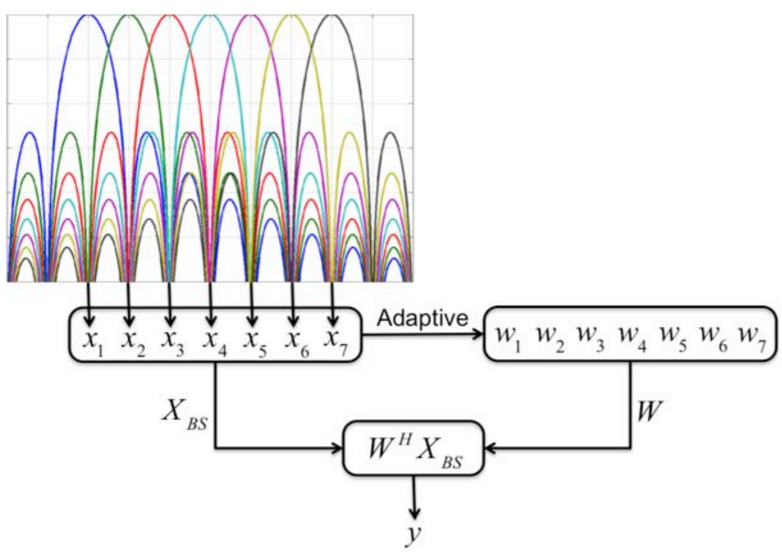
ARRC at OU has been developing a calibrated adaptive beamforming algorithm for active phased-array weather radars. Existing adaptive beamforming algorithms such as Capon and robust Capon has been evaluated for weather application. It has been demonstrated that robust Capon beamforming can mitigate non-stationary clutter such as wind turbine clutter (WTC) that would be extremely difficult to remove in the time or frequency domains. However, these algorithms are not completely satisfactory due to the difficulty in calibration of reflectivity estimates. The high sidelobe levels of the beam pattern generated by these algorithms, while nulling interference, prohibit a robust and efficient calibration procedure.

Another approach involves optimizing the adaptive weights under an extensive sidelobe level constrain. This approach guarantees a robust calibration procedure but trade off the capability for interference rejection. To reject unwanted interfering signal, direction finding and null steering must be performed to steer a null in the beam pattern to the direction of the interfering signal. This increases the computation complexity of the algorithm and makes it unattractive for real-time implementation.

Work is underway to investigate a more attractive approach that utilizes beamspace rather than element-space for processing. The beamspace algorithm first reduce the dimension of the received data by forming fixed-pattern preliminary beams, and the output of the preliminary beams are feed into an adaptive stage to automatically reject interfering signals. By breaking the beamforming algorithm into two stages provides two important benefits: 1) accurate calibration can be done on the output of the first stage, and 2) with reduced data dimension in the adaptive step, the beamspace algorithm is computationally simpler, which makes the algorithm more attractive for real-time implementation. Extensive simulations study is ongoing to select optimum parameters values, and to ensure proper performance across a variety of weather scenarios.



From top-left, clockwise: signal power of weather signal using Fourier beamforming, signal power of weather signal contaminated with WTC using Fourier beamforming, signal power of weather signal using robust Capon beamforming, and signal power of weather signal contaminated with WTC using robust Capon beamforming. Compared to the images in the right column, the impact of WTC at higher elevations is significantly reduced. Furthermore, the leakage of power from the strong core of the storm to other elevation is reduced as well.



Flowchart of the beamspace adaptive processing. In this example, seven preliminary beams are formed and the outputs are labeled x_1 to x_7, adaptive weights are derived using these output and labeled w_1 to w_7, the overall output is the multiplication and summation of the adaptive weights and the preliminary beam outputs.

4. Resource Management for MPAR to Optimize Performance

Tian-You Yu (ARRC at OU and OU School of Electrical and Computer Engineering), Sebastian Torres (CIMMS at NSSL), and David Schvartzman (ARRC and OU School of Electrical and Computer Engineering)

Objectives

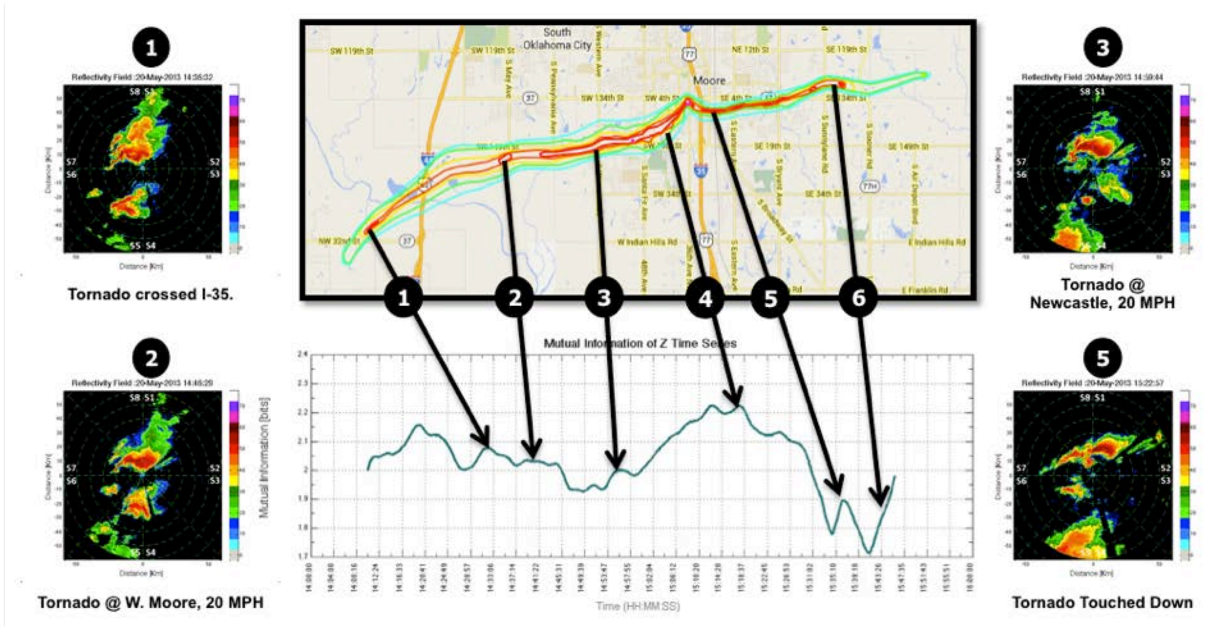
Multi-function Phased-array radar (MPAR) can execute multiple tasks that are traditionally carried out by individual and independent radars. In addition, MPAR is also ideal for adaptive weather sensing given the capability of dynamic and semi-instantaneous beam steering. In this project, the overarching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

Accomplishments

The essential consideration of trade-offs for weather observations includes data quality, spatial sampling, and update time with the goal of improving weather forecasts. Previously, a rudimentary resource management was attempted by the team to gracefully degrade the requirement of data precision to achieve better update time of the storms. The major accomplishment is to investigate the feasibility of information-theory-based methods for driving adaptive weather sensing. The distinguishing attribute of the information measures is that they provide a single metric able to automatically capture the complex tradeoffs involved in the design of scanning strategies for weather observation.

We discovered that the Mutual Information provides a better and more general criterion to investigate relationships between variables. We studied spatial and temporal relationships of weather radar data (focusing mainly in reflectivity field time-series) using information theoretic measures. Using a 2D variant of the Shannon entropy we assessed the level of structuredness of the reflectivity field in spatial dimensions and using mutual information we quantified changes in the temporal dimension. With those variables as indicators of weather phenomena being observed, we derived an adaptive scanning strategy that adjusts update times of different regions of interest of the scene as well as spatial resolutions for those same regions.

As an example, the 2013 Moore tornado case was studied using high temporal and spatial resolution data collected with the University of Oklahoma Advanced Radar Research Center's PX-1000 radar. The Mutual Information between consecutive reflectivity fields is computed as a measure of similarity in the evolution of the weather phenomena in time, and the result is shown in the figure below. The tornado path as reported by the NWS is carefully compared in time to the obtained mutual information plot shown below. As we can see, when the tornado intensifies the mutual information decreases in time (points 1, 2 and 3 shown) and as the tornado starts decaying (point 4) the mutual information starts increasing because the dependence between consecutive scans grows. After crossing Interstate 35 (point 5) the tornedo re-strengthens and again we see a decrease in the mutual information. It starts decaying again after a few minutes and it vanishes (point 6), increasing the mutual information.



Mutual Information of Z time-series computed for the Moore-2013 Tornado.

5. Configurable Phased Array Demonstrator (CPAD) – A Sub-topic of the ARRC's MPAR Risk Mitigation

Yan (Rockee) Zhang, Sudantha Perera, and Xining Yu (all ARRC at OU and OU School of Electrical and Computer Engineering)

Objectives

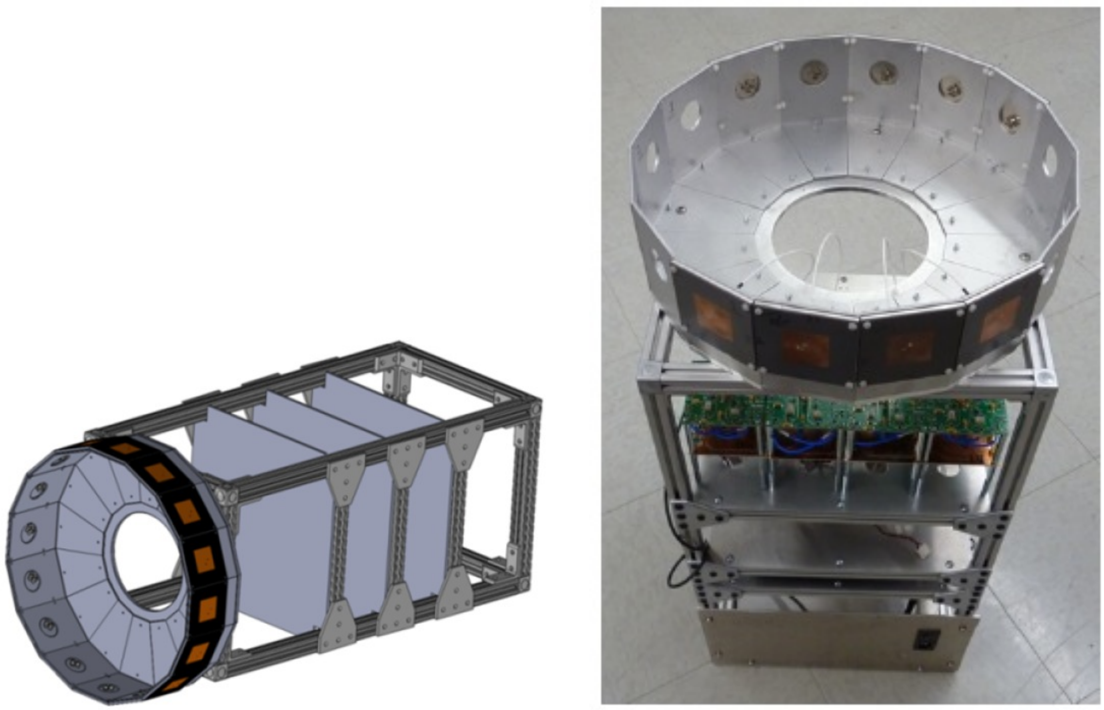
This sub-project is for the engineering risk mitigation of Multi-functional Phased Array Radar (MPAR). The Configurable Phased Array Demonstrator (CPAD) is a small scale, low cost, reconfigurable polarimetric phased array antenna testbed, which is developed to study cross-polarization and side lobe level of active phased array antennas with various element configuration and manifolds. Studying of cross-polarization and side lobe levels with measurements and simulations will pave the way for bringing about possible improvements of phased array antennas in weather radar applications.

Accomplishments

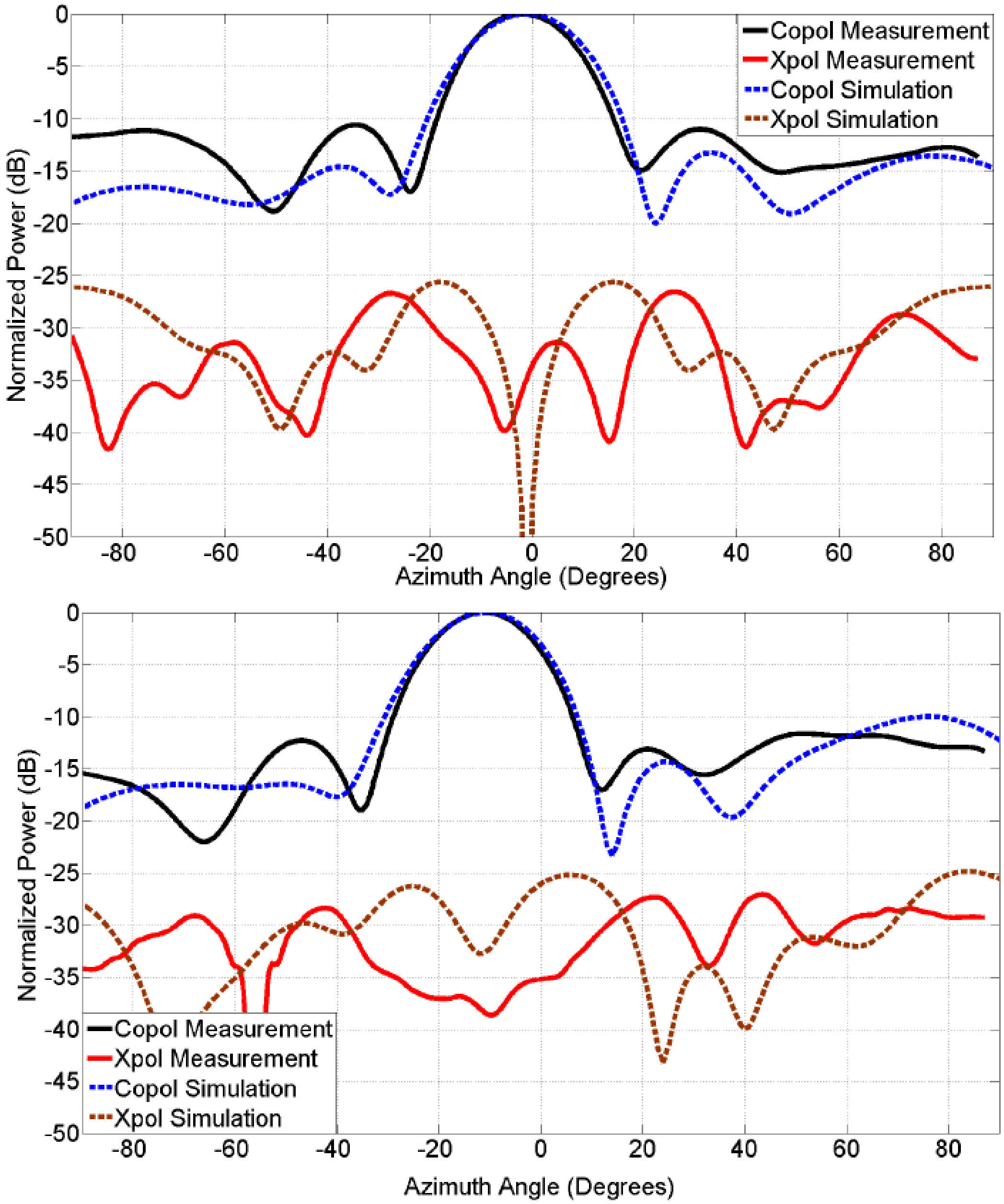
a. Using CPAD to Demonstrate Circular Phased Array Antennas

There are two possible beam steering method for cylindrical phased array antennas, which are commutating scanning and electronic scanning. Cylindrical array with commutating scanning method has unique improvements over planar configuration with electronic scanning, since it can produce an identical antenna pattern at each azimuth angle. But the resolution on radar display will be lower, depending on how many columns on the cylinder. Electronic scanning will provide much smoother scanning for

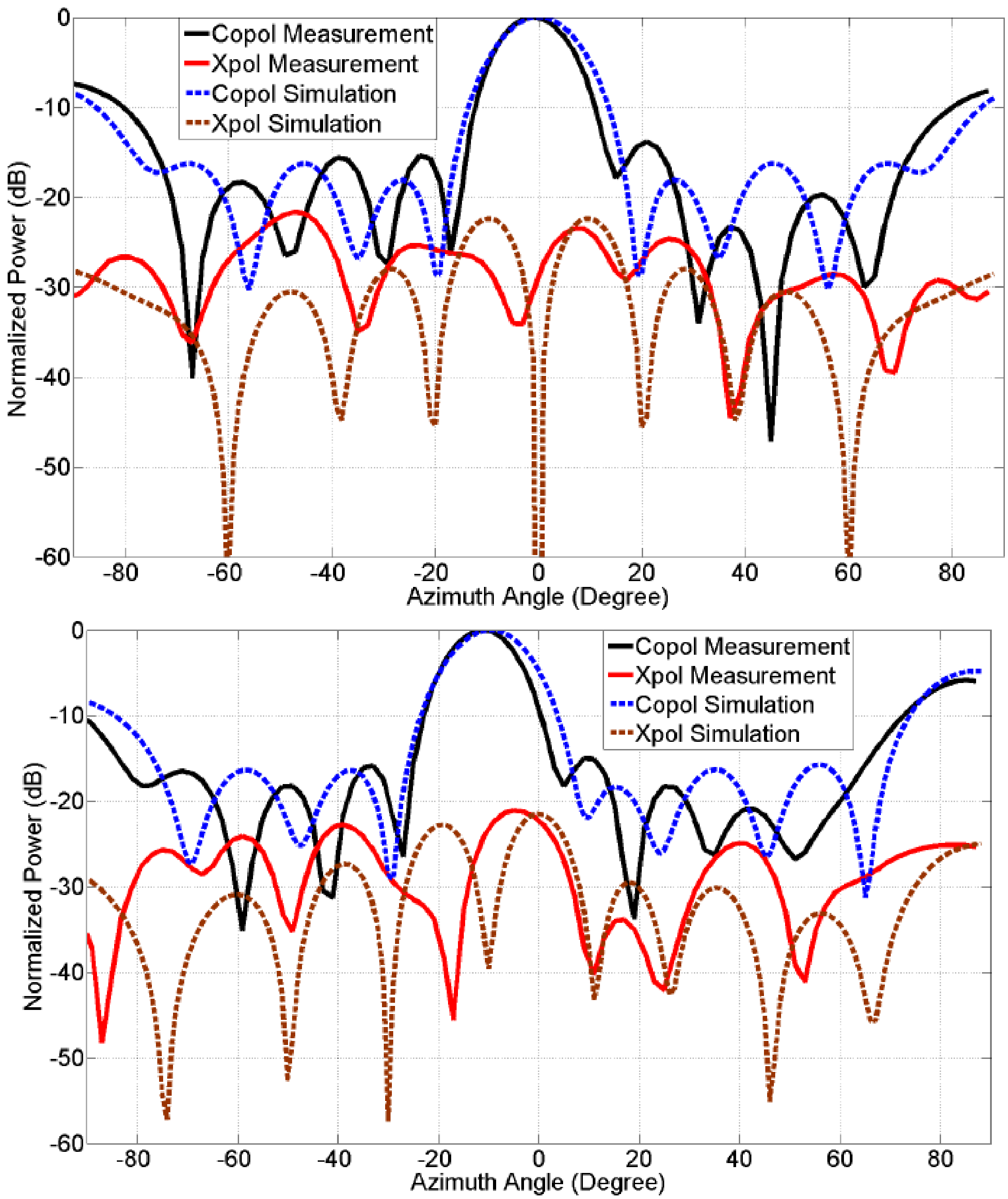
high resolutions. In this study, sixteen-element planar array was configured into sixteen-element full circular array (first figure below). The measurements and simulations of four-element (second figure below) and eight-element (third figure below) circular arrays are taken. This exercise concluded that CPAD could be reconfigured into scalable cylindrical array antenna manifold with minimum change to antenna structure.



Left: 3D model of polarimetric circular array configuration; Right: four-element circular array manifold to study the polarimetric array pattern variation with different scanning angles.



Measured and simulated 4 element Circular array patterns. (a) broadside beam, (b) 10 degree beam-steering.



Measured and simulated 8 element Circular array patterns. (a) broadside beam, (b) 10 degree beam-steering.

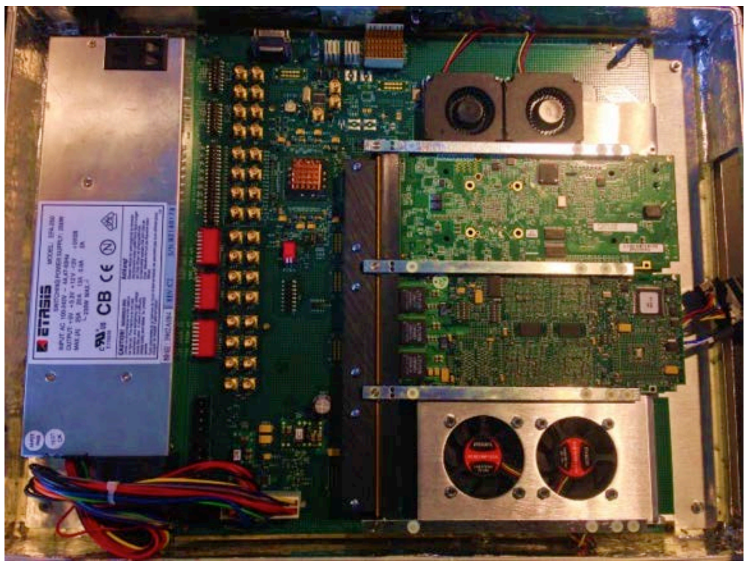
b. Application of Full-Wave FDTD Method in Phased Array Antenna Simulation

Many research groups implement FDTD as a part of their work and some of the implementations are published as open source products. Carrying out feasibility study for introducing periodic boundary condition in simulation of phased array antennas using open source electromagnetic simulation program was started, as a part of the CPAD

project. This program will be able to use in simulation and optimizing sparse array (non-periodic) and larger phased array antenna (periodic).

c. MPAR Backend Analysis

A small-scale MPAR backend testbed based on DSP and Rapid-IO (figure below) is successfully developed and being used to evaluate the real-time data transportation performance and algorithm execution perform in a full-scale MPAR. Associated system simulations are also performed and presented in NWC seminar.



Small-scale testbed for MPAR backend.

6. Polarimetric Phased Array Radar Configuration and CPPAR Demonstrator Calibration

Guifu Zhang (ARRC at OU and OU School of Meteorology), Shaya Karimkashi (ARRC at OU), Richard Doviak (NSSL), Lei Lei (ARRC at OU and OU School of Electrical and Computer Engineering), and other ARRC and NSSL Engineers

Objectives

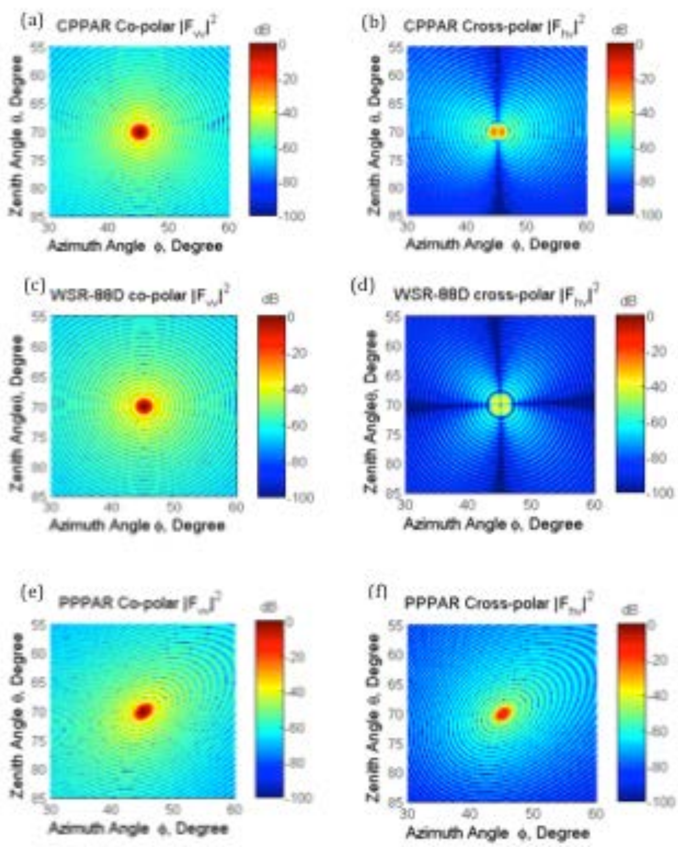
While polarimetric radars with a dish antenna can make accurate multi-parameter weather measurements and the NEXRAD radar network has been upgraded with the dual-polarization capability, the performance of Polarimetric Phased Array Radar for weather remains as an issue to be resolved. Their copolar and cross-polar radiation patterns and cylindrical polarimetric phased array radar (CPPAR) calibration are studied to reveal their advantages and disadvantages.

Accomplishments

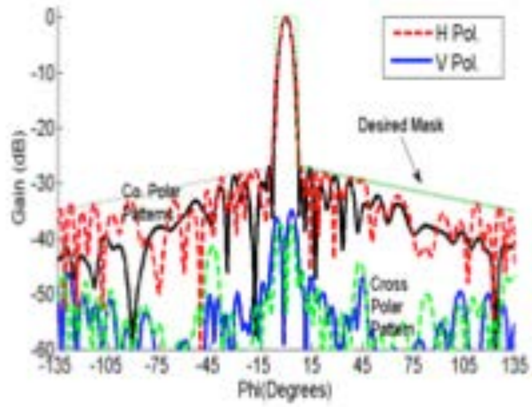
We calculated and compared the copolar and cross-polarization radiation patterns of parabolic dish, planar array and cylindrical array antennas, as shown in the first figure

below, the top row is for a cylindrical array, the middle row for a parabolic dish, and the bottom for a planar array. The cylindrical array (top row) has a symmetric copolar pattern, like the WSR-88D dish (middle row), and has a null on its cross-polar pattern that allows for high accuracy of polarimetric measurements of weather. The planar array (bottom row) has an elongated elliptical copolar pattern and has a coaxial cross-polar peak 12.4 dB below the copolar peak, which is not acceptable for polarimetric measurements of weather. Two calibration approaches: i) simple copolar radiation matching, ii) full correction matrix, have been proposed and studied in Lei et al. (2014).

Although the CPPAR has several advantages such as polarization purity and azimuthal scan-invariant beam characteristics, there is concern as to how to achieve the desired performance in designing a cost-effective CPPAR and in making accurate polarimetric measurements, which require further study. Column antennas have been designed and mounted on the 2-m CPPAR demonstrator, as shown in the left half of the second figure below (Karimkashi et al 2013a&b). The antenna pattern for horizontal polarization is different from that for vertical polarization due to the different effects of mutual coupling. As shown in right half of the second figure below, the matched main beams of the horizontal and vertical polarizations with low sidelobes are achieved through optimization (Karimkashi and Zhang. 2014).



Copolar and cross-polarization radiation patterns for cylindrical array (top row), dish antenna (middle row), and planar array antenna (bottom row).



Left: A picture of the CPPAR demonstrator; Right: Matched copular radiation patterns through optimization.

7. Joint Signal Processing for Simultaneous Weather Measurement and Target Detection with MPAR in the Presence of Clutter

Guifu Zhang (ARRC at OU and OU School of Meteorology), Dusan Zrnic and Richard Doviak (both NSSL), Lesya Borowska (ARRC at OU), and Yinguang Li (ARRC at OU and OU School of Electrical and Computer Engineering)

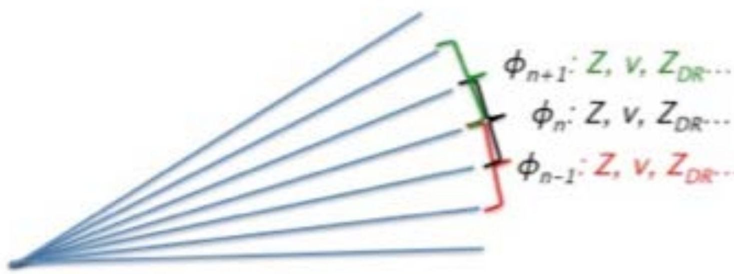
Objectives

It has been realized that it is difficult to meet all MPAR mission requirements with a single beam from each sector of the MPAR. Increasing the number of simultaneous beams would complicate the MPAR system & operation and increase the development cost. It is therefore important to find an efficient scan strategy and the corresponding signal processing for decision-making regarding the MPAR design/development and operation. This is feasible because weather measurements have different requirements for angular resolution and sensitivity at different elevations, and the MPAR will have flexibilities in choosing beamwidth, steering beam direction, and generating waveforms. These flexibilities are useful and should be (and can be) optimally used by using a hybrid scan strategy and developing advanced signal processing algorithms.

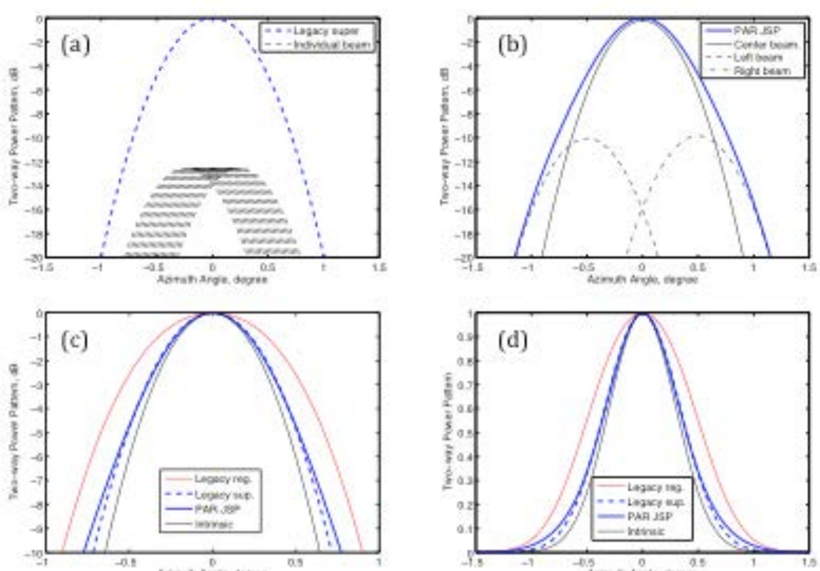
Accomplishments

To effectively utilize the MPAR resources, we proposed a hybrid scan strategy (Zhang et al. 2014a). The hybrid scan strategy contains: i) using a narrow beam with uniform PRTs at low elevations (< 2 deg) to achieve high resolution & sensitivity and clutter cancellation; ii) using staggered PRT Beam-Multiplexing (SBMX) for middle elevations (2 ~ 10 degrees) to save sampling time; iii) using a broad beam at high elevations (> 10 deg). This scan strategy facilitates a volumetric scan in 30 seconds with a single beam from each sector and it would save the MPAR R&D cost by using fewer simultaneous transmitting beams, but require fundamental research in signal processing to meet requirements for weather surveillance.

To obtain super-resolution weather measurements, we propose to collect samples with the azimuth separation of a half-beamwidth, and with a half of the number of pulses, without having to increasing the total data update time (Zhang et al 2014). To preserve the measurement accuracy, the samples from adjacent beams are jointly processed to obtain accurate moment data and effectively mitigate ground clutter, as shown in the first figure below. Comparisons between legacy super-resolution beam and PAR JSP beam patterns are shown in second figure below. Since the PAR JSP beam has a similarly effective pattern as the legacy super-resolution beam, it is expected that the super-resolution data can be obtained with the PAR JSP. This is being tested with the NWRT data.



Conceptual sketch of joint processing of MPAR signals for fast data update.



Comparison of antenna patterns between legacy super-resolution beam and the PAR JSP beam: a) legacy super-resolution beam patterns, b) PAR JSP beam patterns, and c) & d) comparison of effective beam patterns in decibel and linear unit.

8. Cost-Efficient Antenna Element Designs for MPAR

Shaya Karimkashi and Thomas Grabow (both ARRC at OU and OU School of Electrical and Computer Engineering), and Richard Doviak (NSSL)

Objectives

Square patch antenna seems to be a cost-efficient choice for MPAR antenna; however, there are several issues, which should be considered. The cross polarization pattern is relatively high on the other planes but the principle planes, the presence of the surface waves can seriously affect the performance of the antenna array and the strong coupling between the neighboring elements cause defected radiation patterns. Designing a miniaturized single element or an antenna element isolated from the others. Furthermore, taking the substrate materials into account, the fabrication of patch antennas could be very costly. Some other candidates considered for the MPAR antenna include cross dipoles, waveguide slots, slot-dipole pairs, horn apertures, and dielectric resonators. Although cross dipoles, slot-dipole pairs, and horn apertures show a very high performance in cross-polarization isolation, the fabrication process could be very costly. The main goal is to compare all different candidates for MPAR antenna element.

Accomplishments

Different element antennas including microstrip patch, slot-dipole, cross dipole, cross slot, and dielectric resonator antennas are considered as the candidates for the antenna element. The table below compares the several antennas properties. Although more studies are needed to find the best antenna element for the MPAR, initial studies show that microstrip patch is still a very good candidate. The stacked patch microstrip antenna seems to be a promising solution for the antenna since the desired bandwidth, low cross polarization and a very high isolation can be achieved. In addition, this antenna has been designed and developed for many years for the array antennas.

Comparing different antennas

	Isolation	Cross-Polarization	Cost	Efficiency
Stacked Patch	high	good	moderate	high
Slot-Dipole	high	moderate	high	high
Dielectric Resonator	moderate	moderate	high	high
Cross dipole	moderate	moderate	moderate	high

9. Phase Mode Analysis and Calibration of Large Cylindrical Arrays, Including the CPPAR Demonstrator

Caleb Fulton and Ali Mirkamall (both OU School of Electrical and Computer Engineering), and Matt McCord, John Meier, and Redmond Kelley (all ARRC at OU)

Objectives
Identify or establish the relationship between the modal expansions coefficients in large cylindrical arrays and the fields, mutual couplings, and fundamental polarization accuracy limits they represent.

Compare different candidate element geometries and structures in the context of their embedded element patterns—which are based on the above relationships and large-array simulations that exploit these relationships. The CPPAR demonstrator is an important data point in this study.

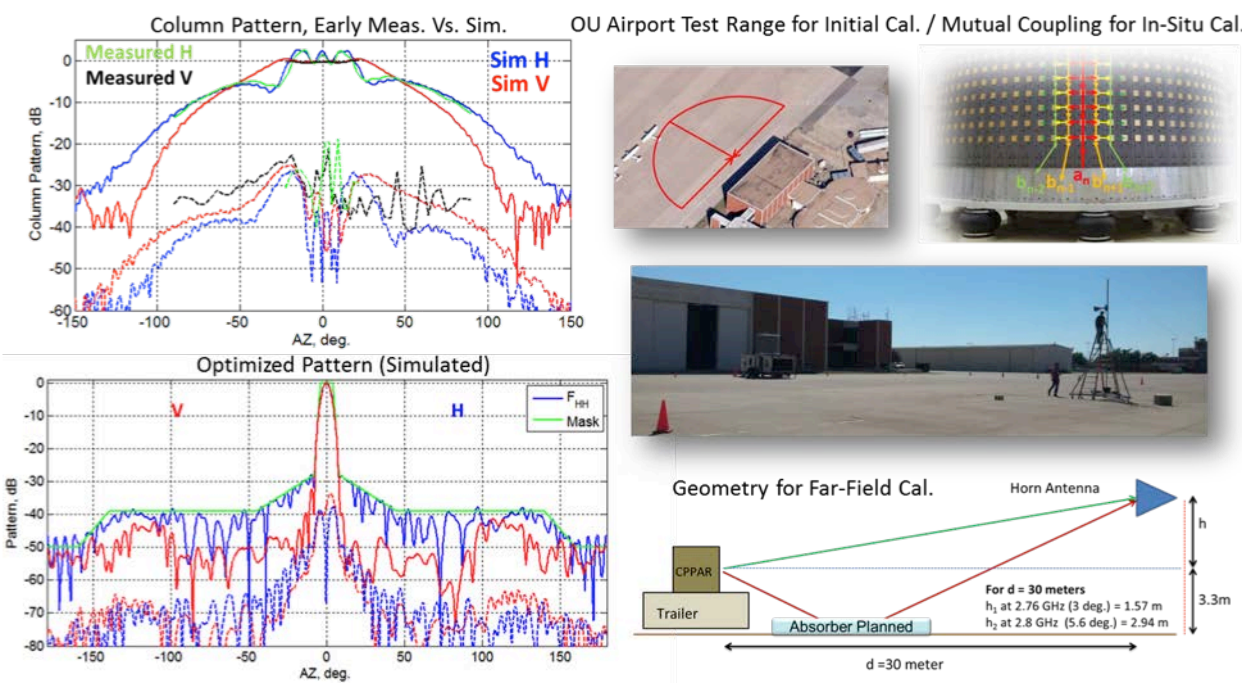
Establish a framework for calibration of a CPPAR that both separately and collectively addresses the requirements and challenges for initial and in-situ calibration, quantifying the effects of random calibration errors after adjustment for systematic element-factor errors. Identify practical measurement limitations for different calibration procedures, including mutual coupling/simulation-supported calibration, near-field calibration, and far-field, outdoor range calibration schemes, and apply these to the CPPAR demonstrator. If measurement resources are available, directly compare the CPPAR's performance to other available demonstrator arrays, such as the 9x9 dual-pol stacked patch from Purdue University, the 12x12 slot-dipole from LMCO/BCI, and the planar version of the CPPAR antenna.

Accomplishments
An extensive theoretical and simulation-based study was conducted to establish the formal relationships between the phase mode (spectral) coefficients of unit cell-based simulation fields and the fields radiated by an element embedded within a large cylindrical array. This was also extended to include the polarimetric version of such patterns/fields, as well as the couplings between two elements. Two journal articles were written, and were submitted after the reporting period. As part of this study, a simulation technique was developed using a commercial finite element solver to evaluate the embedded patterns and couplings of arbitrary elements.

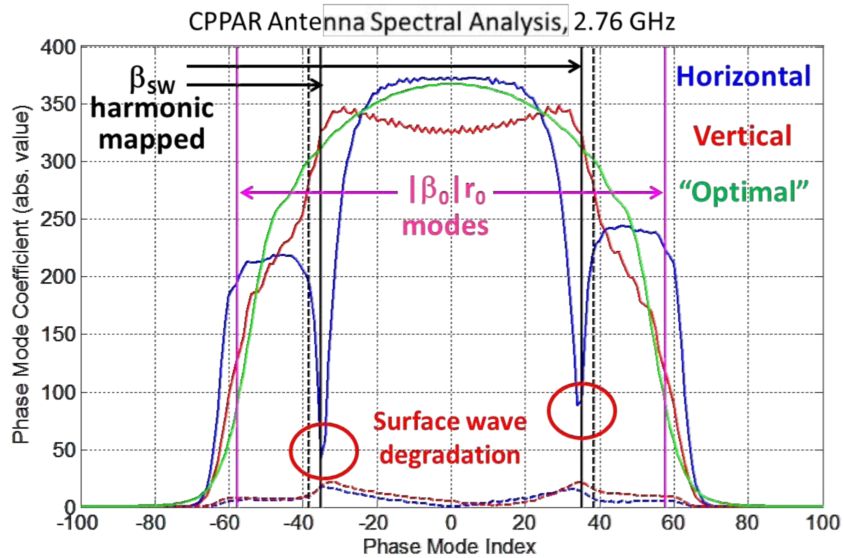
Using this simulation technique, a number of results from the literature were reproduced for simple elements, as documented in the aforementioned articles, after which an extensive analysis of the CPPAR demonstrator antenna was undertaken. As shown in the top left of the first figure below, these simulations match the early measurements quite well over the ranges in which measurements could be taken. The patterns were further subjected to an advanced iterative/adaptive pattern synthesis algorithm over the face of the CPPAR antenna to determine potential limits in forming MPAR-friendly patterns in terms of polarization purity, sidelobe levels, and sector-to-sector isolation. As exemplified in the bottom left plot in second figure below, it was found that while it may be possible (with perfect calibration and no mechanical errors) to form MPAR-friendly patterns with the CPPAR demonstrator, there are fundamental issues associated with the wide element spacing and the excitation of a surface wave during horizontal polarization transmission/reception. The latter is shown in the phase mode spectral representation of the patterns in the third figure below, where the relevant harmonic indices of the surface wave have been noted. The current conclusion is that

future CPPAR antennas should use a combination of thinner dielectric layers and smaller element spacing in order to more easily achieve low sidelobes and better sector-to-sector isolation.

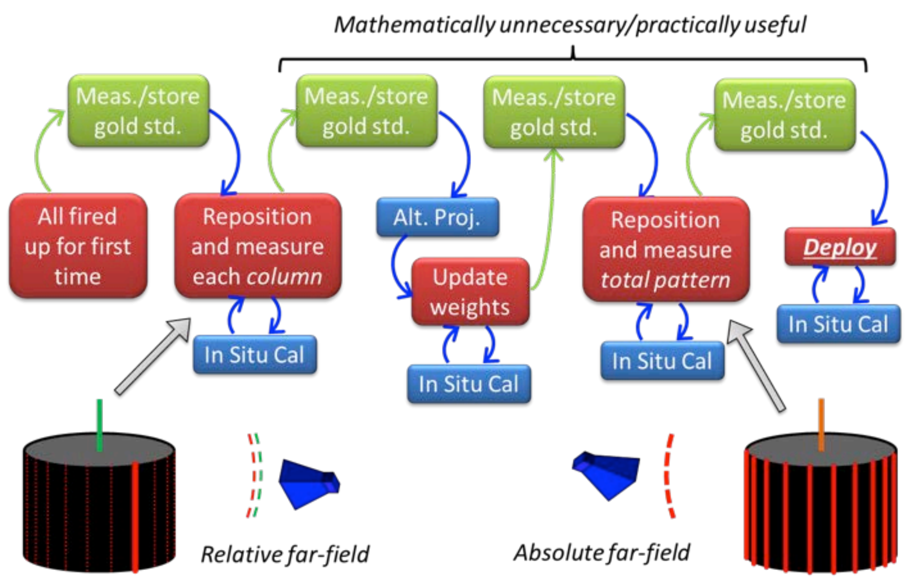
The framework for CPPAR demonstrator calibration is summarized in third figure below, where it shows the steps that will be taken throughout the process. The far-field measurement process from last year, shown to the right of the first figure below, will be improved through the addition of specular patch absorbers and a more accurate interferometric approach to amplitude and phase measurements of column and total patterns. Errors associated with ground reflections and antenna sidelobes have been estimated, and were found to be on the order of -40 dB, roughly 6 dB worse than what would be required for a full size MPAR array. An extensive mutual coupling algorithm has been developed for in-situ calibration to maintain amplitude and phase in the channels over temperature and time, and errors in this algorithm have been quantified relative to those associated with mechanical changes to the antennas themselves. Finally, the near-field test capabilities at OU have been brought online right after the end of this reporting period, and the 9x9 dual-pol stacked patch from Purdue, the 12x12 slot-dipole from LMCO/BCI, and the planar version of the CPPAR antenna will soon be measured and compared.



Simulated and measured CPPAR Demonstrator patterns (top left), Optimized simulated patterns (bottom left), and calibration scheme (right).



Phase mode (spectral) analysis of the CPPAR Demonstrator antenna, revealing that the degradation of the horizontal polarization's patterns is attributable to the excitation of a surface wave and its subsequent interaction with the widely spaced elements.



Detailed CPPAR Demonstrator calibration strategy, making use of careful far-field measurements backed up by in-situ temperature compensation for channels and RF cables

10. Real-Time Digital Beamforming for Cylindrical Phased Arrays

Caleb Fulton (OU School of Electrical and Computer Engineering), Redmond Kelley and Matt McCord (ARRC at OU), and Blake McGuire and Blake James (OU School of Electrical and Computer Engineering)

Objectives

Identification of current and future processing and I/O hardware building blocks that are suitable for such functions in an MPAR-like context, as well as how the overall performance of the architectures will scale with these changes in technology.

Determination of a recommended architecture for a mid- to large-scale cylindrical polarimetric phased array radar (CPPAR) based on near-future hardware and the results of a tradeoff study revolving around the aforementioned framework, and development of a simplified, baseline hardware concept for possible implementation of these enabled real-time, scalable multi-function, and multi-beam capabilities on the a mid-scale (terminal, or T-) CPPAR demonstrator***.***

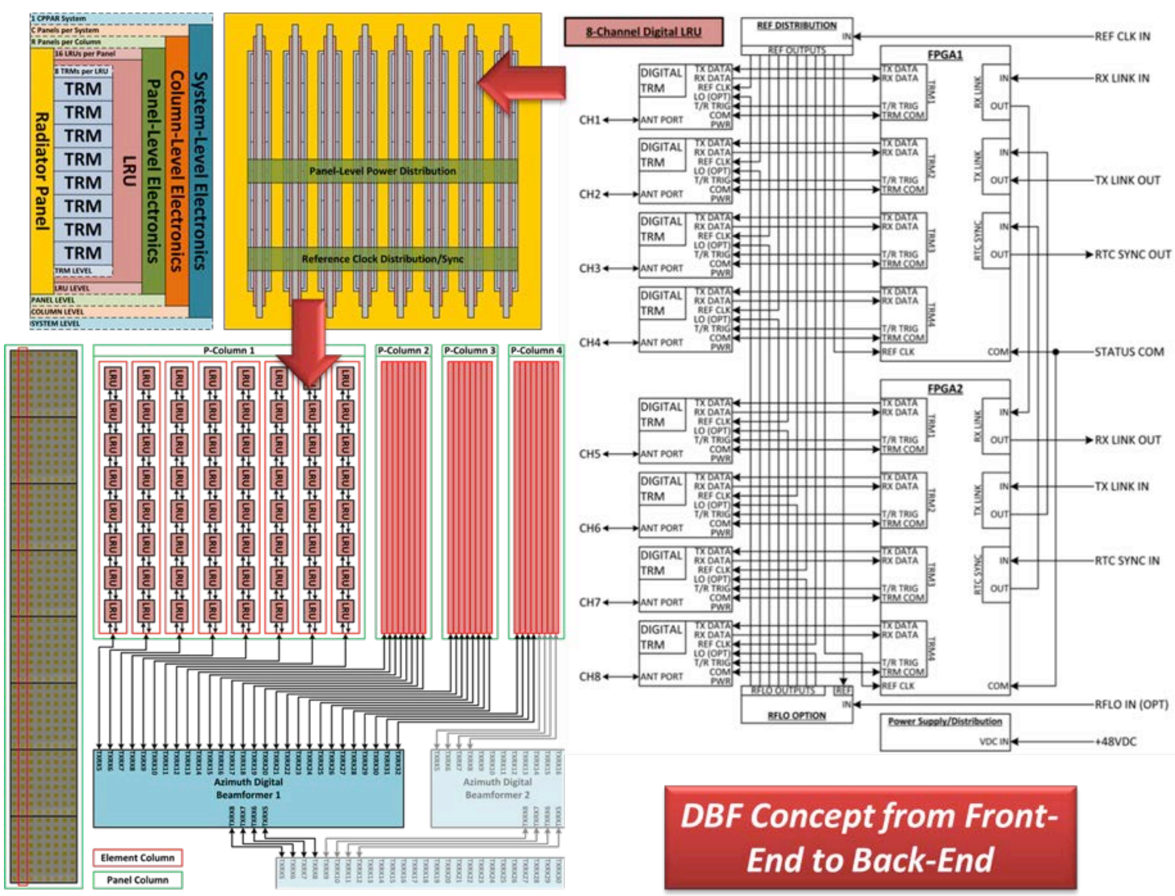
Determine the human, hardware, and time resources that would be required for the development of this baseline solution on the T-CPPAR demonstrator *(note: this is fully documented in the CPPAR Design Study Report, and is not detailed here).*

Accomplishments

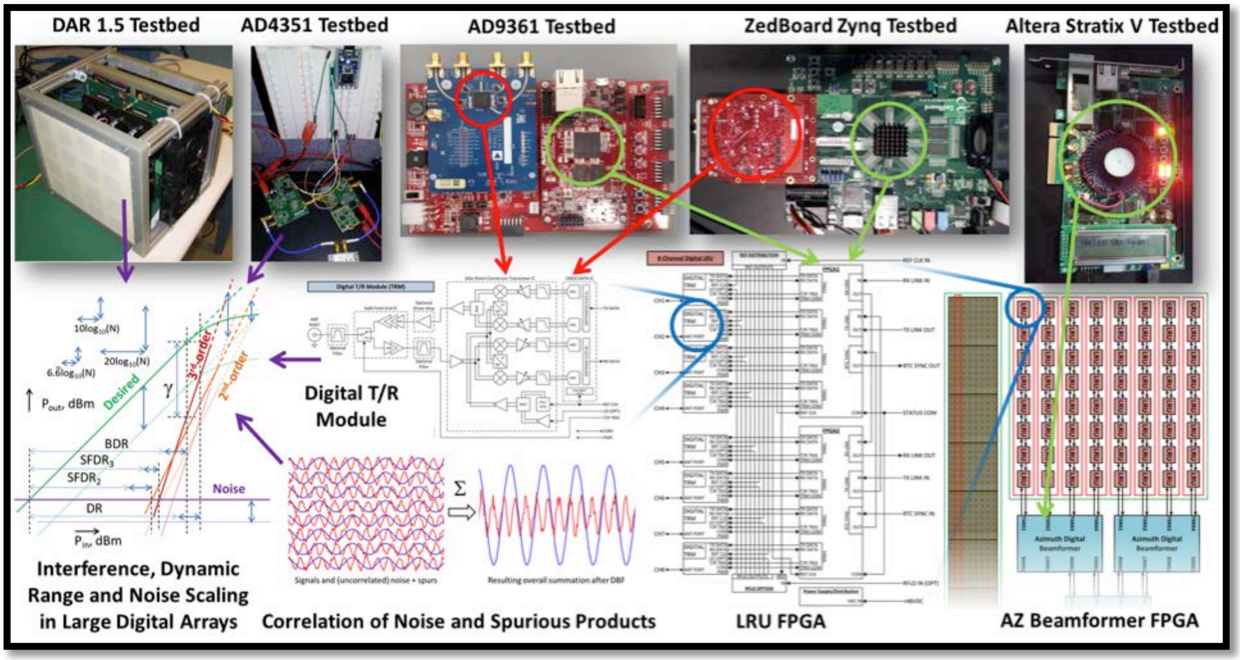
The primary research-oriented aspect of this study was to determine the extent to which emerging FPGA architectures could play a role in a large, full-scale, highly-digital array (including digital at the element level). Traditional FPGAs feature programmable hardware that is very well-suited to many radar functions, such as direct digital synthesis, matched filtering/equalization, fast Fourier transforms, and digital beamforming, they must often be paired with CPUs in order to interface with higher-level system functions at some point in the radar system. Recently, FPGA manufacturers like Xilinx have begun to place dedicated CPU hardware into their devices. Blake McGuire explored, as the research portion of his master's thesis, the benefits and limitations of using the Zynq line of FPGAs in this type of application. It was found that there is an optimal division of labor between the hardware and software functions on these devices, with high-speed and pipelined processing being performed on the FPGA side, and the CPU side handling more decision-dependent algorithms such as command, configuration, scheduling, packetization, and calibration functions. This is the current philosophical approach to a number of related development efforts, including a T-CPPAR subarray.

Another primary accomplishment of this work was the concept development of a digital architecture that would provide the necessary digital beamforming functionality for a T-CPPAR with digitization of signals at the element level. Such architecture represents a step beyond the current "RF to RF" MPAR demonstrators at surprisingly similar costs, and is novel in and of itself in the global history of phased array systems. Owing to the bandwidth and dynamic range requirements for MPAR, this architecture comes with

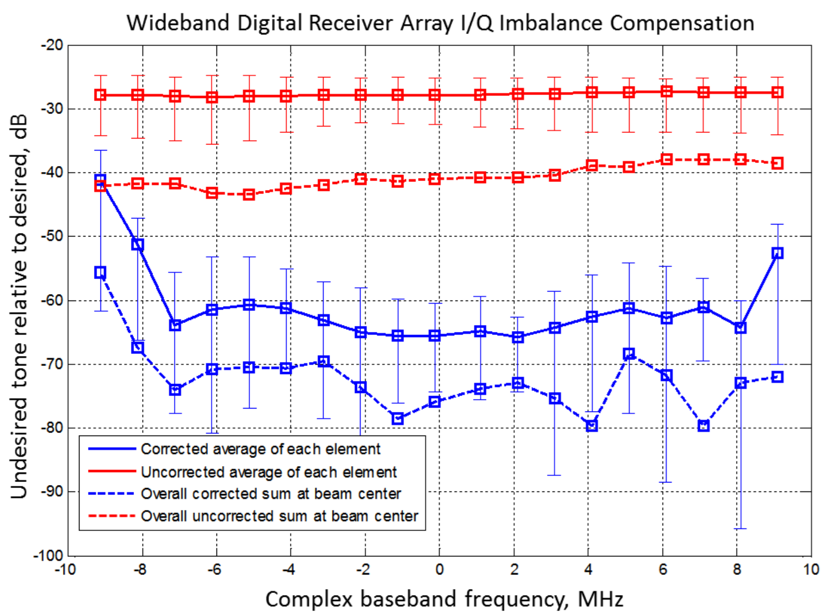
risks that may be more significant for the digital software (control and high-level functionality) and firmware (synchronization of data) than of the RF functions. Thus, this architecture demands careful planning of I/O and processing resources. The first figure below shows the architectural concept resulting from the initial study: a hierarchical/systolic front-end consisting of mid-range, Zynq-like FPGAs for interface, control, and elevation beamforming, paired with a smaller number of slightly more high speed FPGAs forming a parallel azimuth beamforming stage. As detailed in the CPPAR Design Study Report, it supports nearly an order of magnitude more digital beams than should be required for a T-CPPAR, offering many potential areas for future research. However, in the process, a number of risk areas were identified, including dynamic range/signal quality scaling in low-cost transceivers, timing and control systems for element-level digitization (e.g. Blake McGuire's project), and high-speed interconnects for the back-plane azimuth beamformer; each is currently being investigated through a number of testbeds, as shown in the second figure below. The third figure below shows a recent example of the performance improvements that element-level calibration and digitization bring to low-cost, element-level transceivers; here, the analog image rejection limitations in highly-integrated, direct-conversion transceivers have been virtually eliminated through FPGA-friendly, element-level processing.



Overall concept for cylindrical array digital beamformer resulting from this work and the OU/NSSL CPPAR Design Study.



Testbeds that are being used to mitigate risks associated with a large-scale, fully digital array; this includes risks ranging from analog/RF to high-speed parallel I/O in a digital backend.



Wideband direct conversion transceiver image rejection algorithms demonstrated using representative hardware, the ARMY Digital Array Radar demonstrator.

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Awards

G. Zhang, D. Zrnic, and L. Borowska: "Joint Signal Processing for High Efficiency in MPAR Development and Development" OU Intellectual Property Disclosure (#15NOR003), 14 July 2014.

G. Zhang: "MPAR Scan Strategy with Hybrid Waveforms" OU Intellectual Property Disclosure (#14NOR014), 11 October 2013.

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

Mark Yeary (ARRC at OU and School of Electrical and Computer Engineering), and Redmond Kelley and John Meier (both ARRC at OU)

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, and associated data studies.

Accomplishments
The digital backend achieves these objectives: (1) acts as real-time synchronous scan controller, (2) excites RF transmit channels, (3) digitizes RF receive channels and transports raw data pulses into computer, and (4) accepts commands from radar controller. Major tasks that were completed for the Digital Receiver-Exciter (DREx) are as follows:

- DREx documentation shipped
- DREx "dummy server" software shipped
- RF Plates and IF Gold Box tested and shipped
- DREx hardware test-ready software shipped
- DREx final documentation and functionally complete software with test client shipped

In terms of the RF Transceivers, they were 100% physically complete as of 3-26-2014. Each component (TRCTL, LVDD, UDC) has been tested. In terms of the Intermediate Frequency (IF) IF Transceivers, as of 3-26-2014, they were 100% physically complete. The figure below depicts a photo of the IF transceiver. The transceiver has 8 digital cards. Each card has 2 digital waveform generators and 2 digital receivers; hence each of the 8 cards are suitable to support one dual-pol channel. In total, the IF Transceiver box has 16 digital receivers and 16 digital waveform generators. The intermediate frequency is 70 MHz. For synchronization between IF Transceivers, each unit has a SYNCin and SYNCout port that uses an RJ45 connector. Each IF Transceiver relies on a 10 MHz reference signal that is input via an SMA connector. Initial hardware functionality testing has been completed. The IF transceiver tx and rx channels were very stable across temp and should not require additional characterization or calibration.

The ARRC backend has the following features: acts as real-time synchronous scan controller; excites RF transmit channels; digitizes RF receive channels and transports raw data pulses into computer; and accepts commands from radar controller. Software interface commands include: Initialization (bitstreams, synchronization, enumeration); triggering setup (enables, PRTs, pulsewidths, delays); transmit waveform setup (*f* steps, cal, A/φ offset); receive setup (decimation, filter coeffs, cal); RF setup (LO frequencies); status & health (readiness, temps, faults, dataflow); and data acquisition. This project is ongoing.

8-Channel Intermediate Frequency (IF) Transceiver box. Each channel is a dual-polarization digital receiver (two-inputs for H and V) and dual-pol waveform generator (two outputs for H and V).

Theme 2 – Stormscale and Mesoscale Modeling Research and Development

NSSL Project 3 – Numerical Modeling and Data Assimilation

NOAA Technical Leads: Louis Wicker, 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

Overall Objectives

Verification, visualization, and new forecast diagnostic methods are being developed and tested for severe weather forecasting applications for Warn-on-Forecast (WoF) and Hazardous Weather Testbed (HWT) 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 annual HWT Spring Forecasting Experiments, as well as within the real-time, 4-km grid-spacing experimental version of the Weather Research and Forecasting (WRF) model known as the NSSL-WRF, which is run locally and utilized by the SPC for operational severe weather forecasting. The projects described below are ongoing.

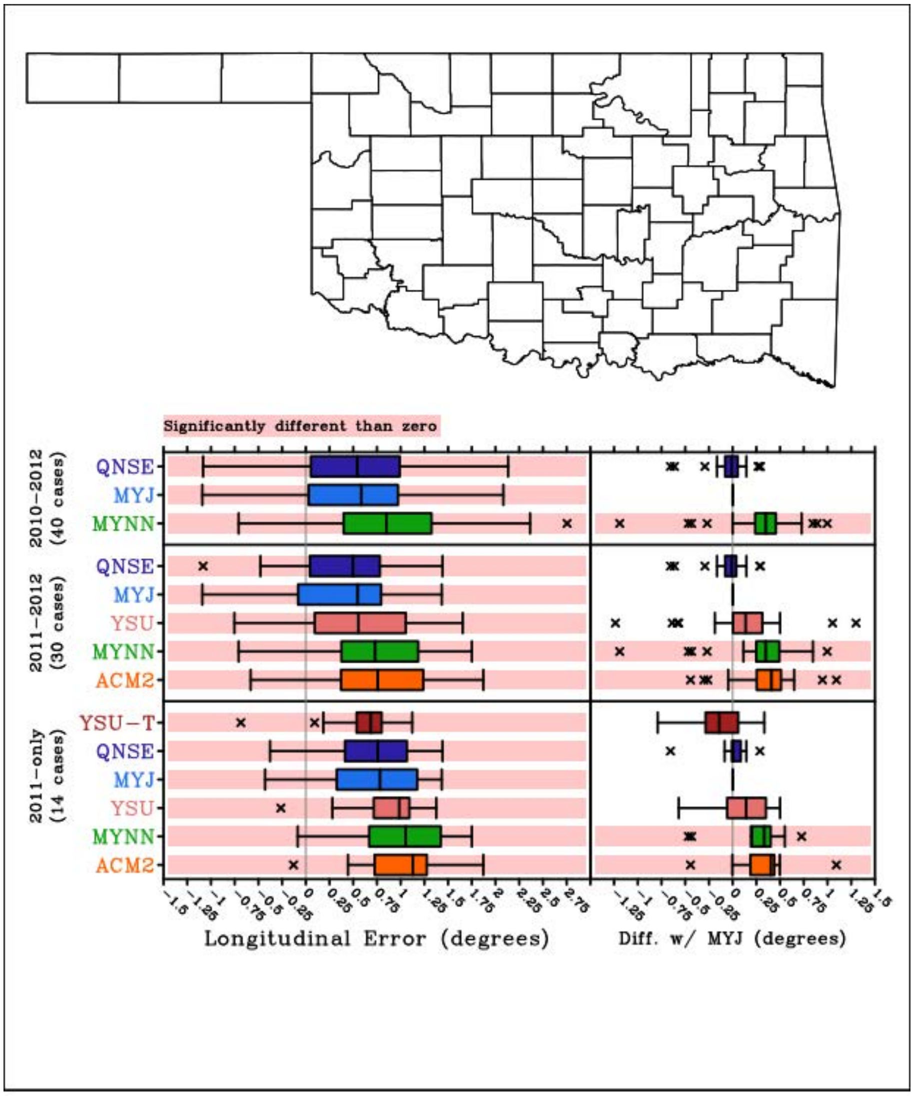
Accomplishments

1. Sensitivity of Forecast Dryline Position and Structure to Boundary Layer Parameterizations in Storm-Scale WRF Model Simulations

Adam Clark (CIMMS at NSSL), Michael Coniglio (NSSL), Brice Coffer (North Carolina State University), Greg Thompson (NCAR), and Ming Xue and Fanyou Kong (both CAPS at OU)

Research was completed in which the sensitivity of forecast dryline position and structure to boundary layer parameterizations in storm-scale WRF model simulations was examined. The research utilized three years of data provided by CAPS in support of the HWT Spring Forecasting Experiments during 2010-2012. The boundary layer schemes MYJ, QNSE, ACM2, YSU, and MYNN were examined. Main results include: Despite having superior temperature/moisture profiles as indicated by a previous study, MYNN was one of the worst performing PBL members exhibiting large eastward errors in forecast dryline position. During 2010-2011, a dry bias in the North American Mesoscale (NAM) model initial conditions largely contributed to eastward dryline errors in all PBL members. An upgrade to the NAM model and assimilation system in October 2011 apparently fixed the dry bias reducing eastward errors. Large sensitivities to

CAPE and low-level shear were found, which were largest between 1.0° and 3.0° degrees east of drylines. Finally, modifications to YSU to decrease vertical mixing and mitigate its warm/dry bias greatly reduced eastward dryline errors.



Box plots for the distribution of average longitudinal 24 h forecast dryline position errors for the sets of cases covering 2010-2012, 2011-2012, and 2011-only (left side). The right side box plots are for the differences in 24 h forecast dryline position with respect to MYJ. The interquartile range (IQR) within each box plot is colored according to the particular boundary layer scheme (indicated on y-axis). The under-laid pink shading indicates that differences with respect to the observations (left side) or MYJ (right side) were statistically significant at α = 0.05. The median is indicated by the straight black line through each box, the box encompasses the IQR, outliers defined by values outside of 1.5 x IQR are marked by crosses, and horizontal lines (whiskers) denote the smallest and largest values that are not outliers. The map of Oklahoma is shown for reference – its horizontal scale matches that of the x-axis for the box plots.

2. An Automated, Multi-Parameter Dryline Identification Algorithm

Adam Clark (CIMMS at NSSL), Andrew MacKenzie (OU School of Meteorology), Amy McGovern (OU Department of Electrical and Computer Engineering), Valliappa Lakshmanan (CIMMS at NSSL), and Rodger Brown (NSSL)

This study was part of a MS thesis by Andrew MacKenzie, but has been taken over by Adam Clark since Andrew graduated in Fall 2013. This work aims to streamline dryline identification by developing an automated, multi-parameter dryline identification algorithm, which applies image-processing and pattern recognition techniques to various fields (and their gradients) to identify drylines. The algorithm is applied to five years of high-resolution 24 h forecasts from Weather Research and Forecasting (WRF) model simulations valid April-June 2007-2011. Manually identified dryline positions, which were available from a previous study using the same dataset, are used as “truth” to evaluate the algorithm performance. Generally, the algorithm performed very well. High probability of detection scores indicated that the majority of drylines were identified by the method. However, a relatively high false alarm ratio (FAR) was also found indicating that a large number of non-dryline features were also identified. Preliminary use of a “random forest” (machine learning technique) significantly decreased the FAR, while minimally impacting the POD. The algorithm lays the groundwork for applications including model evaluation and operational forecasting, and should enable efficient analysis of drylines from very large datasets.

3. Comparing the NSSL-WRF Model and Convection-Allowing Versions of UKMET’s Unified Model During the 2013 and 2014 NOAA HWT Spring Forecasting Experiments

Adam Clark (CIMMS at NSSL), Steve Willington and Dan Suri (both UK Met Office), Jack Kain and Mike Congilio (both NSSL), Kent Knopfmeier (CIMMS at NSSL), Steve Weiss and Israel Jirak (both SPC), Humphrey Lean, Nigel Roberts, and Mark Weeks (all UK Met Office), Andy Dean (SPC), Chris Melick (CIMMS at SPC), Chris Karstens (CIMMS at NSSL), Patrick Marsh (SPC), James Correia (CIMMS at SPC), and Scott Dembek (CIMMS at NSSL)

Beginning in 2013, NSSL and SPC established collaborations with the United Kingdom Meteorology Office (Met Office) as part of annual NOAA/HWT Spring Forecasting Experiments (SFEs). For these collaborations, the Met Office provided 48 h forecasts over the continental US from convection-allowing 4.4- and 2.2-km grid-spacing versions of their Unified Model (UM) during the 5-week long period of the 2013 and 2014 SFEs (ICs/LBCs were derived from the 25-km grid-spacing global version of the UM). Additionally, several Met Office researchers and forecasters participated in the SFEs, while monitoring UM data flow and forecast products. So far, this collaboration has been extremely beneficial. The Met Office has been able to implement some of the unique storm-scale diagnostics developed at NSSL/SPC like simulated reflectivity and updraft-helicity, as well as examine forecast quality over a much more geographically

diverse region than the United Kingdom. Meanwhile, NSSL and SPC have been able to examine forecasts of convection from a high-resolution modeling system completely independent of the WRF model and other US modeling systems. Also, because the Met Office has devoted a very large effort to accurately depicting the boundary layer due to its importance in the UK, the NSSL/SPC were particularly interested in the quality of forecast low-level vertical profiles from the convection-allowing versions of the UM since this is well-known weakness in US models.

To gauge the quality of the convection allowing UM forecasts, daily subjective comparisons of simulated reflectivity were made to the 4-km grid-spacing NSSL-WRF and corresponding observations. The NSSL-WRF is a real-time modeling framework that has been used to provide storm-scale guidance to SPC forecasters since 2006 and is generally highly regarded. Thus, the NSSL-WRF serves as a well-known baseline against which to compare the UM forecasts. In addition, forecast soundings from the NSSL-WRF and UM were compared. Generally, the UM compared very favorably to the NSSL-WRF. In fact, for the majority of cases during 2013 and 2014, the UM was rated as better than the NSSL-WRF. Also, a striking difference between the NSSL-WRF and UM was noticed for forecast vertical profiles of temperature and moisture when capping inversions were present. The UM oftentimes very accurately depicted the sharp gradients in temperature and moisture at the interface of the boundary layer and elevated mixed layer, while the NSSL-WRF and high-resolution WRF model simulations in general had very smoothed out temperature/moisture gradients at this interface. Because these capping inversions are such important factors in convective initiation, further investigations are planned.

4. Implementation and Evaluation of the HAILCAST Algorithm for Explicitly Forecasting Hail Size in Convection-Allowing Models

Adam Clark (CIMMS at NSSL), Becky Adams-Selin (U.S. Air Force Weather Agency), and Scott Dembek (CIMMS at NSSL)

For the first time during the 2014 NOAA/HWT Spring Forecasting Experiment, a maximum hail size diagnostic was output from the various convection-allowing models produced by CAPS and NSSL, which was based on the HAILCAST model coupled to WRF-ARW. Rather than predict hail size explicitly, the HAILCAST model uses convective cloud and updraft attributes to determine the growth of hail from initial embryos. The cloud attributes for the model are those predicted explicitly in the WRF-ARW forecasts and the snow, ice and graupel mixing ratios at the first level above the freezing level at which they exist are used to determine the initial embryo size. For the formal evaluation activity, explicit predictions of hail size from the HAILCAST model within the NSSL-WRF ensemble were evaluated against storm reports and the WSR-88D-derived maximum expected size of hail (MESH) product developed by NSSL as part of the Warning Decision Support System – Integrated Information (WDSS-II) suite of algorithms. It was found that the initial version of HAILCAST severely over-predicted hail sizes. Thus, since the 2014 Spring Forecasting Experiment, Becky Adams-Selin has made numerous changes to HAILCAST, and these changes were implemented in

the current version of the NSSL-WRF. Examination of the updated HAILCAST version shows that it produces much more reasonable maximum hail sizes. Further investigations are ongoing.

5. Developments and Implementation of the NSSL-WRF Ensemble

Adam Clark and Scott Dembek (both CIMMS at NSSL), Israel Jirak (SPC), and Chris Melick (CIMMS at NSSL)

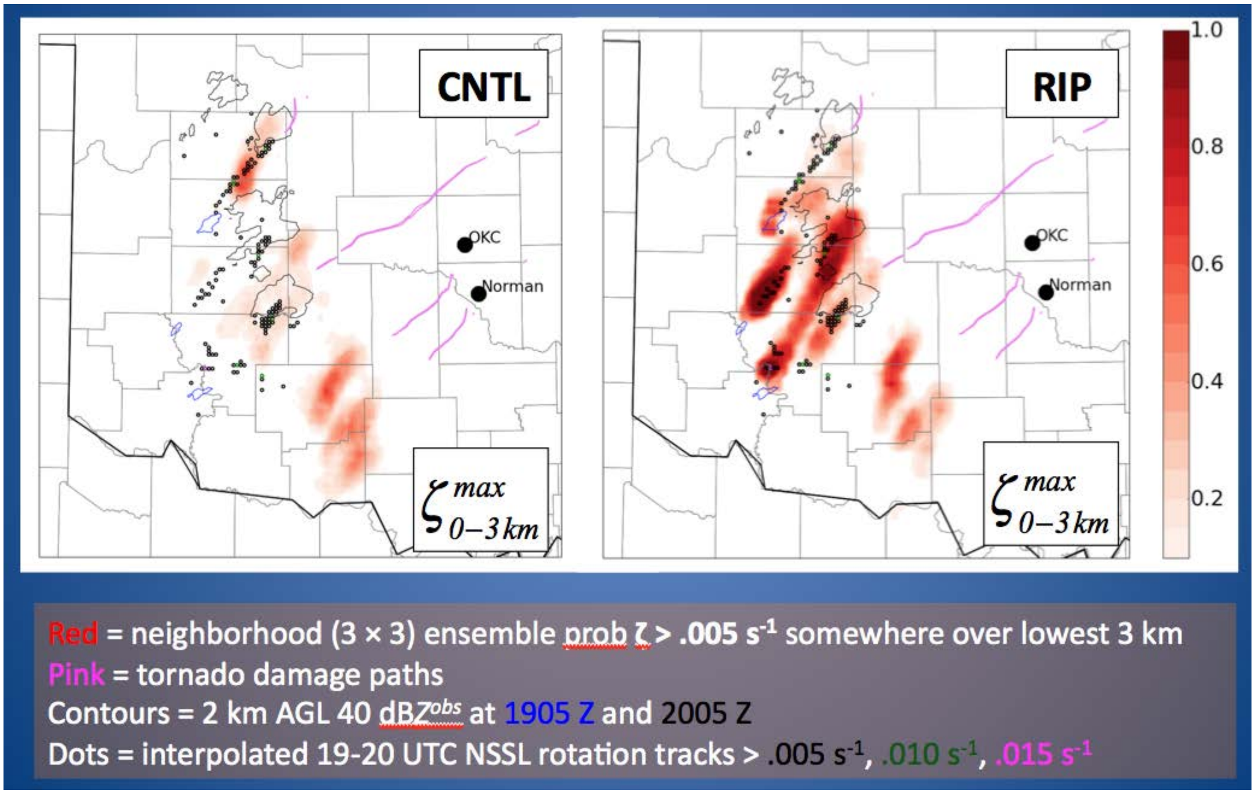
In January of 2014, NSSL was granted an increate in computing allocation on the Jet HPC cluster, which is being used to run a year-round, real-time, nine-member convection-allowing ensemble. This ensemble, which is known as the NSSL-WRF ensemble uses the NSSL-WRF as a control member (ICs/LBC from the NAM), with the other eight members using NCEP's SREF system for ICs and LBCs. The ensemble system will serve as permanent ensemble framework to provide guidance to SPC forecasters and serve as a testing ground for developing an optimal ensemble configuration and useful storm-scale ensemble diagnostics. The ensemble began running in March 2014 and was tested and evaluated in the 2014 NOAA/HWT Spring Forecasting Experiment. Also, a new public website has been developed for displaying the real-time forecasts (www.nssl.noaa.gov/wrf/newsite).

6. Developing the WRF-LETKF System and Testing Convective-Scale Ensemble Data Assimilation Techniques

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

Ensemble Kalman filter (EnKF) data assimilation on convection-allowing scales presents unique challenges. For example, the reflectivity forward operator is highly nonlinear, violating one of the Kalman filter assumptions, and the development of reasonably accurate ensemble covariances is typically slow during the first several radar volume insertions. To address these and other problems, I am applying novel techniques that were developed for meso- and synoptic-scale applications to convection-allowing scales. In concert with those efforts, I'm continuing to refine and expand the capabilities of our WRF-LETKF system, which may become an important part of our near-future Warn-On-Forecast (WoF) prototype system.

During the reporting period, I coded two data assimilation techniques within our WRF-LETKF system: Running-In-Place (RIP) and Gaussian anamorphosis (GA). These technique have not previously been applied to convective-scale EnKF radar data assimilation. RIP is intended to accelerate ensemble spin up, allowing useful forecasts to be produced after fewer analysis cycles (i.e., increasing forecast lead time). GA is intended to make error distributions more Gaussian, thus better satisfying the Kalman filter assumptions and improving EnKF analyses and forecasts. Both techniques are being tested using two tornadic supercell days in Oklahoma: 19 May 2013 and 24 May 2011.



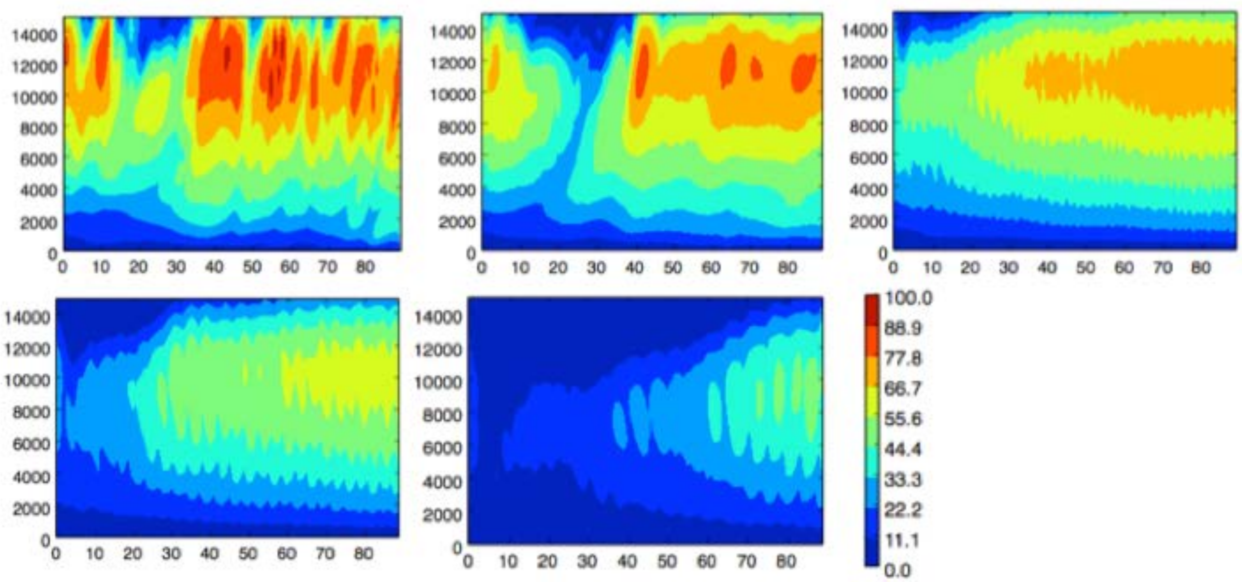
Neighborhood ensemble probabilities (shading) of vertical vorticity > 0.005 s^{-1} over a 1-h forecast initialized after a single LETKF analysis cycle without (left) and with (right) Running-In-Place. NSSL rotation tracks (circles) are used as verification.

7. Grid Spacing Sensitivity of Supercell Forecasts

Corey Potvin (CIMMS at NSSL) and Montgomery Flora (NSF REU Program)

Current computational limitations prevent real-time ensemble forecasting systems from being run on convection-resolving grids, and tradeoffs between ensemble size and model grid spacing will likely be required through the foreseeable future. Understanding of forecast errors arising from finite model resolution is required to optimize such tradeoffs and guide interpretation of ensemble output during operations.

During the reporting period, I ran deterministic, idealized WRF simulations with horizontal grid spacings of 333 m and 1, 2, 3, and 4 km. My REU student, Monte Flora and I then compared the coarser simulations to the 333 m (control) simulation to explore impacts of limited model resolution on operationally important model output such as low-level mesocyclone track and evolution, maximum surface wind speed, and rainfall. The work, which is ongoing, is expected to help guide the configuration of a future in-house, real-time Warn-on-Forecast prediction system.



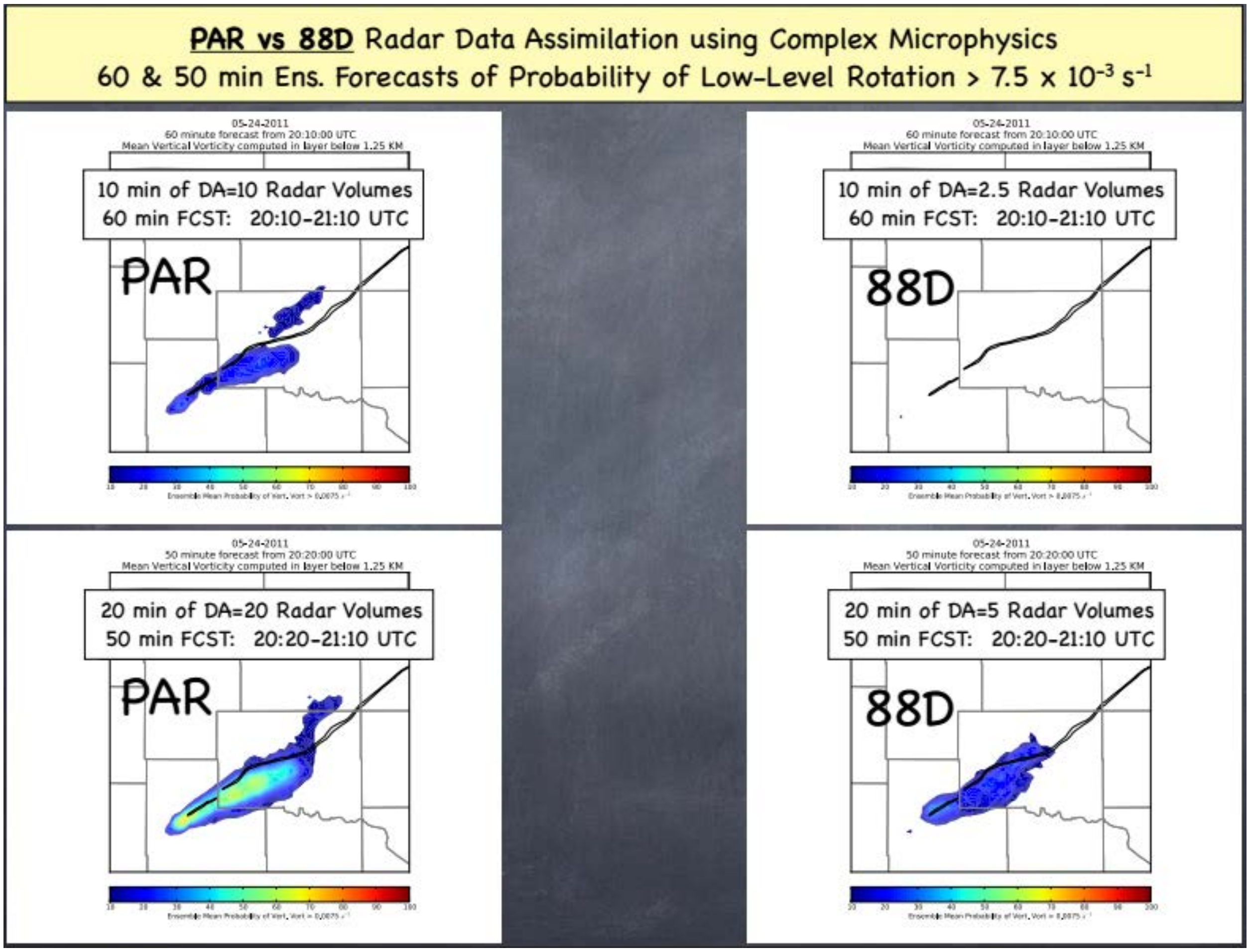
Time-height plots of maximum updraft speed for (clockwise from upper left) 333 m and 1, 2, 3, and 4 km idealized WRF simulations.

8. Impact of Phased Array Radar Data (PAR) Assimilation on Storm-Scale Ensemble Prediction

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

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. Fortunately, the 24 May 2011 El Reno, Oklahoma, tornadic storm was sampled by a long time series (> 3 hours) of MPAR volumes (~ 1 min periods) within 100 km of the radar. This dataset enables examination of the impact of assimilating rapid-scan versus WSR-88D data on 1-h ensemble forecasts of low-level circulation track and intensity. This is the first real-data demonstration of the potential impact of PAR on storm-scale numerical weather prediction.

During the reporting period, Wicker performed numerous experiments that strongly suggest assimilating PAR vs. WSR-88D data generally improves subsequent ensemble forecasts early in the assimilation period. However, the experiments further suggest situations where PAR may not add value to forecasts, for example, when the ensemble initial condition is very good. These issues continue to be explored. My primary role in this work has been to provide guidance on experiment design and interpreting results.



Ensemble 1-h forecasts of vertical vorticity > .0075 s^{-1} when PAR (left) vs. WSR-88D (right) data are assimilated for 10 min (top) and 20 min (bottom).

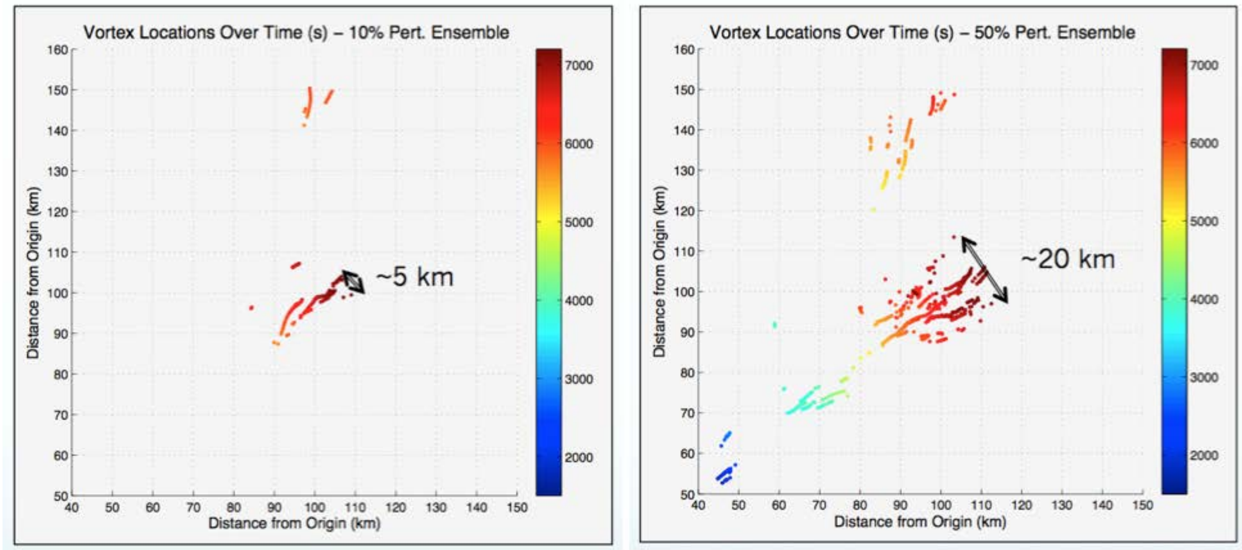
9. Sensitivity of Vortex Production to Environmental Perturbations in High-Resolution Supercell Simulations

Brittany Dahl (OU School of Meteorology), Corey Potvin (CIMMS at NSSL), Louis Wicker (NSSL), Amy McGovern (OU School of Electrical and Computer Engineering), and Rodger Brown (NSSL)

The predictability of supercells and other deep convection is not yet thoroughly understood. Advances in understanding of intrinsic and practical predictability limits will be important for guiding the design of real-time ensemble forecasting (WoF) systems.

M.S. student Brittany Dahl performed sets of 100-m supercell simulations initialized using perturbed versions of the 29 May 2004 Geary, OK sounding. My vortex detection and characterization (VDAC; Potvin 2013) algorithm was used to identify locations, sizes and intensities of tornado- and low-level mesocyclone-like vortices. By varying the sounding perturbation magnitudes, the sensitivity of vortex activity and characteristics to environmental errors was assessed. This study is intended to help clarify what a WoF

system can reasonably be expected to achieve with respect to short-term mesocyclone and tornado prediction. I worked closely with Dahl in implementing the vortex detection algorithm and was an active participant in the weekly research meetings.

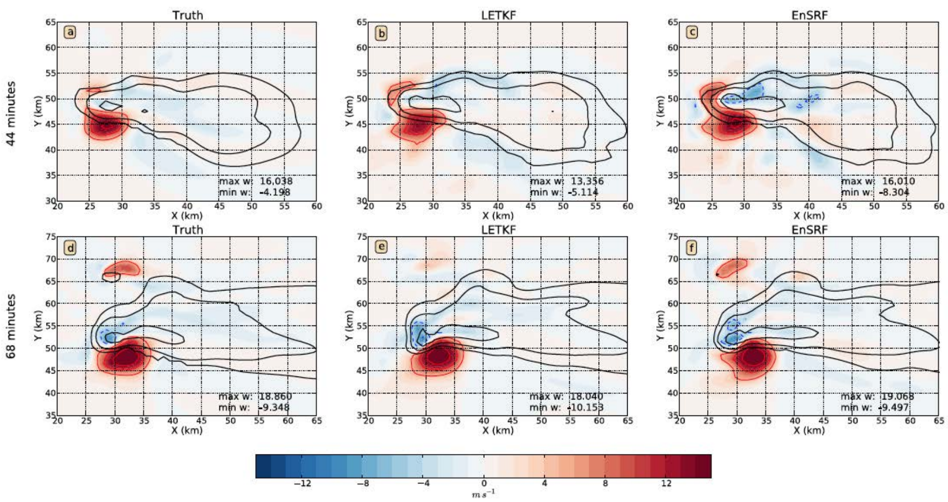


Timing and locations of intense low-level vortices in simulation ensembles initialized with sounding perturbations scaled to 10% (left) and 50% (right) of typical RUC model errors.

10. Radar Data Assimilation Using the Local Ensemble Transform Kalman Filter (LETKF) Versus the Ensemble Square Root Filter (EnSRF)

Therese Thompson (OU School of Meteorology), Louis Wicker (NSSL), Xuguang Wang (OU School of Meteorology), and Corey Potvin (CIMMS at NSSL)

We assisted Ph.D. student Therese Thompson in comparing the efficacy of LETKF vs. EnSRF convective-scale data assimilation using both simulated and real-data experiments. This work will help guide the design of our in-house WoF prototype.

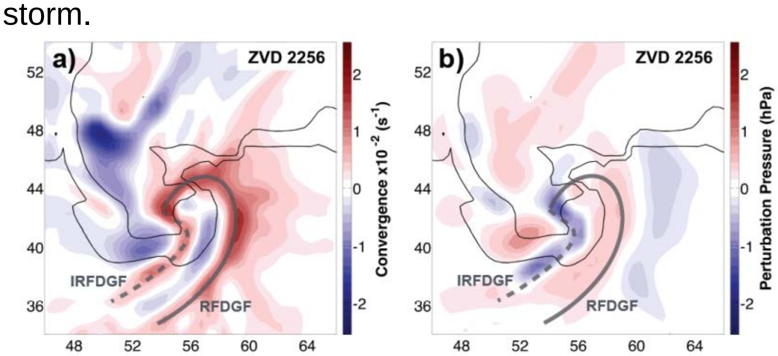


Cross-sections at 2 km AGL of vertical velocity (color-filled contours every 1 m s^{-1}) and reflectivity (black contours every 20 dBZ) for the truth simulation (a), mean LETKF analysis (b) and mean EnSRF analysis (c) after 3.5 radar volumes have been assimilated. Similarly for (d)-(f) except for 6-min forecasts valid after 8 radar volumes have been assimilated.

11. Forcing Mechanisms of Internal Rear-Flank Downdraft Momentum Surges in the 18 May 2010 Dumas, Texas, Supercell

Patrick Skinner (NRC), Louis Wicker (NSSL), Chris Weiss (Texas Tech University), Corey Potvin (CIMMS at NSSL), and David Dowell (ESRL/GSD)

We assisted Ph.D. student, now post-doc, Patrick Skinner in retrieving and interpreting perturbation pressure gradients from EnKF analyses of the 18 May 2010 Dumas, TX supercell. Skinner is using the analyzed pressure gradients along with backwards trajectory analyses to illuminate the forcing mechanisms for rear-flank downdraft surges observed in the storm.

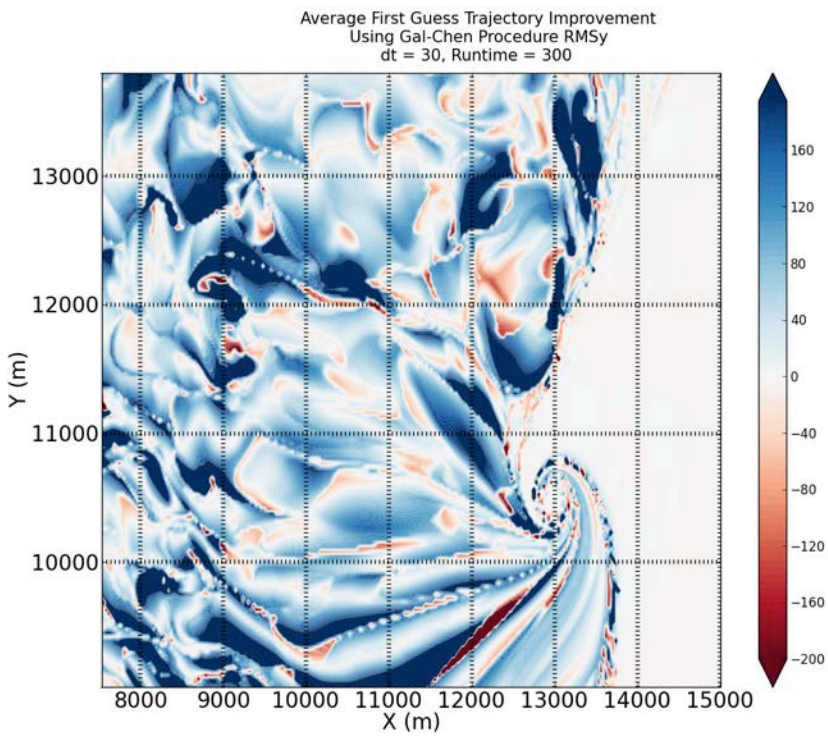


Ensemble mean convergence (x 10^{-2} s^{-1}) at the lowest model level and b) retrieved perturbation pressure (hPa) at 500 m. Simulated reflectivities of 20 and 40 dBZ at the lowest model level are plotted with thin black contours and positions of the rear-flank downdraft gust front (RFDGF) and internal rear-flank downdraft gust front (IRFDGF) are identified with solid and dashed gray lines, respectively.

12. Improving Trajectory Analyses Using Advection Correction

Stefan Rahimi and Alan Shapiro (both OU School of Meteorology), and Corey Potvin (CIMMS at NSSL)

I am serving on committee of M.S. student Stefan Rahimi, who is using Gal-Chen (1982) advection correction to improve trajectory calculations in supercells. The technique has been demonstrated using a 50-m simulation of the 24 May 2011 El Reno, OK, tornadic supercell. Improved trajectory analysis methods are required to maximize the value of difficult-to-obtain field campaign datasets and very high-resolution simulations to advancing understanding of storm dynamics.



Reduction in meridional position errors in 5-min backwards trajectory endpoints from using Gal-Chen advection correction (blue = improvement over linear time interpolation).

13. Variational Multiple-Doppler Vertical Wind Retrievals Within Convective Clouds Observed During the Midlatitude Continental Convective Clouds Experiment (MC3E)

Kirk North (McGill University), Scott Collis (Argonne National Lab), Scott Giangrande (Brookhaven National Lab), Corey Potvin (CIMMS at NSSL), and Pavlos Kollias (McGill University)

We have been assisting Ph.D. student Kirk North in performing variational dual-Doppler wind retrievals of MC3E datasets spanning a range of convective modes. The wind

(especially vertical velocity) retrievals are intended to improve understanding of deep convective processes and improve their parameterization in global climate models.

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

Corey Potvin (CIMMS at NSSL), Daniel Betten and Gordon Carrie (both OU School of Meteorology), and Conrad Ziegler (NSSL)

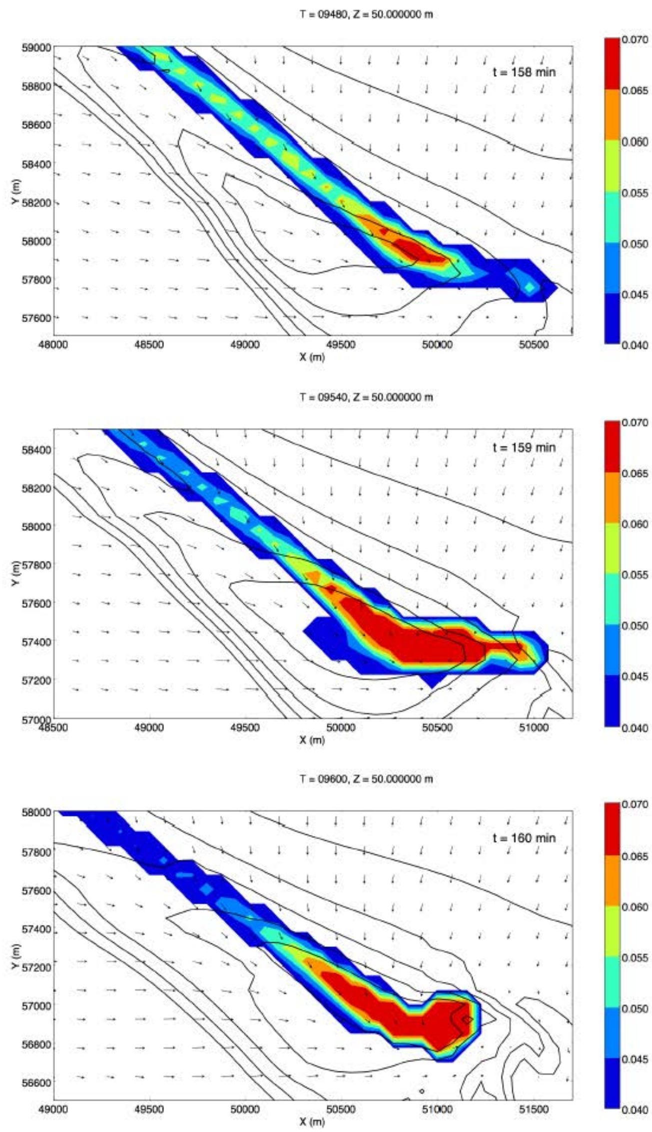
Variational dual-Doppler wind retrieval has been shown to be superior to traditional dual-Doppler retrieval techniques. It is necessary to use the most sophisticated analysis techniques available to fully exploit high-quality dual-Doppler datasets such as those collected during the VORTEX-2 experiment. Yet, variational dual-Doppler retrieval methods are rarely used. This motivated me to take the variational dual-Doppler retrieval code developed by Alan Shapiro and myself and refine it for use by the storm-scale research community. Hopefully, the availability of this code will facilitate the adoption of the variational dual-Doppler retrieval approach by the community.

During the reporting period, Ph.D. student Daniel Betten, Gordon Carrie, and Conrad Ziegler made substantial code and methodological improvements to the software package. Betten continues to use the code to analyze thunderstorm datasets collected during the Deep Convective Clouds and Chemistry (DC3) field campaign. I have also been helping a researcher at the Shanghai Central Meteorological Observatory to use the dual-Doppler retrieval software in investigating damaging wind production in mesoscale convective systems.

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

Doug Dokken, Misha Shvartsman, and Kurt Scholz (all University of St. Thomas), Pavel Belik (Augsburg College), Corey Potvin (CIMMS at NSSL), Brittany Dahl (OU School of Meteorology), and Amy McGovern (OU School of Electrical and Computer Engineering)

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. My primary role during the reporting period was to provide expertise on current tornadogenesis conceptual models.



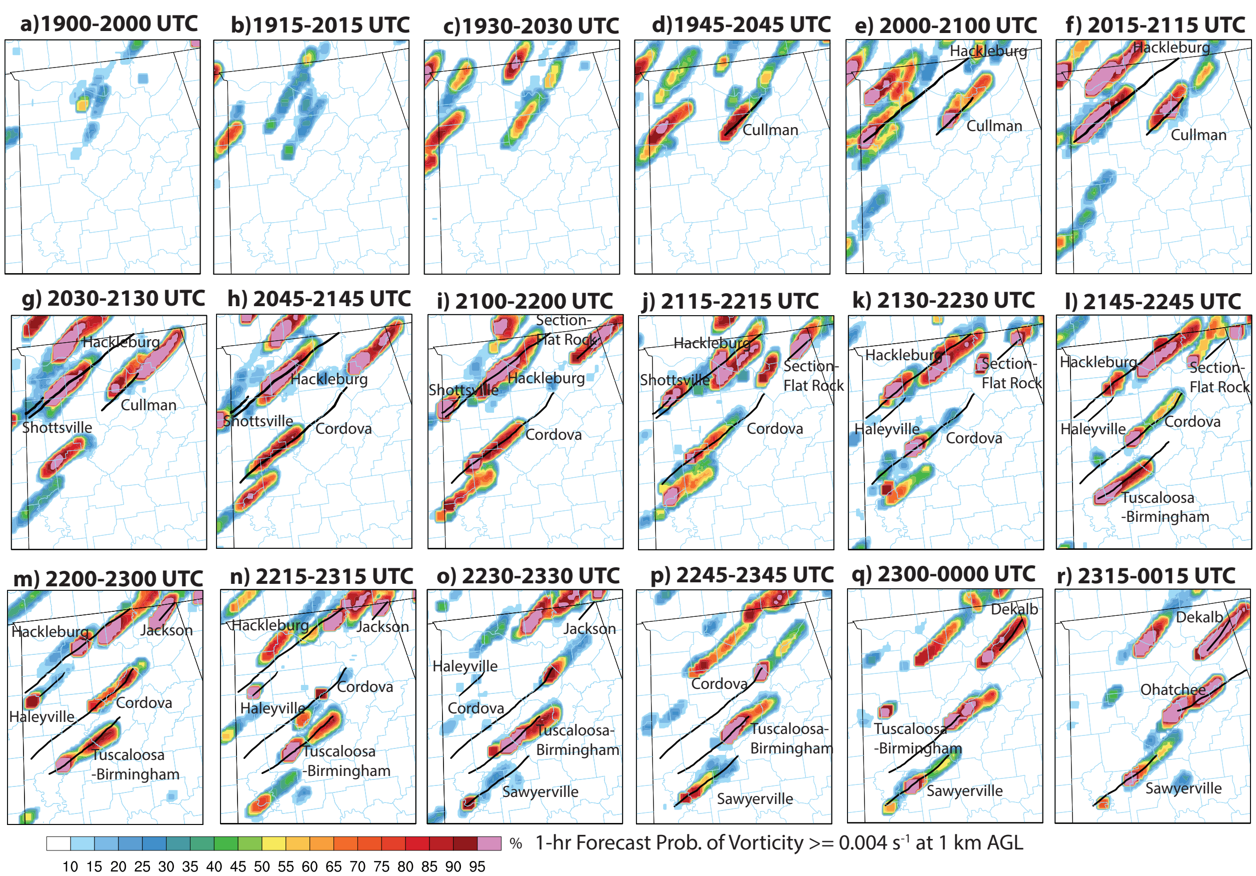
Feeding of developing tornado by vortices hypothetically formed by roll-up of vortex sheet along gust front in CM1 simulation. Vertical vorticity (s^{-1}) is shaded, vertical velocity contoured every 1 m s^{-1}, and horizontal wind vectors plotted as arrows.

16. Storm-Scale Data Assimilation and Ensemble Forecasts for the 27 April 2011 Severe Weather Outbreak in Alabama

Nusrat Yussouf (CIMMS at NSSL), David Dowell (ESRL/GSD), Louis Wicker (NSSL), and Kent Knopfmeier and Dustan Wheatley (both CIMMS at NSSL)

As part of the NOAA's Warn-on-Forecast initiative, a multiscale ensemble-based assimilation and prediction system is developed using the WRF-ARW model and the DART assimilation software. To evaluate the capabilities of the system, retrospective short-range probabilistic storm-scale (convection-allowing) ensemble analyses and forecasts are produced for the 27 April 2011 Alabama severe weather outbreak. The

initial and boundary conditions for the 36-member multiphysics meso- and storm-scale ensembles are obtained from the Global Ensemble Forecast System at 0000 UTC 27 April. Routinely available observations are assimilated on an hourly basis on both grids for more than a day. Prior to the onset of the afternoon tornado outbreak, conventional and radar observations from four WSR-88D radars are assimilated every 5 min into the storm-scale ensemble for a 6-h long period, and forecasts are launched from analyses every 15 min. Results indicate that the storm-scale ensembles are able to analyze the observed storms with strong low-level rotation at approximately the correct locations and to retain the supercell structures during the 0-1 h forecasts with reasonable accuracy. The predicted probabilities of strong low-level mesocyclones of the tornadic supercells correspond well with the observed tornado rotation tracks. The short-range ensemble probabilistic forecasts obtained from this continuous 5-min storm-scale update system demonstrate the potential of a frequently updated, high-resolution NWP systems that could be used to extend severe weather warning lead times. The results also motivate future work to reduce model errors associated with storm motion and spurious cells, and to design storm-scale ensembles that better represent typical 1-h forecast errors.

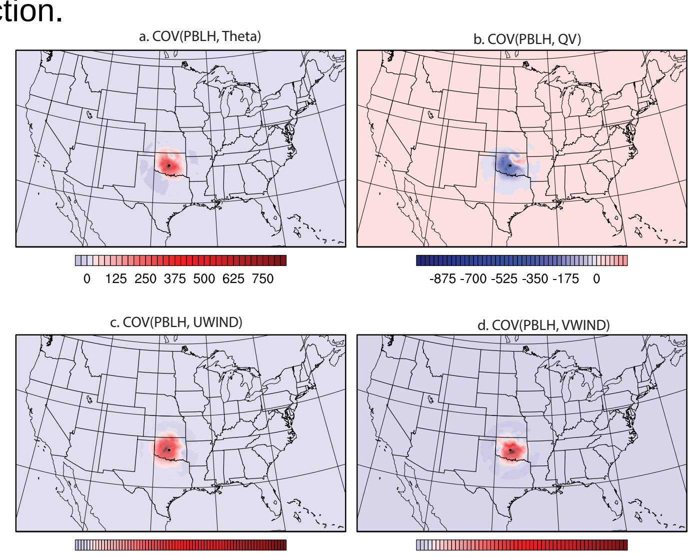


1-hr neighborhood ensemble probability of vorticity forecasts exceeding a threshold of 0.004 s^{-1} at 1 km AGL starting from 1915 UTC analyses and then from every 15-min analyses out to 2300 UTC for the 27 April 2011 Alabama severe weather outbreak. Overlaid in each panel is the NWS observed tornado damage track (black outline).

17. Impact of Assimilating Planetary Boundary Layer Height Observations using an Ensemble Kalman Filter Data Assimilation Technique

Nusrat Yussouf (CIMMS at NSSL) and David Stensrud (NSSL)

One fundamental parameter that characterizes the bulk structure of lower atmosphere and can be estimated from a variety of observing platforms is planetary boundary layer (PBL) height. The typical daytime increase in PBL height, which occurs in response to an increase in surface sensible heat flux, strongly influences vertical mixing of temperature, water vapor and momentum within boundary layer. Accurate knowledge of PBL temperature, water vapor and wind shear are important for diagnosing the likelihood and anticipated severity of deep convection. The importance of PBL height to evolution of boundary layer structures leads to the hypothesis that assimilation of PBL height observations can improve boundary layer analyses. Four mesoscale ensemble experiments are conducted to evaluate the impact of assimilating PBL height observations on hourly analyses produced over a two-day period in July 2004 by an ensemble adjustment Kalman filter data assimilation technique from DART software. The experiments differ only in observations assimilated, with a) PBL height observations from a single boundary layer profiler in central Oklahoma and b) all other conventional observations either assimilated individually (a or b) or in combination (a and b). Results indicate that PBL height observation successfully acts to constrain the vertical influence of surface observations, leading to more accurate PBL height estimates in analyses. Moreover, assimilating PBL height observation together with conventional data leads to improved analyses of near surface variables and is seen to modify positively the analyzed precipitation totals. These results suggest that more accurate boundary layer analyses are possible when PBL heights are assimilated, with likely positive impacts on forecasts of convection.



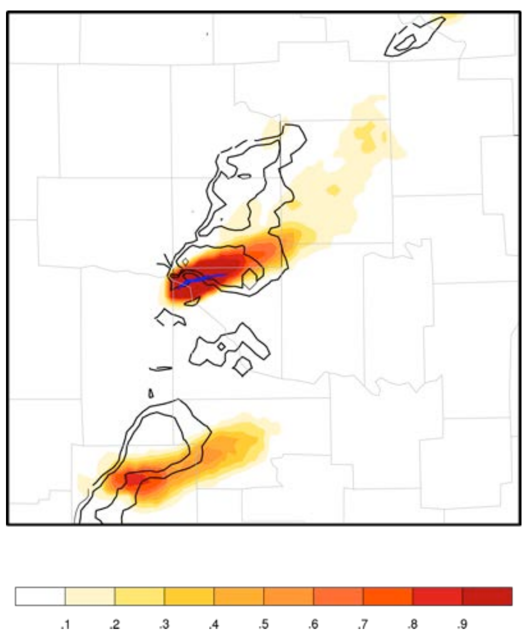
Horizontal localized background covariance values (see color bar) computed with respect to the PBL height (m) observation at the boundary layer profiler location for (a) potential temperature (K), (b) water vapor mixing ratio (g kg $^{-1}$), (c) u-wind component (m s^{-1}), and (d) υ-wind component (m s^{-1}) at 1 km above ground level valid at 2100 UTC 4 July 2004. Black dot indicates the point where covariance values are computed.

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

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

Storm-scale ensemble analyses and forecasts of six tornadic events from springs 2013-14 are produced on a 3-km event-dependent grid. This storm-scale ensemble is nested within a 15-km continental United States (CONUS) ensemble constructed from initial and boundary conditions provided by members of the Global Ensemble Forecast System (GEFS) forecast cycle starting at 0000 UTC. The WRF physics options are varied amongst the ensemble members to address deficiencies in model physics. Single-Doppler observations from several radars are assimilated—beginning just prior to convective initiation—with the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). A series of 1-h forecasts are launched during the 30-60 min period preceding the onset of storm reports.

Of particular interest is the ability of 0-1 h ensemble forecasts (initialized from storm-scale analyses) to reproduce the low-level rotational characteristics of supercell thunderstorms, as well as other convective hazards. Additional experiments have been conducted to evaluate the impact of assimilating radar data and cloud water path retrievals at the storm-scale.

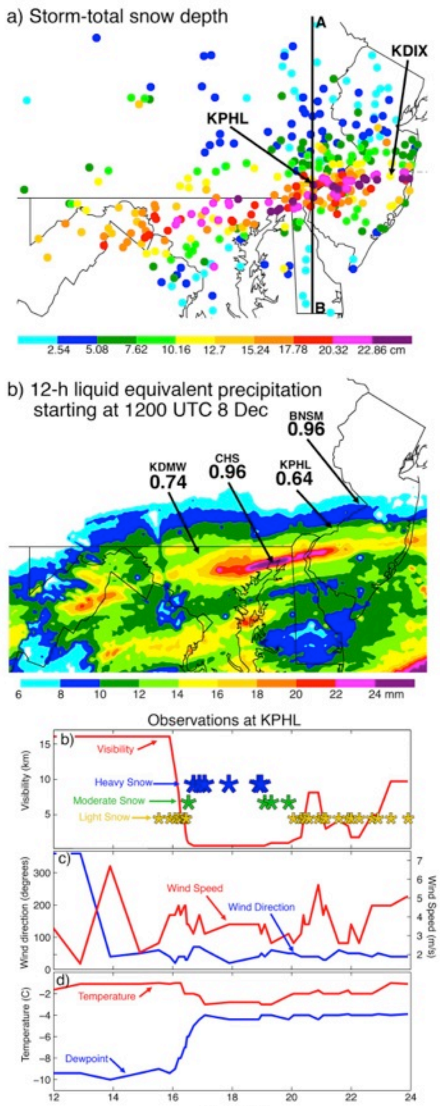


Ensemble forecast of the probability of vorticity exceeding 0.004 s^{-1} in the 0-2 km AGL layer—over central Oklahoma—as derived from 5-min model output for the period 2000 – 2100 UTC 20 May 2013. The forecast is initialized from storm-scale analyses produced at 2000 UTC, using radar data assimilation only. Red shading (see color bar) shows the forecasted probabilities throughout the period. Solid black lines show the observed 25- and 40-dBZ reflectivity contours at 2-km AGL, while the solid blue lines show the tornado damage path.

19. Microphysical and Initial-Condition Uncertainty Effects for the 8 December 2013 Surprise Snowstorm

Heather Reeves, Adam Clark, and Kent Knopfmeier (all CIMMS at NSSL)

Model experiments examining the effects of microphysical assumptions on sublimation cooling and initial condition uncertainty are being conducted to assess how these forms of uncertainty impact forecasts for a surprise snowstorm that occurred over Philadelphia in 8 December 2013. Initial investigation into operational forecasts suggest that model parameterization of sublimation cooling may be substantially under-predicted. Initial condition uncertainty also appears to play a prominent role in dictating whether the model is able to adequately capture the convection.



The observed (a) storm-total snow depth, (b) 12-h accumulated liquid-equivalent precipitation starting at 1200 UTC 8 December 2013 according to the stage IV analyses, and (c) visibility and precipitation amount, (d) 10-m wind direction and speed, and (e) 2-m temperature and dew point.

20. Complete a Real Time Evaluation of Total Lightning Data Assimilation Algorithm within the WRF framework

Don MacGorman and Ted Mansell (both NSSL), Adam Clark (CIMMS at NSSL), Conrad Ziegler and Jack Kain (both NSSL), and Scott Dembek and Valliappa Lakshmanan (both CIMMS at NSSL)

During the first 1-1.5 years of the GOES-R grant (FY12), 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 mass (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. This implementation is motivated by the upcoming launch of the Geostationary Operational Environmental Satellite “R” series (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 evaluation of this algorithm, which results have been submitted to MWR, implicated developing post processing codes to compute a suite of statistics of the archived WRF-NSSL model output data compiled from real-time, CONUS-scale, convective allowing (4km) simulations over 70 days. These real-time CONUS simulations were ran during last FY’s Spring and early Summer with daily summary of the performance of the lightning data assimilation algorithm provided to the project collaborators/mentors as well as to the HWT program participants for their daily map discussions.

We intend to finalize and publish lightning assimilation work evaluating the aforementioned lightning assimilation algorithm and a state-of-the-art variational assimilation code (3DVAR) for the high impact severe weather case of 29 June 2012.

21. Ensemble Verification of Proxy Severe Storm Reports

James Correia Jr. (CIMMS at SPC)

The Storm-Scale Ensemble of Opportunity (SSEO) was used to produce 1st 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.

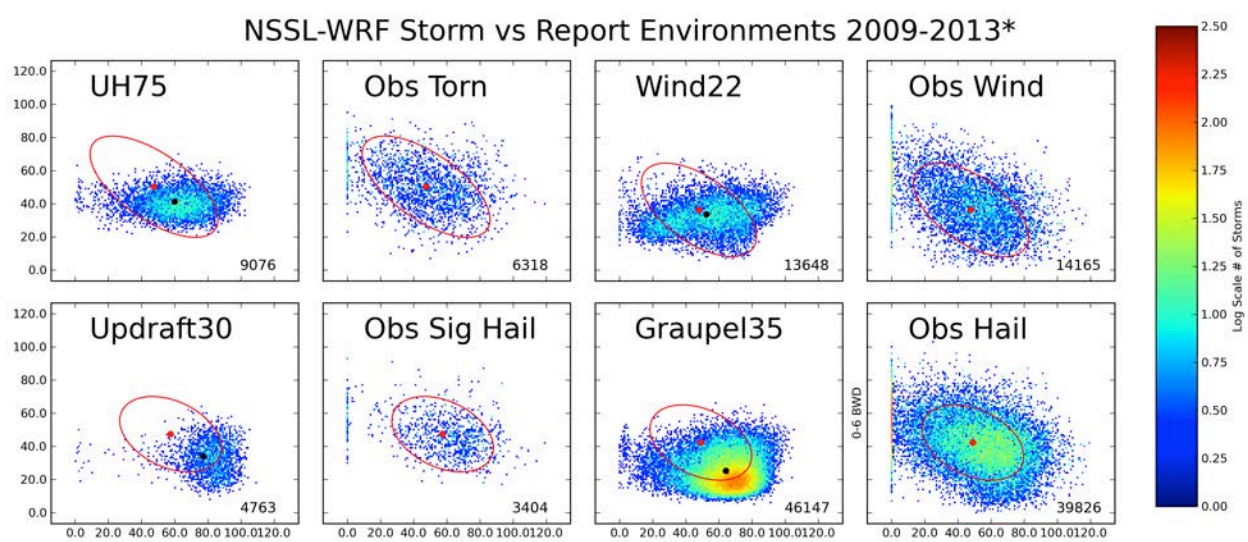
22. A Four-Year Climatology of Simulated Convective Storms From NSSL WRF

James Correia Jr. (CIMMS at SPC)

An approximately 4-year (June 2009 thru April 2013, 12 UTC-12 UTC) climatology of simulated convective storms is 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^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 0-6km 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.

Preliminary results suggest that the model does not compare favorably to the environment in which observed severe storm reports occur. For tornado environments, the NSSL-WRF has lower shear and higher mean CAPE, with the model environment being strongly clustered to higher CAPE. Deficiencies in other variables representing wind, updraft speed, and hail are similar. This represents a limitation that models have at this resolution, not being able to simulate storms in low CAPE environments.



The Wmax (x-axis, converted from CAPE) and vertical wind difference (y-axis, bulk shear) parameter space for updraft helicity ≥ 75 m^2s^{-2} compared to tornado environments, maximum surface wind speed ≥ 22ms^{-1} compared to wind gust reports ≥ 25.7 ms^{-1}, maximum updrafts ≥ 30 ms^{-1} compared to observed significant hail ≥ 2", and vertically integrated graupel ≥ 35 kg m^{-3} compared to observed hail ≥ 1".

23. Evaluation and Acquisition of Computing Resources for Warn on Forecast Efforts

Gerald Creager (CIMMS at NSSL)

Over the course of the reporting period, efforts were undertaken to evaluate the current high performance computation assets available to Warn on Forecast researchers, and to find additional resources to facilitate ongoing and future work. This included significant work with administrators at the University of Oklahoma's Supercomputing Center for Education and Research (OSCER), who manage the Boomer high performance computer system, and personnel at the NOAA/OAR Research and Development High Performance Computing (RDHPC) facilities in Boulder, West Virginia, Princeton, and Camp Springs. This included efforts to quantify the number of cores and amounts of time needed to accomplish the assigned and anticipated tasks, as well as storage resources needed to manage the resultant data.

Conversations with personnel at the NOAA Global Fluid Dynamics Laboratory, who manage the NOAA contact with the National Science Foundation's XSEDE petascale computing programs, led to obtaining an allocation on the Stampede petascale HPC resource at the University of Texas' Texas Advanced Computing Center (TACC). Efforts have been initiated to create a parallel computational infrastructure at TACC that will allow use of significantly more cores than were available to the group on the Boomer resource, and to experiment with performance enhancements hinted at when using the Intel Many Integrated Cores accelerator systems, also known as “Phi”.

24. Identify Potential Hardware Acquisitions in High Performance Computing and Define Requirements

Gerald Creager (CIMMS at NSSL)

In addition to evaluating requirements for computational resources that already existed within the NOAA ecosystem, an effort was undertaken to identify requirements for acquisition of a dedicated resource to Warn on Forecast research. This led to developing a set of requirements, which led to the eventual acquisition of a 4000+ core Cray XE6 system installed in the NSSL computer facility. The new resource represents approximately a 20-fold increase in organic computational facilities over what has been available either via Boomer or in-house within NSSL.

25. Investigate Scaling Requirements for the NSSL WRF Ensemble

Gerald Creager, Adam Clark, and Scott Dembek (all CIMMS at NSSL)

During the current reporting period, a decision was made to expand the NSSL WRF from a single deterministic run of the model to a limited ensemble system. Competition for resources on the RDHPC system Jet, in Boulder, led to scaling tests that identified optimum core counts that should allow timely completion of all model execution, post-

processing and graphics generation within the time requirements for use by the Storm Prediction Center (NCEP/SPC). Similar scaling runs, performed on the recently acquired Cray resource suggest that the Cray performs at a level similar to the Jet RDHPC resource, and which outperformed the resources available to our efforts on the OU Boomer resource.

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Yussouf, N., J. Gao, D. J. Stensrud, 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*, Article ID 731647, 15 pp.

Awards

Adam Clark was presented the Presidential Early Career Award for Scientists and Engineers (PECASE)

Adam Clark was the recipient of the 2014 Dean’s Award for Excellence in Research and Scholarship in the University of Oklahoma’s College of Atmospheric and Geographic Sciences

Corey Potvin was bestowed the Young Scientist Travel Award, International Symposium on Data Assimilation, Munich, Germany

Corey Potvin was nominated for the Presidential Early Career Award for Scientists and Engineers (PECASE) in July 2014

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

Accomplishments

1. Hazardous Weather Testbed – Hydrology (HWT-Hydro) Experiment

J.J. Gourley (NSSL), and Zac Flamig, Race Clark, Brandon Smith, Elizabeth Mintmire, and Steve Martinaitis (all CIMMS at NSSL)

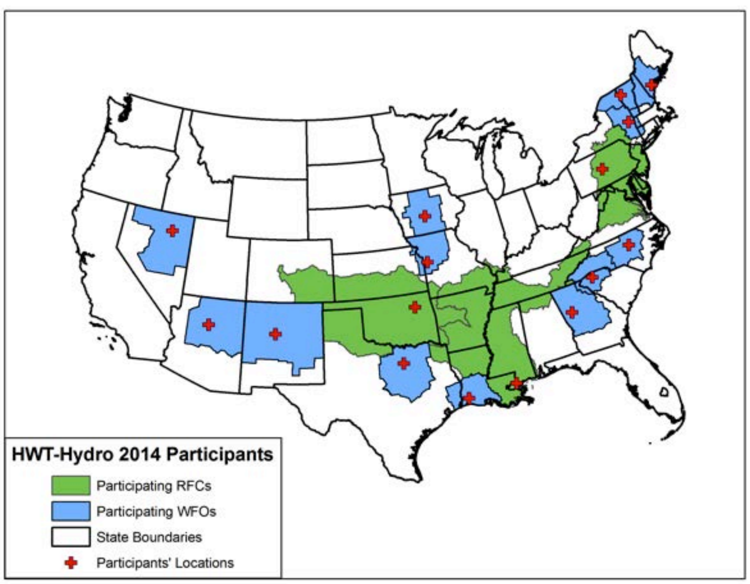
The inaugural Hazardous Weather Testbed Hydrology (HWT-Hydro) Experiment took place in July 2014 at the National Weather Center in Norman, Oklahoma. Over a four-week period, fourteen NWS meteorologists and hydrologists used investigational tools from the Flooded Locations and Simulated Hydrographs (FLASH) suite of flash flooding products to issue experimental flash flood watches and warnings across the conterminous United States. Additionally, forecasters partook in weather briefings, completed surveys, conducted exercises to validate and evaluate their experimentally issued products, and shared their experiences in NWS-wide webinars. The experiment was planned and coordinated by scientists and researchers at NSSL and OU.

At the time of the HWT-Hydro experiment, the FLASH suite of products contained twenty-six products, including output from two hydrologic models, precipitable water tools, forecast and observed precipitation recurrence intervals, and flash flood guidance. Other products from the High Resolution Rapid Refresh weather model and the NSSL Multi-Radar/Multi-Sensor (MRMS) project were tested. HWT-Hydro activities have resulted in the ability to successfully display experimental flash flood forecasting tools on the AWIPS-2 software platform. Also, as a result of collaboration with the NWS Warning Decision Training Branch during and after the experiment, a plan for future development of NWS training modules on FLASH and MRMS products has been

enacted. HWT-Hydro acted as a national Weather Forecast Office (WFO), but primarily focused on flash flood risk areas delineated via daily weather briefings with the Weather Prediction Center's Flash Flood and Intense Rainfall Experiment (FFaIR).

Flash flooding observations were collected for the experiment from several different sources. Operational sources, including Local Storm Reports and flash flood warnings, helped guide evaluation and verification activities. However, additional sources of observations were usually necessary to properly represent the nature and extent of flash flooding impacts. Students with the NSSL/CIMMS Severe Hazards Analysis and Verification Experiment (SHAVE) called residents in and around the experimental HWT-Hydro products. Citizen scientists with the NSSL/CIMMS Meteorological Phenomena Identification Near the Ground (mPING) project also provided useful reports. Finally, automated stream gauges that reached predefined stage heights, return period flows, or exceeded short-fuse time-to-rise criteria were used to validate experimental products.

Forecasters were given the ability to categorize predicted flash flood impacts into "major" and "nuisance" categories, corresponding to categories used in SHAVE surveys and in the mPING smartphone application. Forecasters were also able to assign probabilities to each of their products. Although the lead-time, shape, and size of the experimental warnings roughly followed current operational practices, the experimental flash flood watches were able to span County Warning Area boundaries and could be issued no more than six hours in advance of predicted flash flooding impacts.



Map of participating National Weather Service River Forecast Centers and Weather Forecast Offices.

Flood Warnings and Advisories
Local Storm Reports
CREST Max Return Period
HRRR-Forced CREST
CREST Soil Moisture
CREST Streamflow
SAC-SMA Soil Moisture
SAC-SMA Streamflow
1-hr MRMS Radar-Only QPE
3-hr MRMS Radar-Only QPE
6-hr MRMS Radar-Only QPE
1-hr MRMS Radar-Only QPE to FFG Ratio
3-hr MRMS Radar-Only QPE to FFG Ratio
6-hr MRMS Radar-Only QPE to FFG Ratio
1-hr Precipitation Return Period
3-hr Precipitation Return Period
6-hr Precipitation Return Period
12-hr Precipitation Return Period
24-hr Precipitation Return Period
Precipitable Water Analysis (RAOBs)
Precipitable Water Standard Anomalies (RAOBs)
Precipitable Water Analysis (RAP)
Precipitable Water Standard Anomalies (RAP)
1-hr HRRR QPF
3-hr HRRR QPF
6-hr HRRR QPF
Maximum Ratio of all QPE to FFG Accumulations
1-hr HRRR QPF to FFG Ratio
3-hr HRRR QPF to FFG Ratio
6-hr HRRR QPF to FFG Ratio
1-hr Precipitation Return Period (Forecast)
3-hr Precipitation Return Period (Forecast)
6-hr Precipitation Return Period (Forecast)
Maximum Precipitation Return Period of all Accumulations
MRMS Radar-Only Instantaneous Rain Rate
MRMS Quality-Controlled Composite Reflectivity
MRMS Seamless Hybrid-Scan Reflectivity

List of products tested during the HWT-Hydro Experiment.

2. Objective Evaluation of FLASH Skill

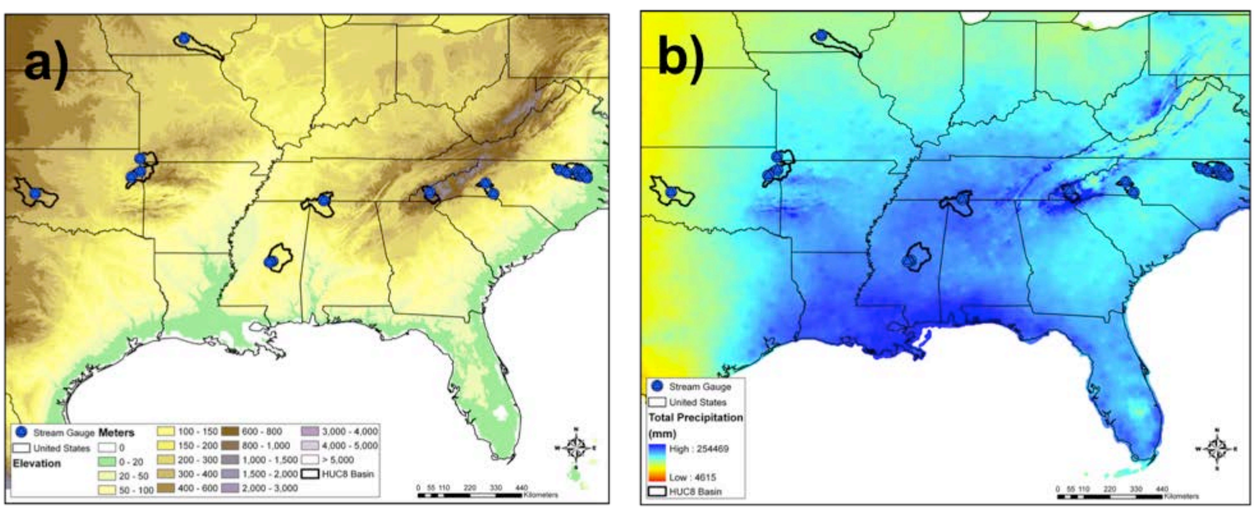
J.J. Gourley (NSSL), and Humberto Vergara-Arrieta, Zac Flamig, and Race Clark (all CIMMS at NSSL)

Ongoing efforts have been devoted to objectively assess FLASH's modeling skill utilizing historical flooding events. Observations from 18 United States Geological

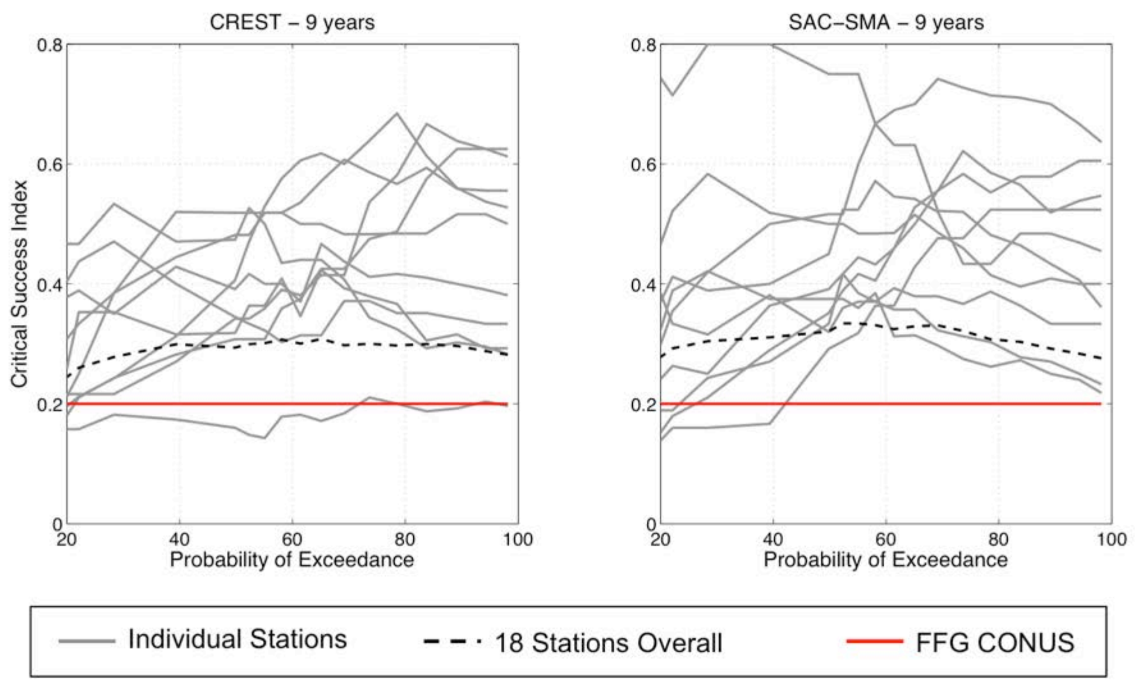
Survey (USGS) stream gauges were used in a pilot study to design a methodology for adequate skill evaluation of FLASH. The study included basins of sizes ranging from approximately 500 km^2 to approximately 6000 km^2, located over areas of different hydrometeorological regimes (first figure below). A total of 189 events, defined as peak flows exceeding NWS flood stages, were identified from the October 2002 – September 2011 period and considered for the evaluation. Stage IV data were used as forcing for the hydrologic models.

The Coupled Routing and Excess Storage (CREST) and the Sacramento Soil Moisture Accounting (SAC-SMA) distributed hydrologic models embedded in FLASH were employed to generate simulations of stream flow for the period of study. These approximately 10 years of simulated flow were employed to derive thresholds based on probability of exceedance for the detection of flooding events by FLASH's modeling system. The critical success index (CSI) was computed for the simulations produced with CREST and SAC-SMA in FLASH to be compared with Conterminous United States (CONUS) wide CSI corresponding to Flash Flood Guidance (FFG). The second figure below shows the summary of the comparison study, where it can be observed that FLASH outperforms FFG.

The evaluation is currently being extended to the complete set of location where USGS observations are available. Likewise, the forcing data of hydrologic models will be replaced with the archives of MRMS data that are presently being produced in a reanalysis effort by NSSL and the National Climatic Data Center (NCDC).



Stream gauges and basins utilized in objective evaluation pilot study: a) digital elevation map on the background; b) 30-year annual rainfall normal on the background.



Critical Success Index (CSI) of FLASH simulations for different exceedance probability thresholds. Left panel: Simulations by CREST model. Right panel: Simulations by SAC-SMA. The CSI corresponding to Flash Flood Guidance reported by Clark et al (2014) is included for comparison purposes.

Publications

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Vergara, H., Y. Hong, J. J. Gourley, E. N. Anagnostou, V. Maggioni, D. Stampoulis, and P.-E. Kirstetter, 2014: Effects of resolution of satellite-based rainfall estimates on hydrologic modeling skill at different scales, *Journal of Hydrometeorology,* **15,** 593-613.

Awards

Race Clark (CIMMS at NSSL) was awarded first place in the graduate student poster competition at the 38th Annual National Weather Association (NWA) Meeting in Charleston, SC. The award is selected by the NWA Weather Analysis and Forecasting Committee. The poster, “A CONUS-wide analysis of flash flooding: simulations, warnings, and observations”, identifies regional trends in the frequency of flash flood observations in NWS Storm Data, flash flood warnings, and flash flood guidance. His co-authors are J.J. Gourley (NSSL), Yang Hong (OU), Zac Flamig (OU), and Ed Clark (NWS). The recognition includes $125 and complimentary membership in the NWA for 2014.

Zachary Flamig (CIMMS at NSSL) was awarded the prestigious 2013 Chateaubriand Fellowship. The merit-based grant is offered by the Embassy of France in the United

States and aims to encourage collaborations, partnerships or joint projects between France and the U.S. Zac Flamig conducted his fellowship at the University Joseph Fourier in Grenoble, France and worked with the Hydrometeorology, Climate and Impacts (HCMI) team at the Laboratoire d'etude des Transferts en hydrologie et Environnement (LTHE) during the spring of 2014.

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. Complete a Real Time Evaluation of Total Lightning Data Assimilation Algorithm within the WRF framework

Alex Fierro (CIMMS at NSSL)

Objectives
Complete a multi-month, real time, CONUS-scale evaluation of previously developed novel cloud-scale total lightning data assimilation algorithm as the final milestone of the Geostationary Operational Environmental Satellite "R" series (GOES-R) program grant/proposal. Also, finalize and publish lightning assimilation work evaluating the aforementioned lightning assimilation algorithm and a state-of-the-art variational assimilation code (3DVAR) for the high impact severe weather case of 29 June 2012.

Accomplishments
During the first 1-1.5 years of the GOES-R grant (FY12), 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 mass (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. This implementation is motivated by the upcoming launch of the Geostationary Operational Environmental Satellite “R” series (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 evaluation of this algorithm, which results have been submitted to MWR, implicated developing post processing codes to compute a suite of statistics of the archived WRF-NSSL model output data compiled from real-time, CONUS-scale, convective allowing (4km) simulations over 70 days. These real-time CONUS simulations were ran during last FY’s spring and early summer with daily summary of the performance of the lightning data assimilation algorithm provided to the project collaborators/mentors as well as to the HWT program participants for their daily map discussions.

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2. *Hazardous Weather Testbed*

James Correia (CIMMS at SPC)

Objectives

Support the generation and display of hourly total severe weather probabilities using multiple ensemble modeling systems. Evaluate the utility of high-resolution ensemble forecast systems for severe storms forecasting by developing diagnostics and visualization for severe storms and their environments using object-based methods.

Accomplishments

a. HWT Severe Weather Forecasting

Support activities including preparing for ingest and plotting of hourly severe weather probabilities by NSSL for use in N-AWIPS. I developed and applied object based techniques 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. Parameters such as hail size were explored using hailcast in two of three ensemble systems. Continued investigating the utility of PBL vertical velocities for identification of boundaries aloft and other turbulent regimes thought to initiate convection. This work is ongoing.

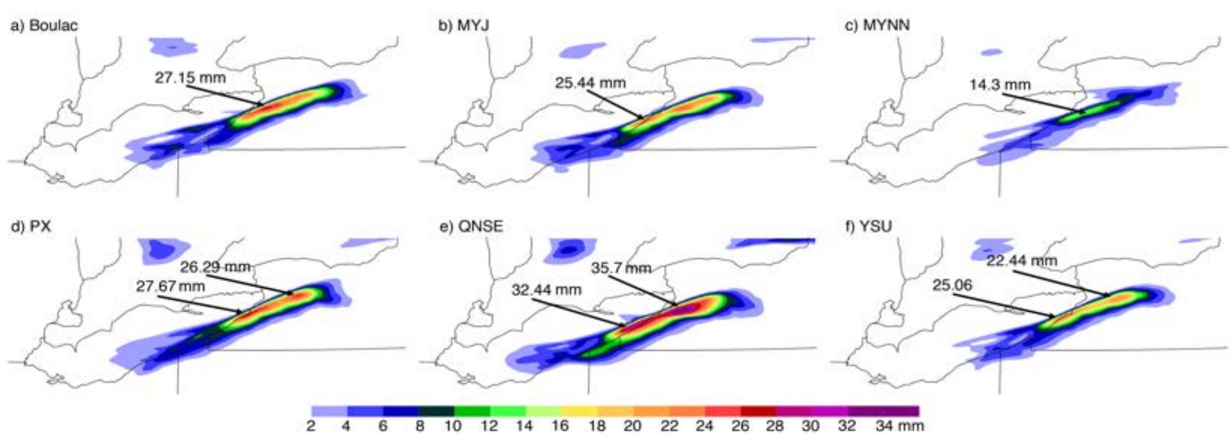
b. SSEO Verification: Hollings Scholarship and REU Students

Pamela Eck from Hobart and William Smith College began a research project in May 2014 working with me on the verification of the Storm Scale Ensemble of Opportunity (SSEO). She followed the preliminary work of Mallory Row from Valparaiso University from July 2013. The verification activities have contributed to knowledge about the individual members character of severe weather forecasts including how half of the members over-forecast and half under-forecast. Mallory's work was presented at the AMS annual meeting in Atlanta, and Pamela's work was accepted for presentation at the AMS Severe Local Storms Conference to be held in fall 2014.

3. Sensitivity of Lake-Effect Snow Forecasts to the Choice of Boundary Layer Parameterization

Heather Reeves (CIMMS at NSSL)

The sensitivity of forecasts of lake-effect snow to the choice of boundary layer parameterization is examined. Six different schemes are tested. Results show that precipitation rates are strong impacted with some schemes yielding more than twice the precipitation than others. Deeper investigation reveals the root cause for these differences is two-pronged. The larger impact comes from the choice of similarity stability profiles for heat, momentum and moisture while there is a secondary impact from the way turbulent kinetic energy is computed on the lowest model layer.



The six-hour accumulated liquid equivalent precipitation starting at 1800 UTC 10 December 2009 for the six experiments. Individual maxima within the band are indicated.

4. Physical Process Studies

Chris Karstens (CIMMS at NSSL)

Expanding upon efforts from 2008, the 2014 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted during the weeks of 5-9 May, 19-23 May, and 2-6 June. Each week, two forecasters participated by issuing probabilistic forecasts for severe convective phenomena (tornado, wind, hail, and lightning) using a prototype web tool. The objectives of this experiment included understanding how forecasters use the PHI system, comparing probabilistic forecasts to traditional warnings for two control cases, collaborating with the HWT Experimental Forecast Program (EFP), and understanding forecasters' thoughts on a paradigm change (deterministic products to continuous probabilistic information).

To achieve the objectives of this experiment, forecasters were tasked with issuing probabilistic forecasts for a variety of real-time and displaced real-time severe weather events. These events were comprised of a variety of convective modes with varying convective evolution. The diversity of these events allowed the facilitators to gauge what aspects of the PHI system worked well versus those needing further improvements. It was found that events with discrete cells (pulse convection or supercells) were easiest for the forecasters to engage and manage, while multicells and linear structures were more difficult. Part of the difficulty was attributable to a large number of hazard areas or potential hazard areas requiring attention, and to the complex evolution of these events (splitting/merging cells, non-linear motion). It was also found that lightning and wind hazards, which can often reside outside of the radar-indicated convective regions, are more difficult to identify geospatially than tornado and hail hazards. To combat these difficulties, the incorporation of improved numerical weather guidance is planned for 2015. This will be achieved by supplying forecasters with improved radar-derived objects, based on recommendations from the 2014 experiment. Additionally, it is planned to incorporate preliminary guidance from a real-time Warn-on-Forecast system.

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

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

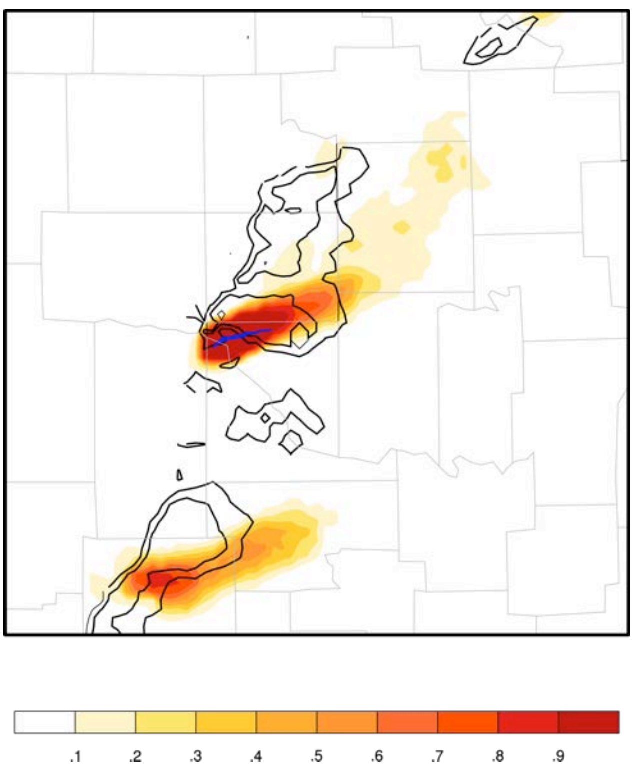
Objectives

The NOAA Warn-on-Forecast (WoF) research project is tasked with the development of very short-range (0-1 h) probabilistic forecasts that accurately predict severe convective storms. Storm-scale data assimilation and ensemble forecasting in a future WoF system will be performed on very-high-resolution (grid spacing ~1 km or less), event-dependent grids. Development and testing of a WRF-based ensemble data assimilation system has begun on somewhat coarser convection-allowing grids.

Accomplishments

Storm-scale ensemble analyses and forecasts of six tornadic events from springs 2013-14 are produced on a 3-km event-dependent grid. This storm-scale ensemble is nested within a 15-km continental United States (CONUS) ensemble constructed from initial and boundary conditions provided by members of the Global Ensemble Forecast System (GEFS) forecast cycle starting at 0000 UTC. The WRF physics options are varied amongst the ensemble members to address deficiencies in model physics. Single-Doppler observations from several radars are assimilated—beginning just prior to convective initiation—with the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). A series of 1-h forecasts are launched during the 30-60 min period preceding the onset of storm reports.

Of particular interest is the ability of 0-1 h ensemble forecasts (initialized from storm-scale analyses) to reproduce the low-level rotational characteristics of supercell thunderstorms, as well as other convective hazards. Additional experiments have been conducted to evaluate the impact of assimilating radar data and cloud water path retrievals at the storm-scale. This work is ongoing.



Ensemble forecast of the probability of vorticity exceeding 0.004 s^{-1} in the 0-2 km AGL layer—over central Oklahoma—as derived from 5-min model output for the period 2000 – 2100 UTC 20 May 2013. The forecast is initialized from storm-scale analyses produced at 2000 UTC, using radar data assimilation only. Red shading (see color bar) shows the forecasted probabilities throughout the period. Solid black lines show the observed 25- and 40-dBZ reflectivity contours at 2-km AGL, while the solid blue lines show the tornado damage path.

CIMMS Task III Project – Storm Tracking and Lightning Cell Clustering using Geostationary Lightning Mapping Data for Assimilation and Forecast Applications

Kristin Calhoun and Benjamin Herzog (CIMMS at NSSL), and Donald MacGorman (NSSL)

NOAA Technical Lead(s): Dan Lindsey and Andy Heidinger (GOES-R Risk Reduction – GOESR3 Program)

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

Funding Type: CIMMS Task III

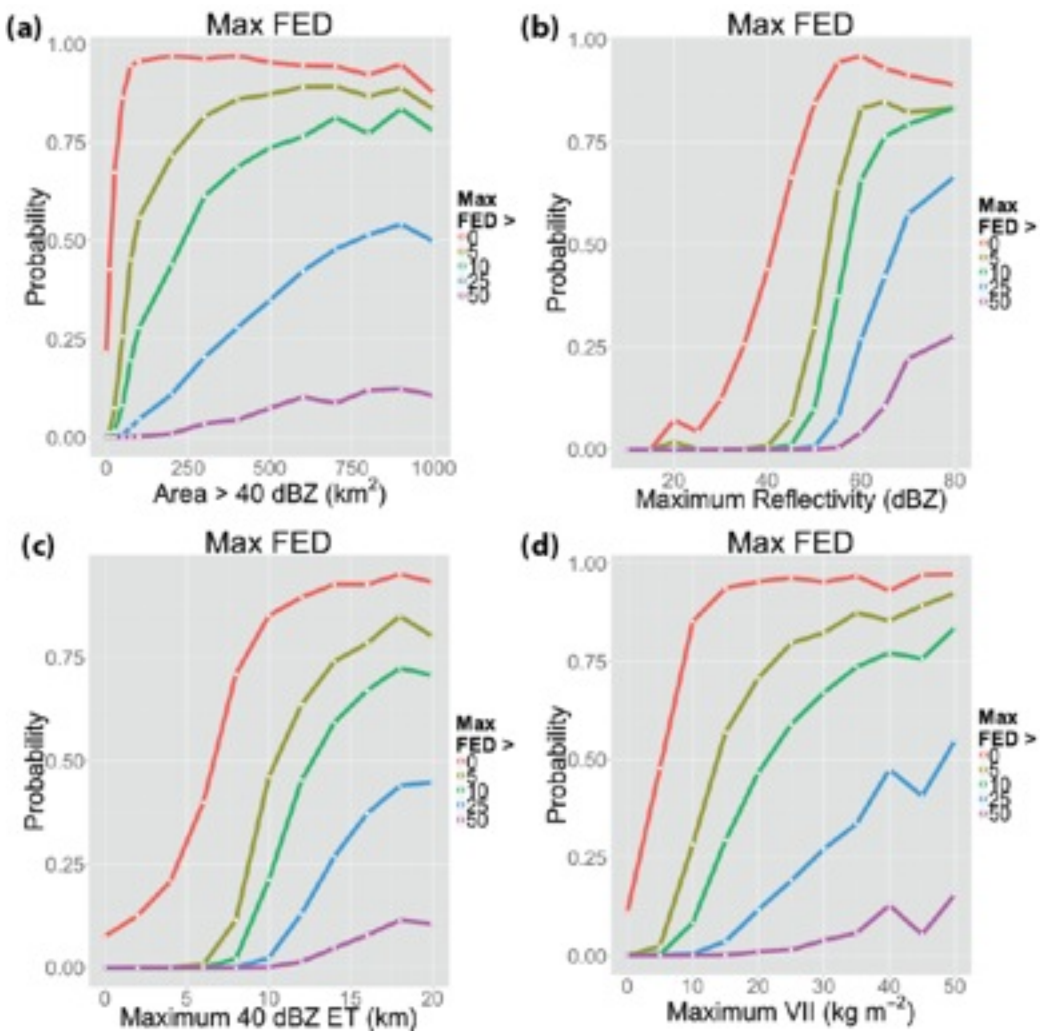
Objectives
The focus of this project is to determine thresholds of lightning rates and lightning density that define storm clusters for use by forecasters and in numerical forecast models.

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 Warning Decision Support System-Integrated Information (WDSS-II) 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 examines the climatological characteristics of total lightning information and relationships between lightning characteristics and radar derived storm attributes in thunderstorms (figure below). Additionally, this research determines how lightning characteristics vary between different thunderstorm types (i.e., supercell, multicell, ordinary). 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.



The probability of lightning occurring given values of: a) Area of Reflectivity > 40 dBZ at -10° C, b) Maximum Reflectivity at -20° C, c) Maximum 40 dBZ ET, and d) Maximum Vertically Integrated Ice.

CIMMS Task III Project – Assimilating Satellite Data into NWP Models to Improve Forecasting of High Impact Weather Events

NOAA Technical Lead(s): Steve Goodman (NOAA/NESDIS) and 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

Objectives
The multi-year goal of this research is to pave the way towards integration of the high-resolution satellite data that will be available from the GOES-R satellite in the best and most efficient manner necessary to produce storm-scale forecasts. Emphasis is placed on assimilating cloudy satellite observations in concert with radar data observations.

Accomplishments

1. Storm-Scale Cloud Water Path Assimilation

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

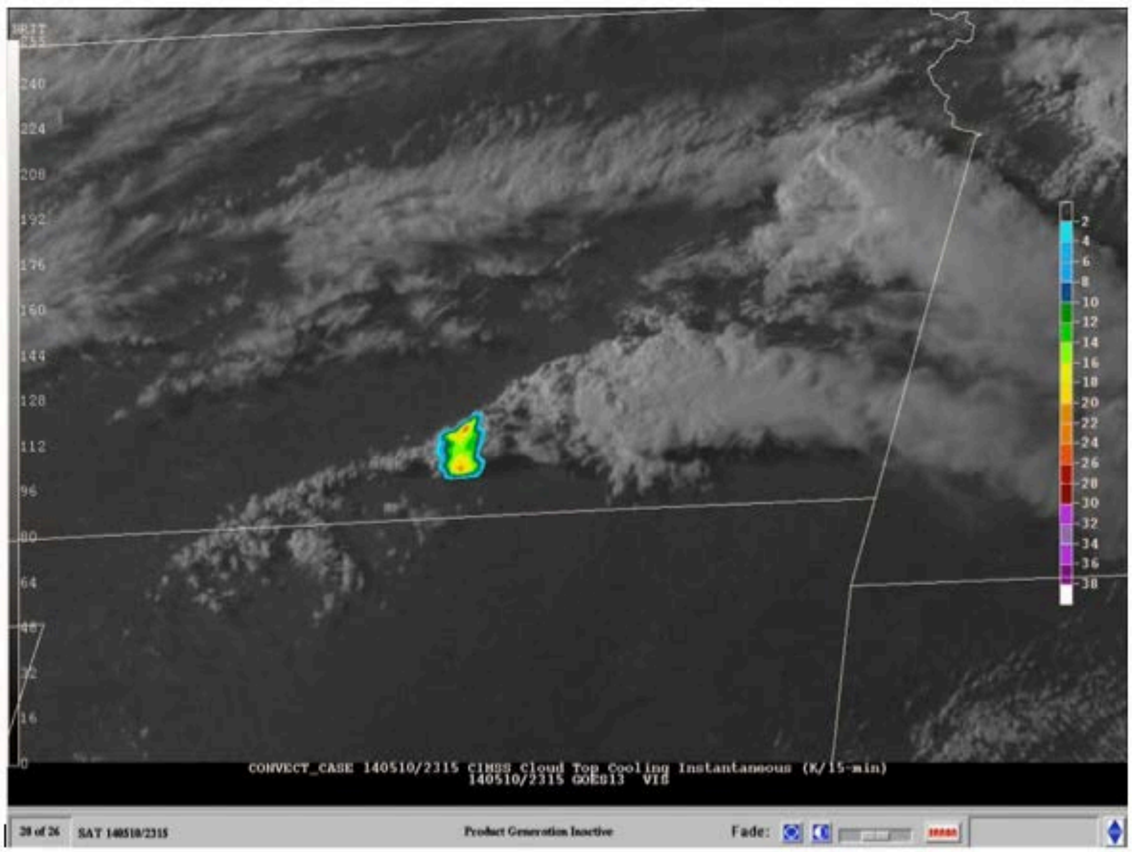
During 2013, research continued into assessing the impacts of assimilating GOES cloud water path (CWP) retrievals into convection permitting models. Emphasis was placed on completing the initial research on determining the impacts of cloud microphysics schemes on CWP data assimilation, improving the CWP forward operator, and using these improvements to assess the relative impacts of CWP and radar data assimilation for a severe weather event on 24 May 2011.

The impacts of assimilating CWP when changing from single moment to hybrid to full double moment schemes was explored using an idealized supercell case and the real 10 May 2010 event. The idealized experiments showed that the frozen hydrometeor characteristics of the supercell generated by CWP assimilation varied significantly as a function of cloud microphysics. In both sets of experiments, assimilating CWP improved the model analysis for all microphysics schemes. Large differences in the CWP and corresponding reflectivity analyses were observed between different schemes. In particular, the full double moment schemes had difficulty in resolving high reflectivity regions, resulting in poor forecasts once CWP data assimilation had stopped.

As part of a group effort for the WoF project, CWP data assimilation experiments have been carried out for another supercell event on 24 May 2011. During 2013, several important improvements to the CWP forward operator have been implemented. These include the use of WRF model levels instead of an interpolation when calculating simulated CWP, variable observation errors as a function of CWP magnitude, and a

parallax correction to adjust the location of tall clouds. The improved forward operator was tested using the 24 May case event and showed that CWP was very effective at initiating convection in the correct locations as well as suppressing spurious convection.

For this event, some 5-minute resolution retrievals were available, mimicking the temporal resolution of GOES-R and assimilating this higher resolution data provided positive results. When combined with radar reflectivity and radial velocity data assimilation, the advantages CWP assimilation remain. However, the effectiveness of CWP data decreases as convection reaches a mature development stage. On going research is underway to test CWP assimilation for in a near realtime environment for multiple case and storm types. Early results from the initial prototype are encouraging.



Observed WSR-88D radar reflectivity at 4 km (a) and ensemble mean simulated reflectivity from control experiment only assimilating conventional observations (CNTL, b), an experiment that also assimilates CWP (PATH, c), an experiment that assimilates convectional data plus radial velocity and positive reflectivity (RADP, d), Same as RADP adding clear-air reflectivity (RAD0, e), and finally (PATHRAD, f), which includes everything except clear-air reflectivity. Individual experiments analyzed at 1915 UTC. Black contour on b-f indicates where WSR-88D radar reflectivity is > 35 dBZ. Note that PATHRAD is quicker to generate high reflectivity values near the observed locations than any of the other experiments.

2. Storm-Scale GOES-R ABI Radiance Assimilation Using an OSSE

Thomas Jones (CIMMS at NSSL), Louis Wicker (NSSL), Robert Atlas (AOML), and Jason Otkin and Rebecca Cintineo (both CIMSS at Wisconsin)

This project leads the NSSL contribution to the larger Observing System Simulation Experiment Testbed led by Robert Atlas. For our portion, assimilation tests employing different combinations of satellite, radar, and other observations are performed for a severe weather event occurring in the southern and central U.S. in June 2005. A high-resolution truth simulation of idealized convection combined with atmospheric conditions from the selected event has been generated using the Advanced Regional Prediction System (ARPS) model at a 1 km resolution. The idealized simulation was used to generate synthetic radar and satellite remote sensing observations for initial assimilation experiments. Each observation type us being tested to help determine the relative benefit of each observation type as well as an optimal blend of satellite and radar data assimilation at convection resolving scales.

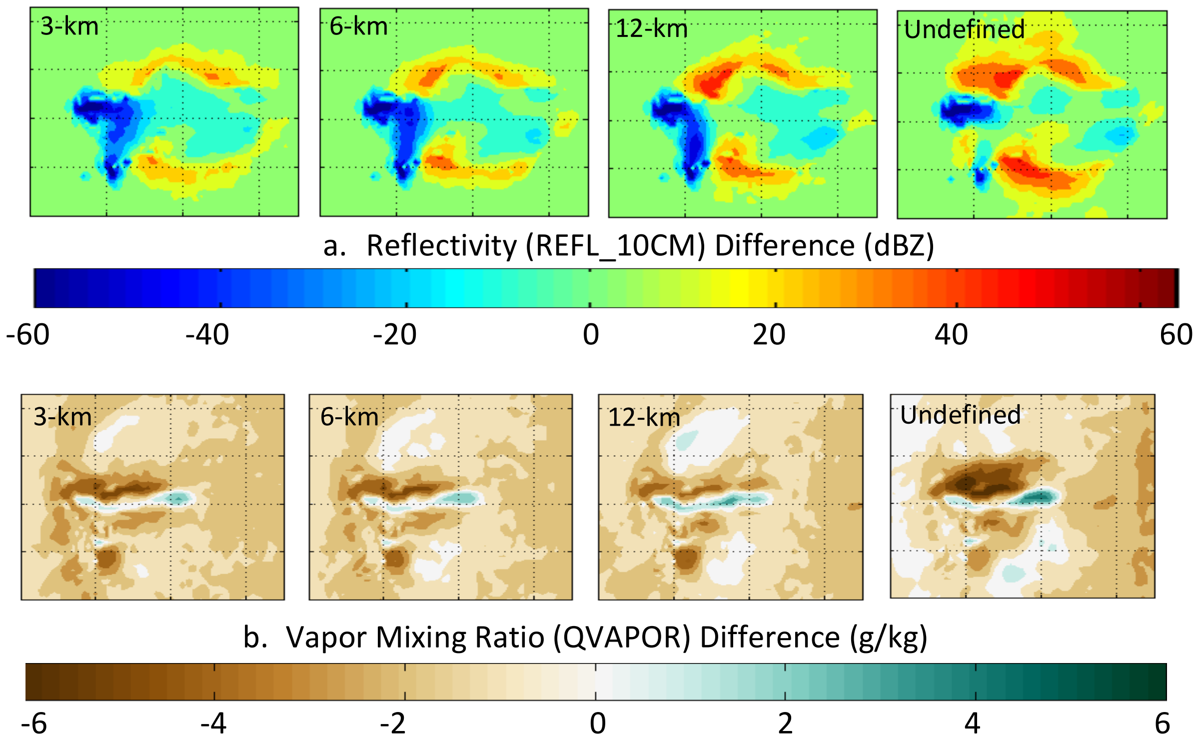
At the conclusion of the idealized experiments, the focus of this project will transition to a full real-data OSSE using the same June 2005 event, which will take place during 2014. The nature run will consist of a blend between the newest 7 km GAMO nature run and potentially operational or ARPS model analysis. From this nature run, both synthetic satellite radiances and radar data will be created for assimilation into an ensemble modeling system.

3. Honors and Hollings Student Mentorship

Thomas Jones (CIMMS at NSSL), Jessica Tomaszewski (OCS at OU Honors Student), and Kyle Chudler (Hollings Scholar Student, University of Michigan)

Both students conducted research into the importance or horizontal (Kyle) and vertical (Jessica) localization radius to assimilating CWP data into an ensemble modeling system for an idealized supercell event. Large sensitivities were observed, especially for vertical localizations, indicating that care should be taken when selecting these radii for a particular experiment. Smaller vertical localization radii generally performed better when comparing truth reflectivity to that generated from an hour of assimilating CWP data. In particular, an undefined vertical localization radius, used for previous CWP and satellite radiance studies, was almost always the poorest performer.

For example, differences in vapor mixing ratio (QVAPOR) at 2 km for a 30 minute forecast showed a large area where the undefined experiment significantly under-produced moisture by as much as -7 g kg^{-1} (see figure below). Through visual comparison of the four experiments, it can be ascertained that defining a vertical localization for CWP assimilation in WRF-DART greatly reduces this dry area. This is an important consideration as the decrease in moisture in the near-storm environment could have negative impacts the continued forecast of on going convection. Work is underway to test a real data case to see if similar results can be found.



Differences (Experiment – Truth) in (a) reflectivity and (b) vapor mixing ratio 90 minutes after model start at model level 5 (2 km). Positive values indicate where the trial generates higher values than Truth, while negative values indicate the opposite.

Publications

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*, **141**, 3273-3299.

Jones, T. A., J. Otkin, D. J. Stensrud, and K. Knopfmeier, 2014: Forecast evaluation of an Observing System Simulation Experiment assimilating both radar and satellite data. *Monthly Weather Review,* **142**, 107-124.

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-Hour and 3-Hour 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-hour period probabilities to test the ensembles ability to capture events at specific times. This method was applied to 3 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. This work is ongoing.

b. Severe Weather Proxies for Use in 1-Hour Convective Outlooks

Multiple ensemble systems were used to develop multivariate depictions of severe weather probabilities at the hourly time scale. These probabilities were developed from variables such as hail size, updraft helicity, updraft speed, and surface wind speed. Different Gaussian smoothers were tested along with different variable thresholds, to arrive at 1-hourly probabilities sufficient to serve as first guess guidance to forecasters. The probabilities were found to be too large and were adjusted downward using increasing thresholds and smaller radii smoothers. Since these were grid-based probabilities efforts to remove the effect of large swaths in favor of “events” are needed. This work is ongoing.

c. Collaboration with the EWP-PHI Program

The EFP worked collaboratively with the EWP to deliver our experimental forecasts, usually the 3-hour and 1-hour update forecasts, twice a day. A briefing was conducted and forecasts were delivered. A Q&A 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 in the Probabilistic Hazard Information experiment. This work is ongoing.

These projects are ongoing.

2. Experimental Warning Program

Kristin Calhoun, Darrel Kingfield, and Chris Karstens (all CIMMS at NSSL), William Line (CIMMS at SPC), Matt Elliott and Lance VandenBoogart (both CIMMS at WDTB), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB in Norman, OK), and Gabriel Garfield (CIMMS at OUN)

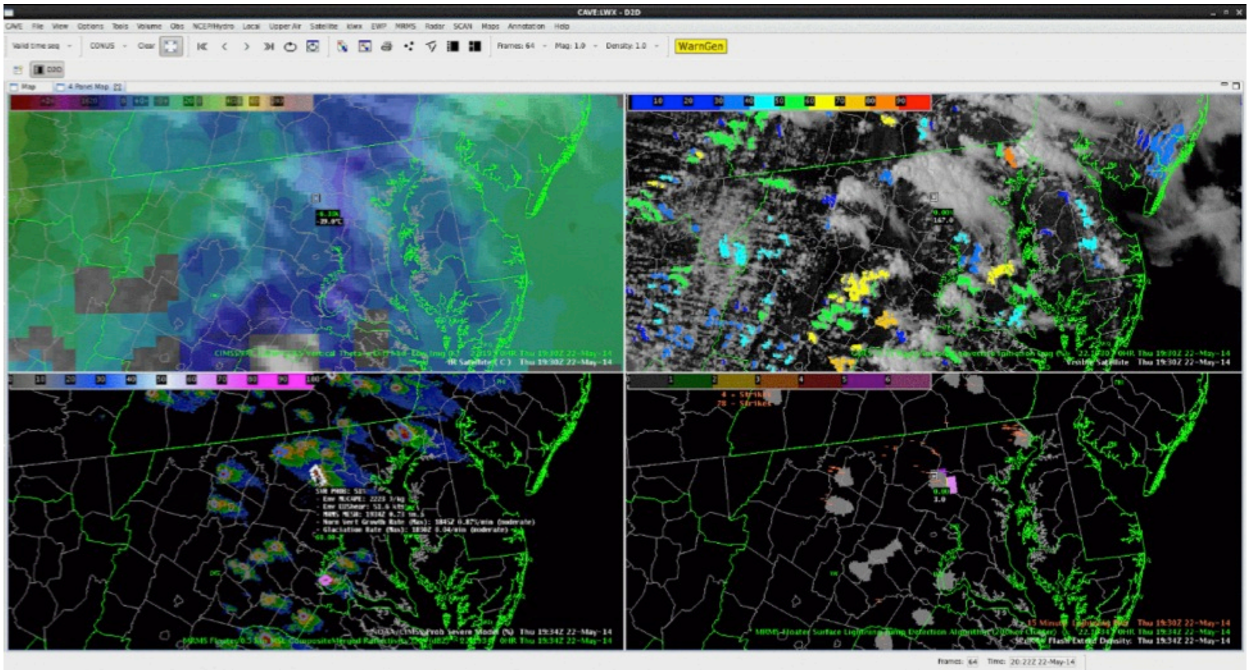
The 2013 Experimental Warning Program spring real-time experiments were conducted over a period of three weeks in May and included approximately 40 participants split equally between operational forecasters and severe weather researchers. Each day, the forecasters participated in simulated nowcasting 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 Proving Ground Activities

The HWT provided the GOES-R Proving Ground with an opportunity to demonstrate baseline and future capabilities products associated with the next generation GOES-R geostationary satellite system that have the potential to improve short-range hazardous weather nowcasting and forecasting. This year, Proving Ground activities were part of

the EWP Spring Experiment that took place during the weeks of 5 May, 12 May, 19 May and 2 June. Twelve National Weather Service (NWS) forecasters representing four NWS regions and four broadcast meteorologists evaluated GOES-R products, capabilities and algorithms in the real-time simulated short-term forecast and warning environment of the EWP using AWIPS-II (see figure below). GOES-R products were generated from current satellite-based, land-based, and numerical model-based datasets, and included: NSSL-WRF GOES-R ABI Synthetic Imagery, NearCast model forecasts and analyses of atmospheric moisture and instability, GOES-R Convective Initiation (CI) algorithm, Probability of Severe (ProbSevere) model, Overshooting Top (OT) Detection (OTD) algorithm, Pseudo Geostationary Lightning Mapper (PGLM) total lightning, Lightning Jump algorithm, and Total Lightning Tracking Tool (TLTT). Additionally, GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) 1-minute imagery was available from 8-24 May for participants to evaluate. Many visiting scientists also attended the EWP over the four weeks to provide additional product expertise.

Product feedback from the evaluation was abundant and came in several forms, including daily surveys, daily debriefs, weekly debriefs, 358 real-time blog posts, informal conversations in the HWT and four “Tales from the Testbed” webinars. Common feedback included: suggestions for improving the algorithms, ideas for making the displays more pleasing, best practices for product use, and situations in which the tools worked well and not so well. Participants would like to see synthetic satellite imagery produced with other NWP models as it provides an alternative for visualizing model data and a method for quick model forecast evaluation. Forecasters valued the total lightning products and ProbSevere model, as they often provided lead-time and confidence for issuance of experimental warnings. Many forecasters expressed a desire to see the NearCast analyses and forecasts in their home offices, finding the observation-based instability and moisture fields to be unique and successful in highlighting regions of increased (decreased) convective potential. Participants acknowledged that the OTD algorithm would likely have increased utility at night, in areas where radar coverage is lacking, and for forecasters responsible for large forecast domains when monitoring mature convective evolution. The CI algorithm provided lead-time to initial convective development at times, but was often too erratic and inconsistent for forecasters to use confidently. The version of the TLTT tested had numerous software flaws, with users agreeing its greatest impact would be in post-event, research settings. Finally, participants experienced many situations in which the 1-minute satellite imagery provided operationally significant information not captured in current 5-15 minute imagery. This work is ongoing.



AWIPS-II 4-panel display of multiple GOES-R products demonstrated in the 2014 HWT-EWP Spring Experiment. Display includes NearCast theta-e difference and GOES-East infrared satellite imagery (upper left), GOES-R CI algorithm and GOES-East visible satellite imagery (upper right), ProbSevere model and MRMS composite reflectivity (lower left), Lightning Jump Algorithm, PGLM total lightning flash extent density and NLDN cloud-to-ground lightning strikes (lower right).

b. Experimental Warning Guidance

See OST Project 13 – Research on Integration and Use of Multi-Sensor Information for Severe Weather Warning Operations, elsewhere in this report.

c. Coordination of EWP Experiments

The EWP expanded testbed activities from one 4-week project in 2013 to five projects over the course of 14 weeks in 2014. Coordination duties included sending invitations to forecasters to apply to the Spring Program, organizing selection committees, receiving applications and disseminating them to the proper selection committees, overseeing the selection committees, apprising forecasters and their MICs (meteorologist-in-charge) of selections, sending logistical information to selected forecasters, soliciting training material from the principal investigators, updating the EWP website and blog, organizing planning meetings for principal investigators, checking on the status of technology in the testbed, giving a facility tour to visiting forecasters, briefing forecasters on the purpose of the projects, alerting various groups of our weekly webinar, providing overview of the project during the webinar, arranging a group picture at the end of the week, and sending shift information to forecasters' MICs.

Weekly coordination duties included providing daily forecast briefings, selecting operation areas, and answering questions from visiting forecasters. Additional duties included preparing daily forecast briefings and summaries, as well as a summary of the week's activities.

During the ENTLN Experiment (July-August 2014), CIMMS personnel observed forecasters during a controlled experiment in the Hazardous Weather Testbed. The goal of the experiment was to determine the value of ENTLN lightning data to the warning process (i.e., does lightning data improve warnings?). A narrated weather briefing was created for each displaced real-time case. Forecasters used these briefings to acquaint themselves with each case before beginning.

d. Evaluation of Earth Networks Total Lightning Products for NWS Warning Services in the Hazardous Weather Testbed

Kristin Calhoun and Darrel Kingfield (both CIMMS at NSSL), Lans Rothfusz (NSSL), Woody Roberts (ESRL/GSD), James Ramer (CIRES at Colorado and ESRL/GSD), Brian Motta (NWS Forecast Decision Training Branch), Bill Callahan (Earth Networks, Inc.), and Matthew Elliott and Tiffany Meyer (both CIMMS at WDTB)

Earth Networks Incorporated (ENI) has indicated the potential for their total lightning data and Dangerous Thunderstorm Alerts (DTAs) to increase lead-time over current National Weather Service (NWS) severe weather and tornado warnings, while maintaining a similar probability of detection and false alarm ratio. The DTAs are based on a proprietary storm tracking and lightning flash rate threshold algorithm and are produced for storms across the continental United States (CONUS) and adjacent coastal and land areas at 1 min intervals. Currently, for operational NWS forecasters, the DTA products are currently displayed outside the NWS operational Advanced Weather Interactive Processing System (AWIPS) software using the StreamerRT web application.

Initial development and integration of the Earth Networks (ENI) in-cloud and cloud-to-ground flash locations was completed by CIMMS/NSSL in early 2014 for the NWS AWIPS2 operational platform. The integration of ENI DTA system into AWIPS2, including products associated with the DTA such as the DTA polygon, cluster identification and past track, was completed by GSD in the spring of 2014.

Planning and development for Hazardous Weather Testbed (HWT) activities were led by CIMMS/NSSL. Six weather event scenarios were chosen for forecaster evaluation within the HWT of the ENI lightning and DTA products. These scenarios ranged in intensity from high-impact tornadic to marginally severe events and covered a variety of geographic locations. The weekly experiment design has one forecaster working "control" event for each scenario, operating under current radar products only, while the other two forecasters work the event with the addition of ENI Total Lightning Data and/or DTA algorithms. This design allows for multiple forecasters of varying levels of expertise to complete the same warning scenarios multiple times in order to produce

repeatable results across a number of events and reduce the influence of singular forecaster expertise on the verification statistics. The ultimate goal is to determine if the DTAs could lead to improved forecasts and warnings within NWS operations.

In addition to the forecaster use and evaluation within the HWT, an effort to compute verification statistics of the DTA versus standard NWS warnings for a large, continuous sample of across the CONUS coverage of the ENI is being led by CIMMS/WDTB. Lead time, probability of detection (POD), false alarm ratio (FAR), and skill scores for both the highest DTA level and NWS Warnings over the same time period are calculated using storm data for verification. For 2013 only, the NWS warnings have a much higher POD and lower FAR for severe weather than the DTAs; however, the POD and FAR are similar for tornadoes (see figure below). The DTAs have slightly better lead times than NWS warnings over 2013 for the first report from a storm: 25.4 min for severe and 27.1 min for tornadoes compared to 22.8 min for severe and 14.7 min for NWS warnings. This verification dataset will later be expanded to include 2014 as well.

Probability of Detection (POD) and False Alarm Ratio (FAR) binned by month for 2013 for ENI's Dangerous Thunderstorm Alerts and National Weather Service Warnings. (a) POD for Severe Weather only (hail >1 in or winds > 58 mph), (b) FAR for severe weather, (c) POD for tornadoes, and (d) FAR for tornadoes.

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.

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. Develop 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. Conduct radar data quality control and develop probabilistic data displays for the Warn-on-Forecast project;
3. Conduct enhanced verification of severe weather events.

Accomplishments

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

Kiel Ortega and Travis Smith (both CIMMS at NSSL)

The Multi-Year Reanalysis for Remotely Sensed Storms (MYRORSS) finished production processing for the years 2000 through 2011. Seven of the years were processed in Norman at NSSL, while the other 5 were processed at NCDC. Currently, a data transfer is occurring so that the entire dataset is contained at both NSSL and NCDC. The major activity for MYRORSS has been quality controlling the processed data for significant errors due to corrupted single-radar data. Processing of daily accumulations of hail size and storm-scale rotation grids has begun. These grids will feed into hail and rotating storm climatologies for the entire contiguous United States. Processing of supplementary data, such as near-storm environment parameters, continues, as does continued downloading of raw radar data from NCDC.

2. Warn-on-Forecast Projects

Chris Karstens (CIMMS at NSSL)

During the evaluation period, numerous requests for automated and manually quality-controlled radar datasets were facilitated. The source radars were primarily comprised of NWS WSR-88D radars, but also included terminal weather radars (e.g., TOKC) and research radars such as the MPAR and experimental dual polarization radar (KOUN). These quality-controlled datasets were assimilated into analyses used to drive an ensemble of Numerical Weather Predication (NWP) models within the Warn-on-Forecast project. Additionally, initial code development was conducted for infusing probabilistic forecast guidance from a Warn-on-Forecast system into a prototype web tool allowing forecasters to issue probabilistic forecasts for severe convective weather hazards (tornado, wind, hail, and lightning). The tool presents to the forecaster guidance for strong mid-level storm rotation via exceedance probabilities. The exceedance probabilities are derived from vertical vorticity from individual members of the ensemble on a grid of 3 km horizontal spacing. The forecaster is provided the ability to adjust the guidance probabilities, based on knowledge extraneous to the Warn-on-Forecast system (e.g., observations of a tornado). With initial preparations in place, future HWT experiments will explore the presentation of Warn-on-Forecast guidance in warning decision-making.

3. Severe Hazards Analysis and Verification Experiment (SHAVE)

Kiel Ortega (CIMMS at NSSL)

The Severe Hazards Analysis and Verification Experiment (SHAVE) completed its 9th year of intensive data collection. Over 61 days of data collection nearly 5,000 reports were collected. This brings the total number of operations days up to 594 and the total number of reports to 66,864 for all years in which SHAVE has operated. An intensive quality control process was also completed significantly cleaning up the database of inaccurate and incomplete data. SHAVE hail data continues to drive research in single- and dual-polarized radar hail detection and calibrating multiple-radar, multiple-sensor (MRMS) hail sizing algorithms. For MRMS and single-polarized radar hail detection and sizing, the final analysis using 21,563 SHAVE hail reports over 389 cases from 2006 through 2012 was completed. Dual-polarized radar evaluations continue, with a Hail Size Discrimination Algorithm (HSDA) currently being evaluated using SHAVE and targeted for operational deployment in early 2015. SHAVE data also continues to support GOES-R Global Lightning Mapper/Lightning Jump research. Results are currently being compiled for conference presentations and journal publication. This project is ongoing.

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.

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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 Projects

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

Objectives

Our CIMMS student employees (Zachary Biggs and Nick Cooper) 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.

In fall 2013 Nick did validation work on a new algorithm the Branch was excited to bring into the baseline after NSSL had sufficiently developed it. The Precip/No Precip algorithm was developed to solve a frustrating challenge for the NEXRAD program – mitigating wind farms and interference. The Precip/No Precip algorithm was expected to more accurately tell what echoes are hydrometeors and which are not, to include the difficult task of removing what is effectively moving clutter that other clutter detection algorithms are unsuccessful at handling. The net benefit would be an improvement to a number of products including QPE. Nick conducted a number of case studies that enabled NSSL scientists to further refine the algorithm. He later briefed his results to the ROC Director and to a challenging Data Quality Team consisting of top national radar scientists. The algorithm is expected to be part of the Build 16 baseline. This is truly outstanding work.

The next algorithm Nick worked on in development with NSSL was R(a). Nick conducted case studies much like he did for the Precip/No-Precip algorithm. In some cases, R(a) did well in blocked radials, and in some cases it did very poorly (tropical moisture). He met with Alexander Ryzhkov (CIMMS at NSSL) who confirmed the results of his work. R(a) has since been improved based upon his work. R(a) also is expected to become part of the baseline but still continues to be refined.

The latter half of the year had Nick doing more work on the data quality approach to improving QPE, especially with radar calibration and calibrating ZDR. In one presentation he provided a compilation of Legacy PPS vs. Dual Pol vs. Q3 cases from good and bad ZDR sites. One of his better cases showed that ZDR calibration played a role in the QPE troubles KLIX had. Q3 started to show promise of being a good QPE algorithm through the winter months. Other casework Nick conducted also showed that Q3 had the best results during winter.

Another area Nick assisted with was a field test the Applications Branch conducted to determine optimized values for two adaptable parameter coefficients used in rain rate equations. Nick's results were summarized in briefings to the Data Quality Team.

Near the end of the fiscal year, Nick began working full time. His Honors Research project with Maj. Jeff Cunningham investigated if a ZDR bias exists when the radar beam passes through the melting layer. He is also working with Branch members to write C code to fix problems that will be included in the baselines for Builds 15/16. This culminates in a very impressive skillset; particularly the RPG programming, which traditionally is reserved for ROC software engineers.

No less impressive is Zack's work. Most of his time was spent on the redesign of the Branch's import and analysis program. This program is to be used in the future by ROC members outside of the Applications Branch (ROC Hotline) to maintain radar calibration across the fleet. The Branch had refined three new ZDR monitoring methods that have been developed in MATLAB (the Weather method, Bragg method, and Sunspike method). These methods must be implemented into the import and analysis program if Branch personnel are ever to be relieved of a monthly duty to produce calibration statistics across the fleet. The old import and analysis program would not be able to get through the amount of data needed, thus, an entire redesign of the Import and Analysis program began. This new design will still allow the user to import data, much like they have been able to do previously. However, the program will be able to ingest Level-II radar data more easily, process it, and make plots, unlike the original method. Thus, it saves the user the step of first importing the data and converting it before processing and plotting. So far the Sunspike method and the Bragg method have been successfully integrated into the new system.

Zack, like Nick, also is working with Branch members to write C code to fix problems that will be included in the baselines for Builds 15/16.

These projects are ongoing.

2. ROC Engineering Branch Projects

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

Objectives

The ROC Engineering Branch has the responsibility for designing, integrating, and deploying WSR-88D hardware, software, and communications improvements. To do this it needs tools that can simulate raw data to quickly determine the suitability of proposed system modifications and to generate various statistics and graphics for data analysis. An update to a Transmitter, Utilities, Generator Simulator (TUGSIM) design is needed to simulate Automatic Transfer Switch (ATS) characteristics. This is a difficult task because the elements of the TUGSIM (i.e., transmitter, utilities, and generator) are not well documented or specified, but the updated simulator is required to support comprehensive simulator functionality. The initial 2012 TUGSIM design needs to be modified and the updated design needs to be thoroughly documented. CIMMS student employees Mitchell Milligan and Joshua Wakeam provided important contributions to these efforts.

Accomplishments

Mitchel and Joshua were able to provide TUGSIM updates to enhance NEXRAD critical radar test and training capabilities. They developed an advanced understanding of the simulator design, determined the appropriate changes to the TUGSIM that were required, and successfully accomplished the modification. They updated and thoroughly documented the new TUGSIM design with ATS logic for replication and use

at non-operational NEXRAD radar sites. These non-operational sites are now able to perform experiments for prototyping of potential future NEXRAD radar improvements, training for new electronic technicians and engineers, and system operability testing to verify the completeness of component repairs.

They also completed a new TUGSIM circuit and software design. They built and bench tested a complete breadboard including a Printed Circuit Board (PCB) design. Once the design was verified, they completed the subassembly and system test of the breadboard. Then they interfaced with various PCBs vendor to obtain a first article manufactured product for ROC non-operational system testing. The unit test was positive and a quantity purchase was approved. Finally, they documented the design and specification to baseline the new TUGSIM.

These projects are ongoing.

Awards
Zackary Biggs was presented with a Certificate of Achievement dated 13 September 2013 for his work on the ASP file, NEXRAD's log of events that is quite useful when analyzing radar performance. The issue with the file is there is so much information in it that it is impractical to find anything specific. Zack developed an Excel Add-In, programmed in Visual Basic, which processes 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 also sees information about RDA and RPG alarms. In addition, users can see the Legacy and Dual Pol calibration information the radar calculated during every volume scan. These are then 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.

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 Experimental Forecast Program (EFP); perform research into application of new tools, exploring usefulness of winter weather local storm reports, extracting more information from local storm reports by updating and developing new decoder process, and applying verification techniques to convection allowing models/ensembles and experimental forecasts in near real-time within the HWT; and transfer of those activities found to be promising and of value from the HWT into daily operations at SPC.

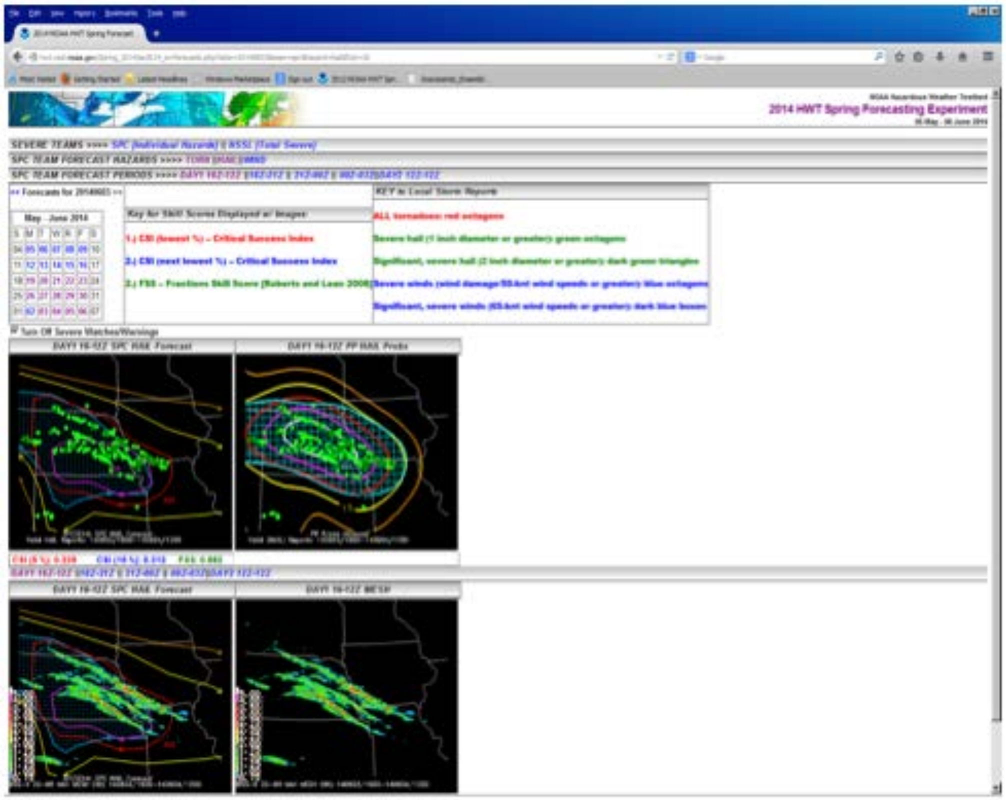
Accomplishments

1. Hazardous Weather Testbed

Chris Melick (CIMMS at SPC)

Objective forecast verification was conducted for the third consecutive year in near real-time during the 2014 HWT Spring Forecast Experiment (2014 SFE). As with the two prior years, the primary goal was to test the value of forecast verification metrics in the daily evaluations against subjective impressions of convection allowing model performance from the participants during the five-week period of the SFE. Following the initial findings from the 2012 SFE, computations of Fractions Skill Score (FSS) for neighborhood probabilistic guidance of simulated reflectivity from convection allowing ensembles continued to be used as a useful measure of skill for four different ensemble systems, one of which was introduced during the 2014 SFE [i.e. NSSL-WRF ensemble described in Clark et al. 2014]. In addition, the Critical Success Index (CSI) and FSS were calculated once again in the evaluation of experimental probabilistic forecasts for severe thunderstorms created by the participants each day (Melick et al. 2013).

For the first time the SPC desk produced individual hazard (tornado, wind, hail) probabilistic forecasts for three-hour time windows instead of one probabilistic forecast for total severe. Spatial plots of forecasts and time-matched observations (see figure below) were created for the 2014 SFE with the ability to display the computed statistic alongside the appropriate product on webpages (http://hwt.nssl.noaa.gov/Spring_2014/). While the preliminary local storm reports (LSR) served as the primary verification dataset, images from other observation sources were also made available to complement the LSR data for subjective comparisons. Of these, radar-derived maximum expected size of hail (MESH) from the National Severe Storms Laboratory (NSSL) served as a valuable surrogate for the occurrence of hail given the scarcity of LSRs in low-density population areas. One of the goals after the conclusion of the 2014 SFE was to explore gridded MESH fields as an alternative and comparison to traditional LSRs (Melick et al. 2014). This project is ongoing.



Sample spatial plots from 2014 SFE website illustrating the ability to display verification metric scores for experimental severe hail forecasts. The probabilistic forecasts for 16Z-12Z are valid starting on 4 June 2014 for a mesoscale "area of interest" centered on Joplin, MO. For the top row, the left panel shows the probability contours generated by the SPC desk for the 20-hr period while the right panel matches to the practically perfect (PP) hindcast derived from the LSRs. In addition, a 10% or greater hatched area for significant severe storms is also predicted/analyzed, with the verifying observations from the LSRs overlaid on top of each of the plots. Beneath the experimental forecasts, the CSI (at both 5% and 15% probability thresholds) and FSS are displayed. The bottom row is similar except that the verification dataset is accumulated, radar-derived MESH over the same time interval. A checkbox on the webpage shown allows the user to toggle on or off a transparent overlay of severe thunderstorm/tornado watches and warnings issued by the NWS.

2. Objective Verification: Internal Evaluation of Convection Allowing Models

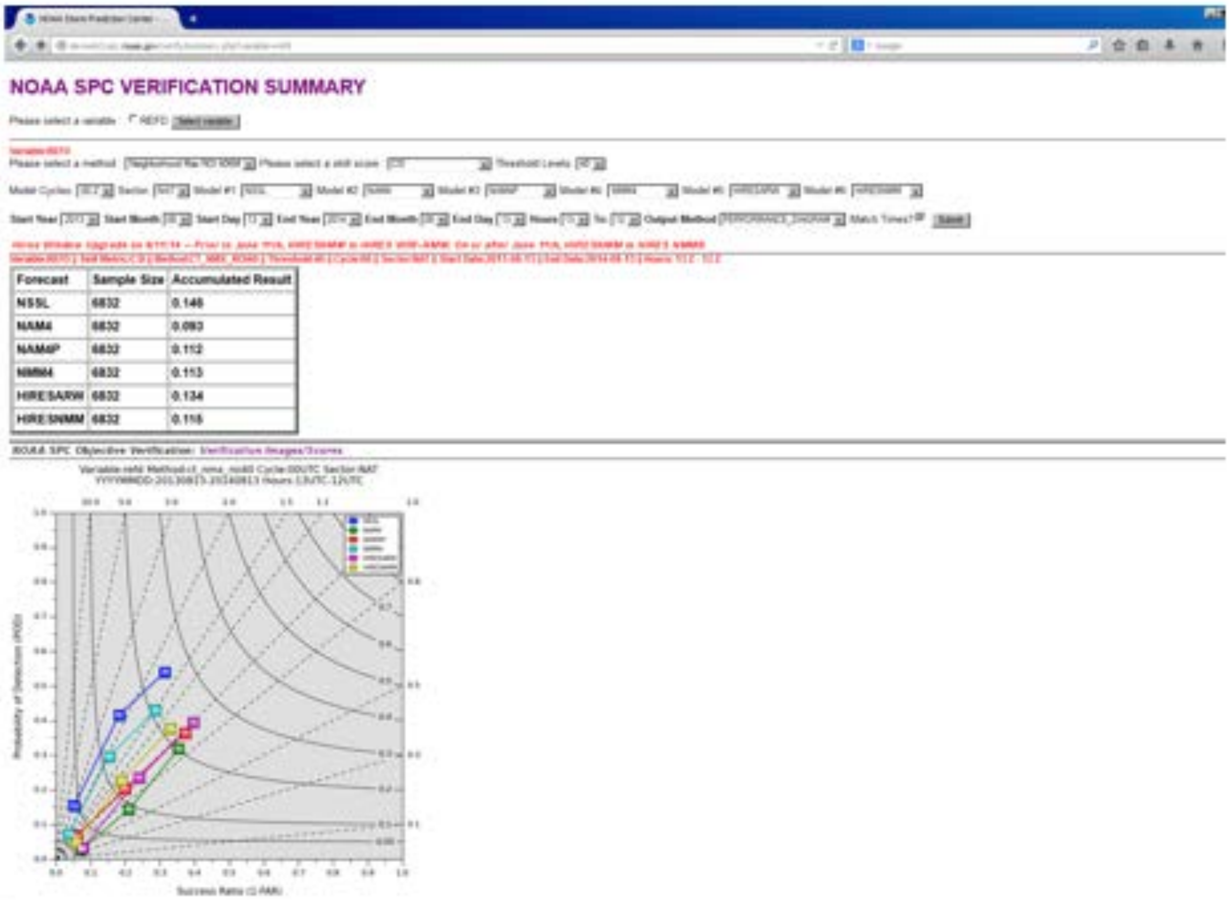
Chris Melick (CIMMS at SPC)

Objective verification of high-resolution model forecasts has been tested locally since August 2013. Following similar work conducted previously in the HWT (e.g., 2012 and 2013 SFE; e.g., Melick et al. 2013), the aim was to transition successful research activities into operations and to better identify those methods and metrics that can serve as benchmarks for performance criteria at SPC. Because of its relevance to severe

weather, simulated 1-km above ground level (AGL) reflectivity was considered using output from several convection-allowing models (CAMs). All CAMs considered have grid spacing of about 4-km, incorporate hourly output for a 24-hour period (13Z-12Z), and were initialized daily at 00 UTC and 12 UTC.

The verification of high-resolution reflectivity forecasts is performed using gridded radar observations of mosaic hybrid-scan reflectivity from the National Mosaic and Multi-Sensor QPE (NMQ) System. Standard forecast verification metrics (e.g., Critical Success Index[CSI]) are obtained by creating forecast- and observed- storm grid points from the reflectivity data. Objects are defined by specifying thresholds (30, 40, and 50 dBZ) and comparing “grid-point” to “grid-point”. Since predictability is generally low on the convective grid scale, a more meaningful technique was also pursued which accounts for spatial uncertainty, and relies on setting a radius of influence (ROI) to incorporate a “neighborhood” around each grid point. Initially, a 40-km ROI is used to be consistent with SPC Convective Outlooks (i.e., within 25 miles of a point). In order to calculate CSI for this method, a field of “neighborhood” maximum values are generated from both the forecast- and observed-raw reflectivity grids and then for the threshold applied. In addition, a 2-D Gaussian kernel operator is utilized with the weighting function set to 10 grid points, thereby effectively spreading the response to a 40-km distance. This acts to create spatial probability distributions for the events identified in the “neighborhood” method. Using a variation of the Brier score to verify probability forecasts, the fractions skill score (FSS) was utilized to directly compare the fractional event coverage in the CAM forecasts against those observed from the NMQ System.

A rigorous diagnosis of the various forecast verification metrics is made possible by creating multiple display options on an internal website. First, spatial plots matching forecasts and observations each hour are created daily with the ability to display the computed statistic. Second, a separate web page was designed to allow for a summary of the objective results in a table/graph type format. The daily statistical results have all been stored in a Postgres database application for centralized easy access in order to facilitate a more generalized framework for conducting internal evaluations. Displays are driven by the choice of a date, verification method and, in the case of a time series representation, the verification metric selection from a drop down menu. In addition to an hourly type synopsis for a particular day, multiple day accumulated scores can also be viewed via the table/graph page (see figure below). This project is ongoing.



Example table and performance diagram from SPC internal webpage which summarizes multiple day (one year; 8/13/2013–8/13/2014) verification metrics for 1-km AGL simulated reflectivity from six different CAMs. The summary output is created from a variety of user options: forecast verification method (grid point or neighborhood), forecast verification metric (e.g., CSI), probability threshold (30,40,50 dBZ), model cycle (00 UTC and 12 UTC), geographical sector, forecast time period, and style of summary type output (e.g., performance diagram, csv files).

3. Local Storm Reports: New, Experimental Decoder and Updated Webpages

Chris Melick (CIMMS at SPC)

The SPC has been decoding National Weather Service (NWS) Local Storm Reports (LSRs) in an automated fashion for about 20 years. In addition, daily webpage displays that contain summary graphics and text listings of the decoded reports have been created by SPC since the late 1990s. Minor changes in the format and content have occurred periodically since then, and webpages provide a primary source of storm report information and are used frequently by a wide range of customers. In April 2014, SPC introduced an experimental version of the preliminary daily storm report summary through several enhancements on a new webpage

(http://www.spc.noaa.gov/exper/reports/; Mosier and Melick 2014). These enhancements include a new page framework and layout, improved functionality and personalization, and the ability to access more information from each LSR. The content enhancement in the latter occurred because parts of the LSR had historically been truncated or ignored for the sake of brevity. As a result, an experimental LSR decoder was developed that processes all information contained in the report. The effects of this upgrade meant the source of the report was retained, the remarks section was extended to include all 500 characters, and the precision of the report magnitude was now included (e.g., measured, estimated, or unknown). Also, for the first time, the LSR decoder extended beyond traditional severe convective weather to include winter weather reports. A separate webpage was also made available for these winter weather reports. This project is ongoing.

4. The Usefulness of Winter Weather Local Storm Reports at the SPC

Chris Melick (CIMMS at SPC)

Winter weather events occur often across the contiguous United States and can have significant societal and economic impacts. Given its mission to forecast short-term hazardous mesoscale weather phenomena, the National Weather Service (NWS) Storm Prediction Center (SPC) has issued mesoscale convective discussions (MCD) for winter weather since 1997. While some subjective comparisons against traditional surface observations have been accomplished at SPC, a more thorough evaluation of winter weather MCDs has started recently.

SPC has been decoding National Weather Service (NWS) Local Storm Reports (LSRs) in an automated fashion for about 20 years as a quick means to summarize severe weather events. Beginning in 2012, a new LSR decoder was developed to include winter weather storm reports from the NWS. Although LSRs have some shortcomings, the observations are immediate and thus could serve in documenting trends in precipitation type and intensity as well as provide an additional method to verify the MCD product. An examination of characteristics from winter weather LSRs during all calendar days in 2010 through 2012 was conducted by Sullivan et al. (2014). The ultimate goal of this type of analysis is to identify any consistent trends or biases and the usefulness of the LSR dataset for winter weather events. This project is ongoing.

5. GOES-R Proving Ground Activities

William Line (CIMMS at SPC)

The SPC provides the GOES-R Proving Ground with an opportunity to demonstrate baseline and future capabilities products associated with the next generation GOES-R geostationary satellite system that have the potential to improve hazardous weather nowcasting and forecasting. After familiarization shadow shifts with SPC forecasters in operations, selected GOES-R proxy products were identified as having potential to fit into the forecast process and to provide unique and complementary information to SPC operations. Initial products implemented into the SPC's operational N-AWIPS system

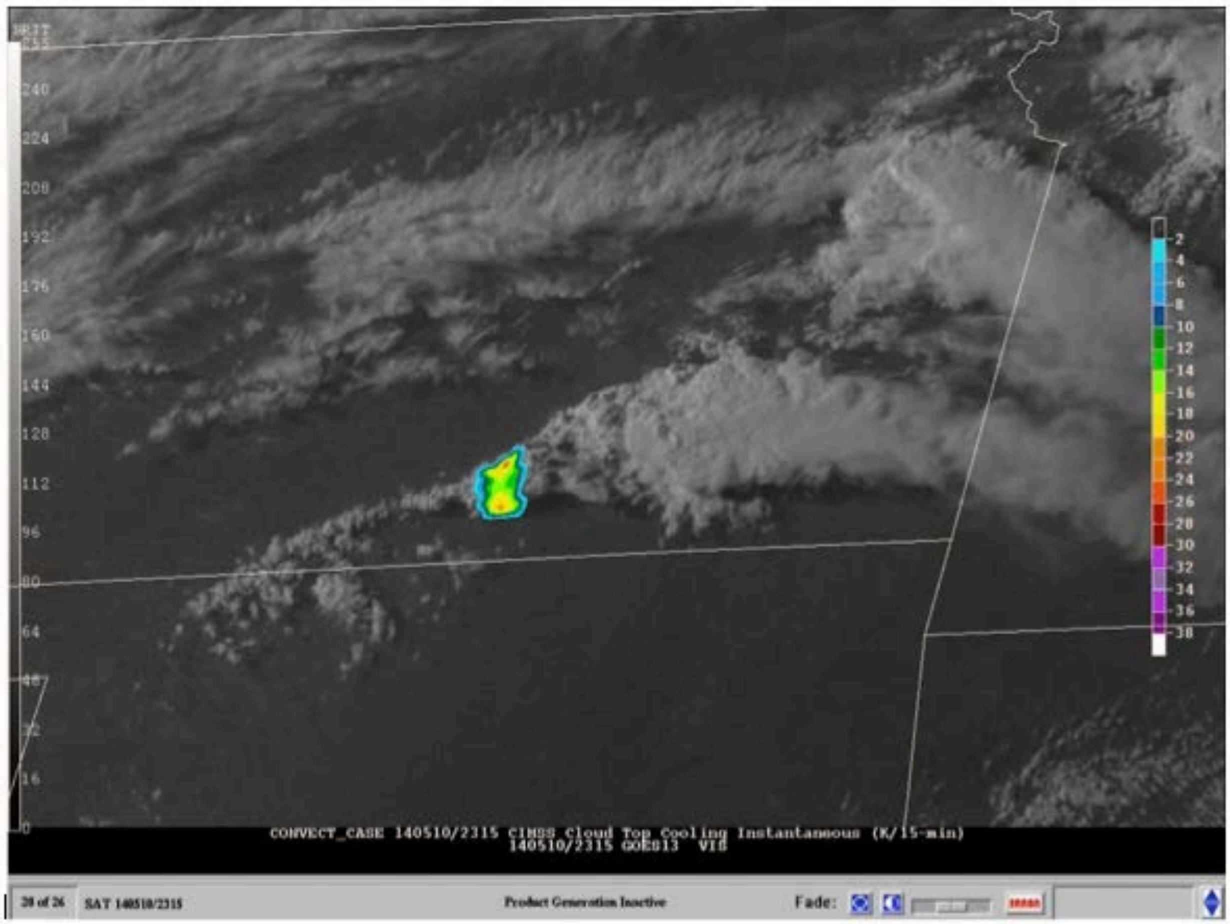
experimentally include the Overshooting Top Detection (OTD) algorithm, Cloud Top Cooling (CTC) algorithm and NearCast model analyses and forecasts of atmospheric moisture and instability. Additionally, GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) 1-minute imagery was available to forecasters during periods in August 2013 and May 2014, demonstrating a capability of the GOES-R Advanced Baseline Imagery (ABI).

Forecasters were introduced to these products over time and provided one-on-one training on how to properly interpret the information they provide. Line further interacted with forecasters by monitoring and demonstrating the products in operations in real-time. The gradual exposure to appropriate pre-operational GOES-R products and capabilities during multiple seasons and over different weather regimes provides SPC forecasters an opportunity to help determine operational applicability, as well as critique and suggest improvements for products relatively early in their development cycle. Additional products have been under evaluation by Line to determine their suitability for testing and evaluation in SPC operations.

Feedback from SPC forecasters regarding their use of the products comes in the form of verbal and email communication. Forecasters have found the OTD product to be an objective and visually complementary means of monitoring the evolution of mature convective systems. The overlay on satellite imagery allows users to easily and quickly spot OT features and their trends, and has proven to be especially valuable at night when it is difficult to manually identify small-scale storm top features in IR imagery. Similar to the OTD algorithm, forecasters appreciate the simple display of the CTC product overlay on satellite imagery (see figure below). Forecasters have utilized this product when monitoring for initial convective development, as it signals and quantifies the rate of rapid growth. The NearCast model provides SPC forecasters with an observation-based tool to help monitor the thermodynamic environment. They have found value in viewing the evolution of convection with respect to NearCast moisture and instability by overlaying the analyses on satellite imagery. Finally, SPC forecasters experienced many situations in which the 1-minute satellite imagery provided operationally significant information not captured as well (or at all) in current 5-15 minute imagery. The products and capabilities under evaluation have been referenced in various SPC forecast products throughout the period.

Additional GOES-R demonstrations took place as part of the HWT Spring Experiment from May 5 to June 6, primarily in the short-term forecast and warning environment of the EWP. Twelve National Weather Service (NWS) forecasters representing four NWS regions and four broadcast meteorologists evaluated various GOES-R products, capabilities, and algorithms using AWIPS-II. Demonstrated products included: NSSL-WRF GOES-R ABI Synthetic Imagery, NearCast model forecasts and analyses of atmospheric moisture and instability, GOES-R Convective Initiation algorithm, Probability of Severe model, Overshooting Top Detection algorithm, Pseudo Geostationary Lightning Mapper total lightning, Lightning Jump algorithm, Total Lightning Tracking Tool, and GOES-14 SRSOR 1-minute imagery. Product feedback from the evaluation was abundant and came in the form of daily surveys, daily debriefs,

weekly debriefs, 358 real-time blog posts, informal conversations in the HWT and four "Tales from the Testbed" webinars. This project is ongoing.



SPC NAWIPS display of Cloud Top Cooling product and GOES-East visible satellite imagery from 10 May 2014. Product was referenced in a SPC mesoscale discussion as it highlighted where the greatest cooling (most rapid growth) was occurring with the developing line of storms.

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.

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.

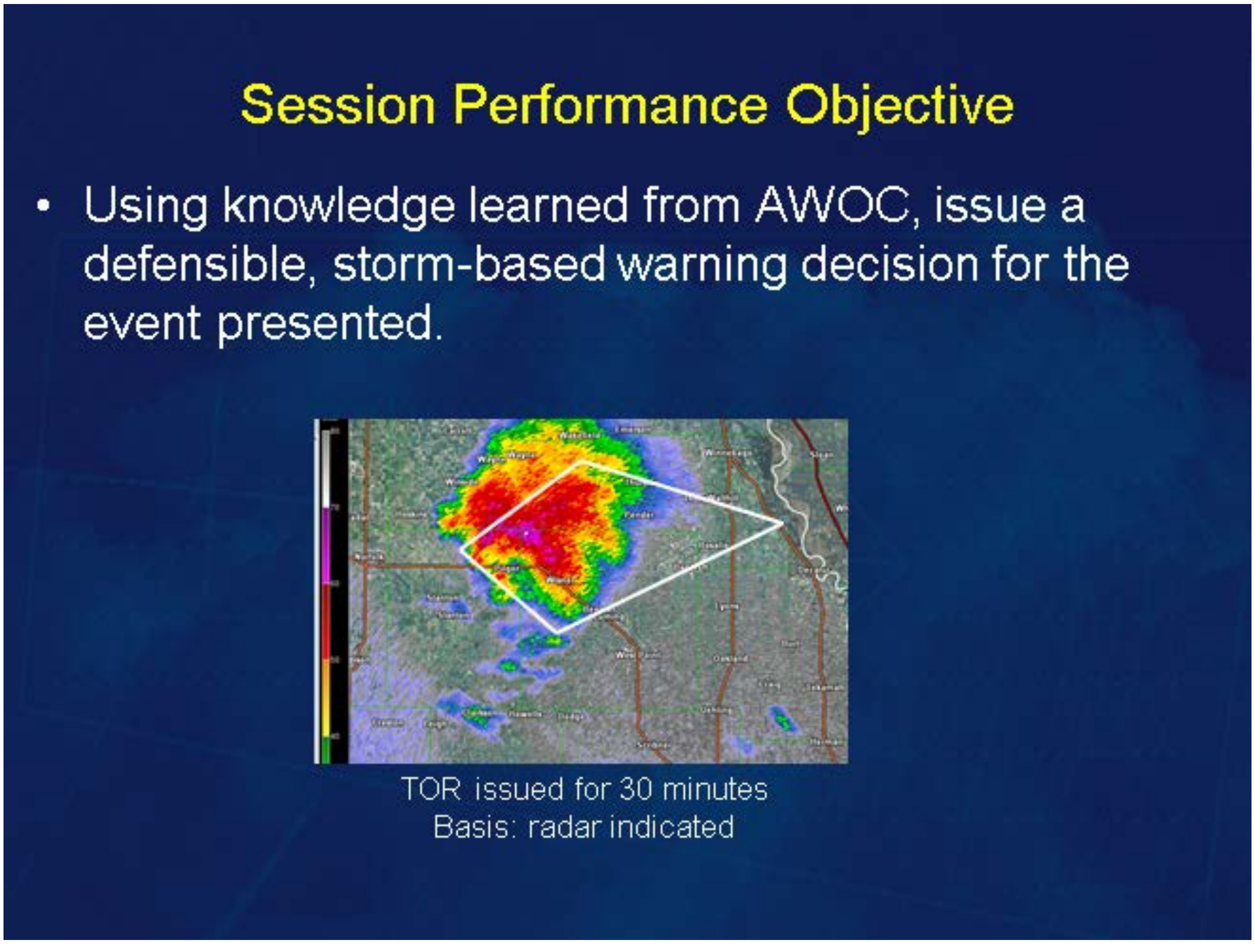
Accomplishments

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

Chris Spannagle, Steven Martinaitis, Tiffany Meyer, 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 delivery of AWOC, and CIMMS personnel were critical to the success of AWOC. After the initial AWOC release (which included tracks on Core Operations and Severe Weather), a third track (the AWOC Winter Weather track) was released in June 2006.

In collaboration with WDTB instructors, CIMMS scientists updated existing AWOC Core and AWOC Severe Track material for new hires to the National Weather Service. This work also included updating web pages and scripts for the AWOC Severe Forecast Challenge and a module for the AWOC Core Track. CIMMS scientists also contributed logistical support for both tracks of AWOC and its management. This support included responses to questions from the field, assistance for local facilitators and provision of certificates of completions to students, and utilizing a semi-automated method of producing statistical progress reports of students and forecast offices using NOAA's Learning Management System. This project is ongoing.



Example slide presented during the Advanced Warning Operations Course (AWOC) Severe Track, Warning Decision Making instructor-led training (ILT) session. This slide presents the performance objective for the training session: to apply the knowledge they have gained from previous lessons to make a warning decision and be able to explain the meteorological logic behind their decision.

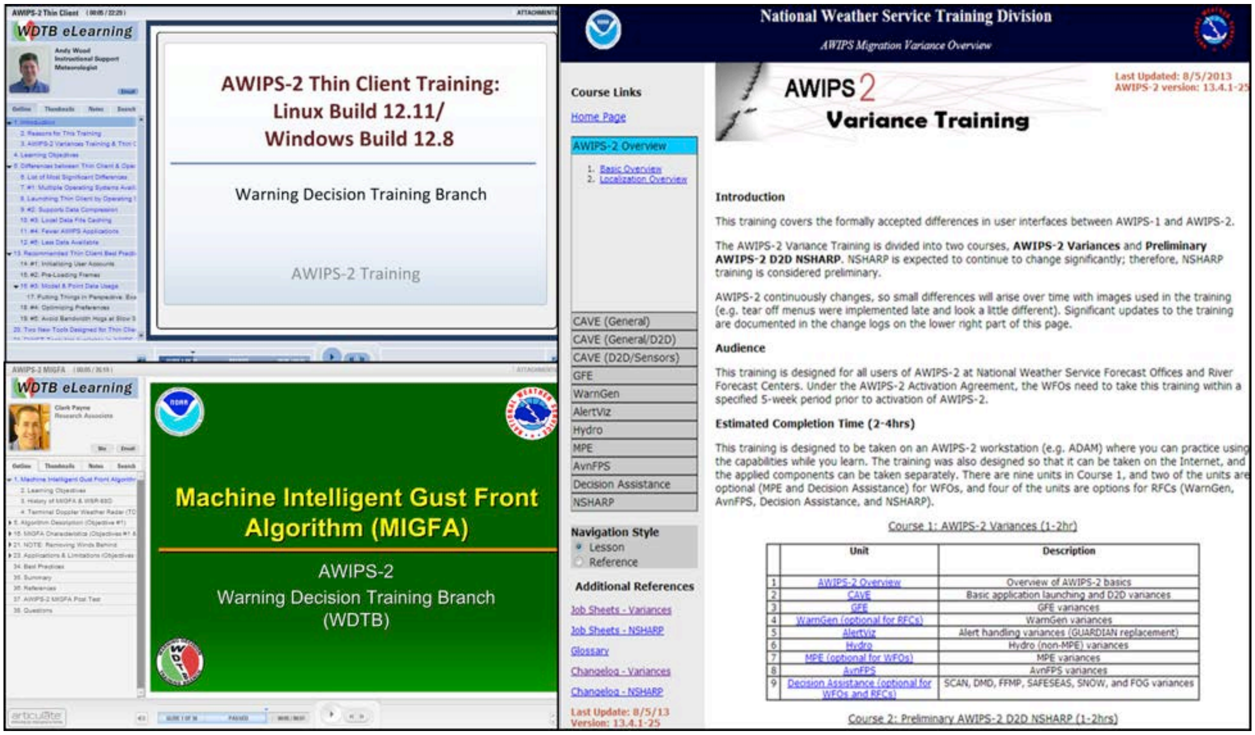
2. Advanced Weather Interactive Processing System (AWIPS) – II Training

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

NOAA's NWS has embarked on a re-development of their Advanced Weather Interactive Processing System (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 the AWIPS-II Variances 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-2 workstations as a job reference. The AWIPS-II 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. Examples of new and updated training, respectively, are the Machine Intelligent Gust Front Algorithm (MIGFA) and Thin Client courses. Likewise, the installation and initial testing of other AWIPS-related tools performed during this year include Total Lightning, Tracking Meteogram, Hazard Services, and Data Delivery enhancements. Lastly, Local Analysis and Prediction System (LAPS), Mesoscale Analysis and Prediction System (MAPS) Surface Assimilation System (MSAS), and Local Data Acquisition and Dissemination (LDAD) training lessons were also updated throughout the year as changes were made to these applications. This work is ongoing.



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

3. Distance Learning Operations Course (DLOC)

Matt Elliott, Jill Hardy, Steven Martinaitis, Dale Morris, Clark Payne, Chris Spannagle, Tiffany Meyer, Dan McKemy, Lance VandenBoogart, 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 NWS Warning Decision Training Branch. 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 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 scientists 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 work is ongoing.

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

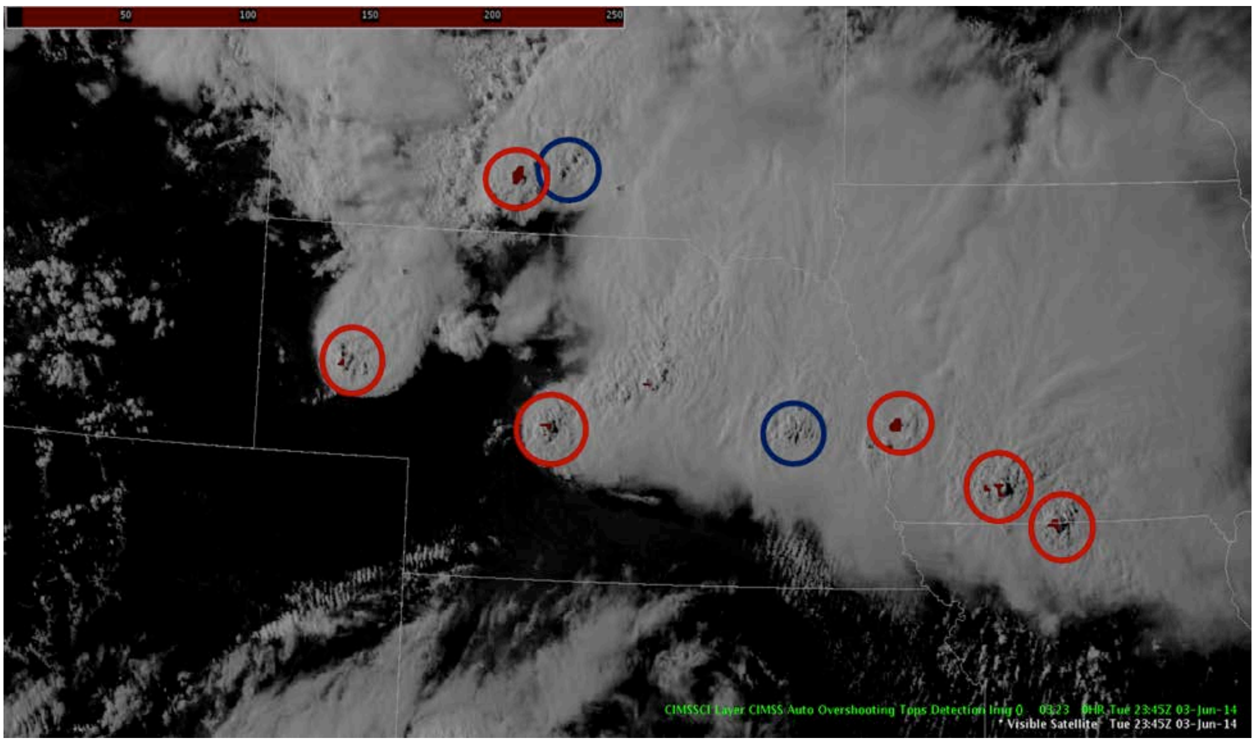
4. Experimental Warning Program/NOAA Hazardous Weather Testbed Support: Tales from the Testbed Webinars

Matt Elliott and Lance VandenBoogart (both CIMMS at WDTB)

The 2014 Spring Experimental Warning Program (EWP2014) occurred from 5 May 2014 to 6 Jun 2014. The goal of this project was to test and evaluate new applications, techniques, and products to support Weather Forecast Office (WFO) severe convective weather warning operations. Three primary projects were geared toward WFO applications: evaluation of multiple GOES-R convective products (including pseudo-geostationary lightning mapper products when operations were expected within the Lightning Mapping Array domains [OK, western TX, AL, DC, FL]), evaluation of the

Variational LAPS model, 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, with 3 NWS forecasters and 1 broadcast meteorologist each week (for a total of 12 NWS forecasters and 4 broadcast meteorologists). At the end of the week they delivered a webinar, entitled “Tales from the Testbed,” to NWS organizations and research institutions detailing their experiences. CIMMS staff facilitated these weekly webinars by assisting the participants in developing and presenting a short and focused PowerPoint discussing 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 help the participants with screen captures and write-ups for the webinar presentation. This work is ongoing.



This image shows an example graphic from a “Tales from the Testbed” webinar that was facilitated by CIMMS staff during the 2014 Spring Experiment (EWP2014). This graphic shows satellite overshooting top detections overlaid on visible satellite imagery with the red (blue) circles highlighting overshooting tops that were (were not) detected by the algorithm.

5. Multiple-Radar/Multiple-Sensor (MRMS) Training

Matt Elliott, Jill Hardy, Tiffany Meyer, Chris Spannagle, and Andrew Wood (all CIMMS at WDTB)

In FY15, Multiple-Radar/Multiple-Sensor (MRMS) software will be integrated into operations within NCEP’s national centers and the NWS. MRMS is a system of

automated algorithms that uses data from multiple radars, surface and upper-air observations, lightning detection networks, satellites, and numerical weather models. The data products produced from MRMS will serve as a basis for increased situational awareness at NWS field offices for hazardous weather and water. The initial rollout will contain over 100 new products with which most NWS forecasters have little familiarity. CIMMS staff (with WDTB leadership) is developing four tracks of training content to ensure these new data are effectively utilized by WFO and CWSU forecasters for improving severe weather warnings and aviation forecasts. These tracks will include: an introduction to the MRMS system and its products, a severe track, an aviation track, and a hydro track. The first of these tracks, the introduction, was the main focus of work during this reporting period. Subject matter experts have provided MRMS product technical documentation from NSSL. This documentation was the basis of WDTB's MRMS product quick-reference guides, which are meant to consolidate and adapt the technical information into a form that is suitable for forecasters. Once complete, the reference guide will be available on-line to NWS forecasters.

CIMMS staff participated in two other activities related to the MRMS training. For two separate weeks in April, CIMMS staff helped conduct the MRMS-Severe Best Practices Experiment in the Hazardous Weather Testbed. Each week, four NWS forecasters used MRMS products in an operationally representative warning environment and provided feedback on the best practices of the data. This experiment was a vital link in the research-to-operations/operations-to-research (R2O/O2R) process for MRMS severe products. In May, CIMMS personnel accompanied WDTB staff to the NWS Weather Forecast Office (WFO) in Fort Worth, Texas where they observed the use of MRMS products during warning operations. They documented the forecasters warning methodology and best practices related to the suite of MRMS severe products that was available at the WFO. This information provided insight on how to best deliver training content to forecasters. This work is ongoing.

CIMMS and WDTB staff observe the use of MRMS products at the NWS Weather Forecast Office in Fort, Worth, Texas.

6. Weather Event Simulator (WES)

Dan McKemy (CIMMS at WDTB)

Now in its thirteenth year since its 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 WDTB's major training initiatives, allowing students to apply lessons in an operational context. Over the past year, the WES was used in the development of training simulations for the Advanced Warning Operations Course (AWOC), Distance Learning Operations Course (DLOC), Tropical Tornadoes Course, and Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS) familiarity training.

The WES architecture continues to remain in step with Advanced Weather Interactive Processing System-I (AWIPS-I) releases. WES 9.14 was released in January 2014 to maintain this paradigm. Two of the biggest changes in the WES software with this version of WES were: (1) The incorporation of new WarnGen templates that included Tornado and Flash Flood Emergencies, and (2), making the WES compatible with SAILS data. This updated version of WES also included several small upgrades for the Graphical Forecast Editor (GFE), Aviation Forecast Preparation System (AvnFPS), and Display 2 Dimensions (D-2D). CIMMS staff also provided extensive support to NWS forecast offices in the installation and troubleshooting of the most recent software release and WES training cases, as well as responding to technical questions from users.

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

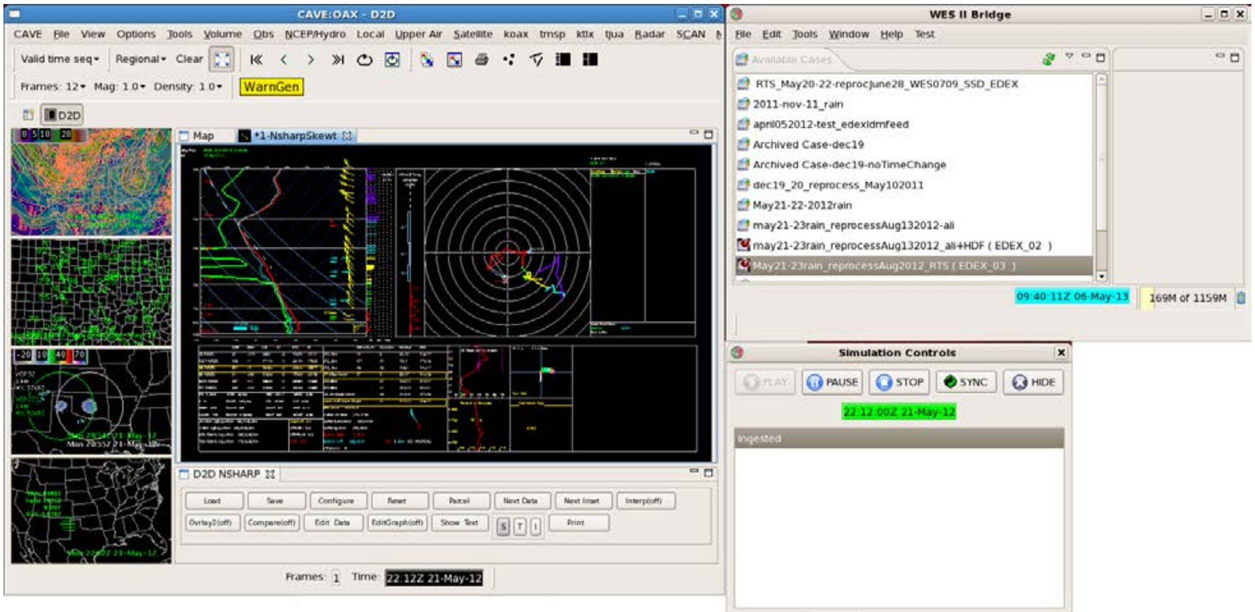
7. Weather Event Simulator – II (WES-2)

Dale Morris, Dan McKemy, Tiffany Meyer, and Ali Virani (all CIMMS at WDTB)

The new Advanced Weather Interactive Processing System (AWIPS-2) software being deployed in all NWS forecast offices results in the obsolescence of the existing Weather Event Simulator (WES, or WES-1). A need therefore exists to preserve existing simulation functionality provided by WES-1 and support the NWS Directive 20-101 requirement for every forecaster to complete two simulations prior to each significant weather season. Moreover, the WES system is the primary method staff members at a local Weather Forecast Office (WFO) use to view and analyze any archived weather data from AWIPS. As a result, the WDTB is developing the WES-2 Bridge, based on the AWIPS-2 platform. This design will also serve as a prototype method of incorporating training functionality into the "baseline" AWIPS-2 system. To support this development and to ensure compatibility between AWIPS-2 and WES-2 Bridge, significant collaboration occurred between CIMMS personnel, WDTB instructors, the NWS Office of Science and Technology, and the AWIPS-2 contractor.

CIMMS staff at WDTB collaborated with the NWS and the AWIPS-2 contractor on the design and implementation of an updated archival solution, based on changes in both the AWIPS-2 architecture and the playback requirements of WES-2 Bridge. Because WES-2 Bridge is the primary method that NWS forecasters as well as researchers and students at universities and other institutions will access archived case data in AWIPS-2, CIMMS staff at WDTB performed significant amounts of testing to verify the archive software functionality works correctly, interfaces well with WES-2 Bridge, and produces a dependable archive of all data types available in AWIPS-2 including model, satellite, radar, surface and upper-air observations, derived products, and the like. Finally, training materials were prepared on how to use the new archival system; these materials will be published and released to WFOs in the late Summer 2014.

CIMMS staff at WDTB have tested and refined WES-2 Bridge functionality, including the ability to synchronize simulations for an emerging distributed simulation requirement, that will eventually span the NWS enterprise from national and regional centers down to individual forecast offices. External partners may eventually be included in these distributed simulations as well. The WES-2 Bridge features a case converter so that existing AWIPS-1 format case data will be viewable in the WES-2 Bridge/AWIPS-2 system; otherwise most previously collected AWIPS-1 data would be unusable. The case converter will allow training and research activities based on the AWIPS-1 storage paradigm to continue in the new system. The WES-2 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-2 infrastructure, the updated WESSL provides a method to engage forecasters with feedback as they complete simulations. The initial release of WES-2 Bridge to NWS WFOs is anticipated in Fall 2014, pending AWIPS-2 development and deployment activities. This work continues.

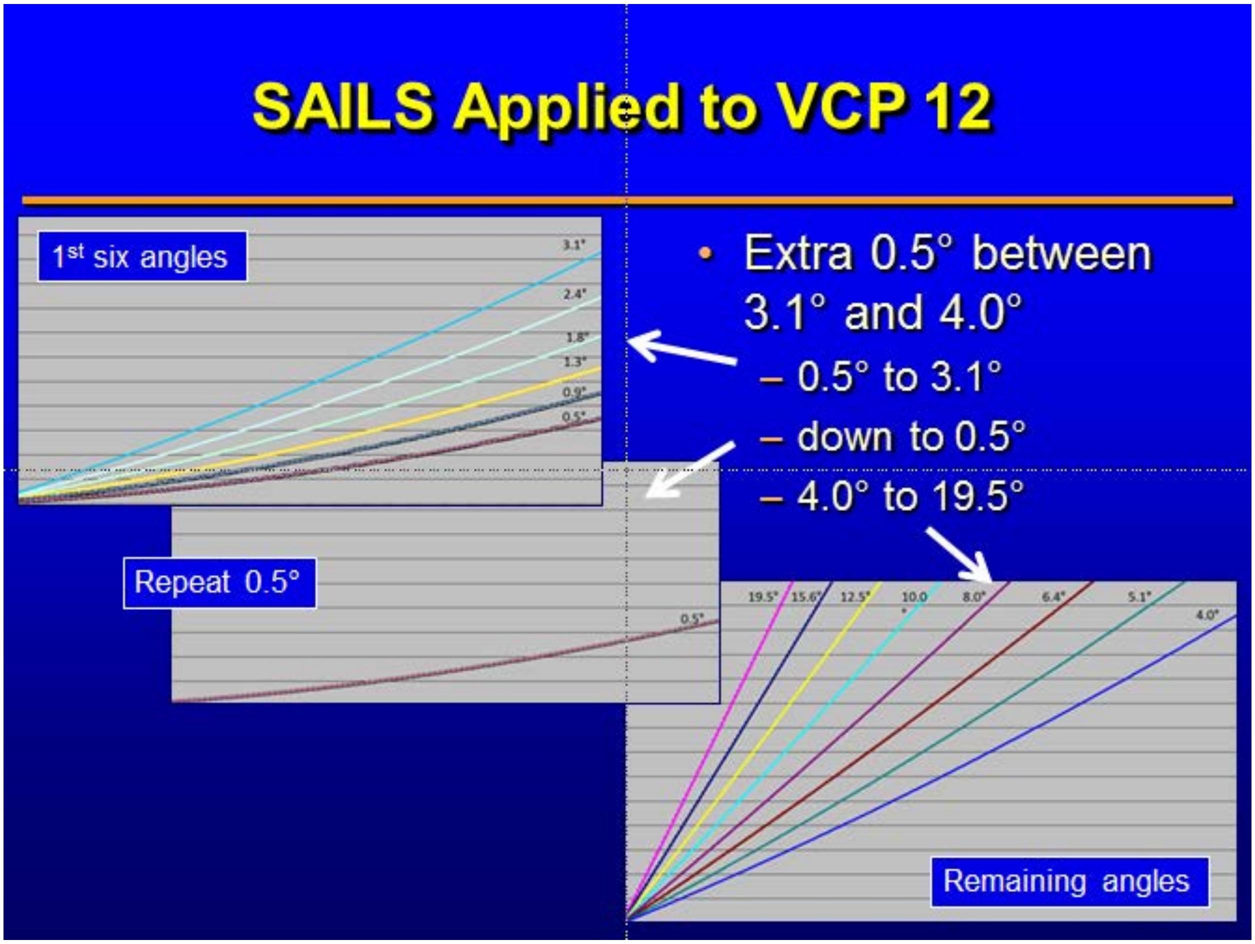


Sample displays shown from the WES-2 Bridge software. Left: The AWIPS-2 visualization software known as CAVE (Common AWIPS Visualization Environment) in its "D2D perspective". Top right: The WES-2 Bridge main window allows cases to be loaded, unloaded, edited, simulated, and reviewed. Bottom right: The WES-2 Bridge simulation control window controls the time of the simulation and its current state (play, paused, stopped). The WES-2 Bridge software ensures that, as the simulation progresses, both the simulation window and the CAVE window are synchronized in time.

8. WSR-88D Build Improvement Training

Matt Elliott, Clark Payne, and Andrew Wood (all CIMMS at WDTB)

During the past year, there were several major upgrades made to the WSR-88D Radar Data Acquisition Unit (RDA) and Radar Product Generator (RPG) software. This latest software upgrades (Builds 14.0 & 14.1) contains several new applications, including Radial by Radial (RxR) Noise Estimation, Coherency Based Thresholding (CBT), Storm-Based Auto PRF, and Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS). These builds also includes updates to exist components of the Radar Product Generator (RPG) and Radar Data Acquisition Unit (RDA) software, including Initial System Differential Phase (ISDP), Eight-Hour Performance Check, the Automated Volume Scan Evaluation and Termination (AVSET), and the dual-pol RPG algorithms. 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 work is ongoing as the WSR-88D continues to receive periodic software and hardware upgrades.



This example shows a slide from the on-line training developed by WDTB for WSR-88D Build 14.1. This slide discusses the Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS) and how this additional 0.5° tilt fits into Volume Control Pattern (VCP) 12 during a standard volume scan.

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

NOAA Technical Lead: Stephan 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 (EWP) at the National Weather Center in Norman. The work described below is ongoing.

Accomplishments

1. General Overview

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB)

The tenth full year of the CIMMS/NWS-Meteorological Development Laboratory (MDL) scientist position was completed during this review period. During this year, the scientist graduated from his position as Operations Coordinator for the Experimental Warning Program's (EWP) spring experiments in the NOAA HWT in order to concentrate on being a co-principal investigator on two independent experiments (described in separate sections). 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. The CIMMS/MDL scientist remained the liaison between the HWT and NWS-MDL. He continues to collaborate with NSSL

scientists who are involved in the EWP, including attending scientific and technical meetings and retreats, and is the coordinator of a weekly brown-bag lunch devoted toward EWP-related topics. At these brown bag lunches, there are local and guest speakers, software demonstrations, and general discussions on recent severe weather episodes.

The CIMMS/MDL scientist continues to be involved with the severe weather warning R&D activities at CIMMS and NSSL and served as a co-principal investigator and subject matter expert for the MRMS severe weather warning products. The process to transfer MRMS technology to operations at NCEP was well underway in FY14, and the CIMMS/MDL scientist has been involved in the following activities related to the MRMS tech transfer, 1) conducting an advanced experiment in the Hazardous Weather Testbed spring program to gather MRMS-Severe “best practice” information and determine the benefits of MRMS-Severe data via testable hypothesis as a basis for the development of warning decision training materials with the WDTB, 2) Development manager for creating the capability to display operational MRMS products in the National Weather Service AWIPS2 system, and, 3) supporting the collaborative MRMS “community” on the NOAA Virtual Laboratory (VLab).

2. MRMS-Severe Best Practices Experiment

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), and James LaDue and Robert Prentice (both WDTB)

The CIMMS/MDL scientist was a co-principle investigator for an independent experiment within the NOAA HWT, conducted separately from the regular spring experiment in the NOAA HWT which was carried out in April 2014 with NWA forecasters acting as evaluators and experiment subjects. The MRMS-Severe Best Practices Experiment (MRMS-SBPE) was designed to two main aspects. The first aspect was to gather “best practices” information using MRMS-Severe products to help augment severe weather warning decision-making. This included polling the forecasters on the best products to use, the best ways to display the data (colormaps, 4-panel display layout, units, etc), and offer suggestions for new products. The second aspect, which was the bulk of the experiment, was to conduct controlled experiments designed to test several hypotheses that MRMS-Severe data can improve storm diagnosis and triage, improve warning lead time, and improve warning precision by reduce false alarm area and improving warning polygon alignment. All of the information gathered during this experiment is being used as the basis for the development of MRMS operational training materials by the WDTB. The controlled experiments were designed by dividing the forecasters into two teams, one operating without MRMS products, and one operating with MRMS products. Both teams still had at their disposal the traditional suite of severe weather products and data sources (e.g., radar data, etc.). Archive data sets were carefully chosen to represent a spectrum of severe weather scenarios and to test the various hypotheses. The forecasters were asked to perform a variety of exercises, led by a proctor, to evaluate the MRMS products.

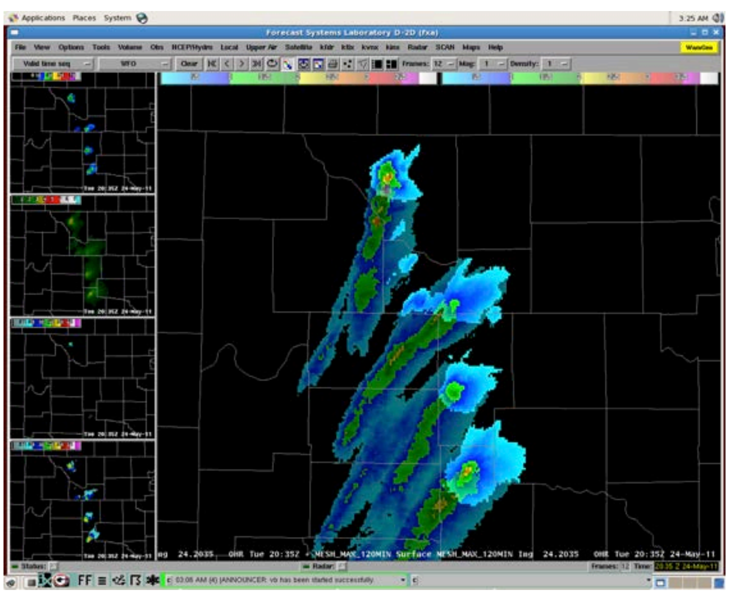
The analysis of the data collected has begun and will conclude in FY15, culminating with a peer-reviewed journal article. Initial results have shown that MRMS products do indeed improve storm diagnosis by reducing the amount time it takes to determine if a storm is severe or tornadic (in some instances by more than 50%).

3. MRMS Product Display for AWIPS2

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), and Darrel Kingfield and Robert Toomey (both CIMMS at NSSL)

The operational MRMS system at NCEP is expected to be online and disseminating data to the weather enterprise on 1 October 2014. The NWS is one of the main customers of these data. Therefore, work kicked off to design and develop the initial display of the MRMS data in the NWS's AWIPS-II. The CIMMS/MDL scientist was the development manager overseeing two NSSL employees, one hired recently as a full-time AWIPS-II developer. All three employees are the AWIPS-II development team in Norman, and have been involved in the AWIPS-II National Experimental Product Development Team, including participating in a weeklong training workshop in Huntsville, Alabama.

The initial development task, slated for AWIPS-II Build 14.3.1 (to be deployed February 2015), involves the display of 2D products from the Satellite Broadcast Network (SBN) feed, being disseminated from the NCEP MRMS system. The task is being developed using the NOAA Virtual Laboratory. The figure below shows an example of the MRMS data as it appears in AWIPS-II.

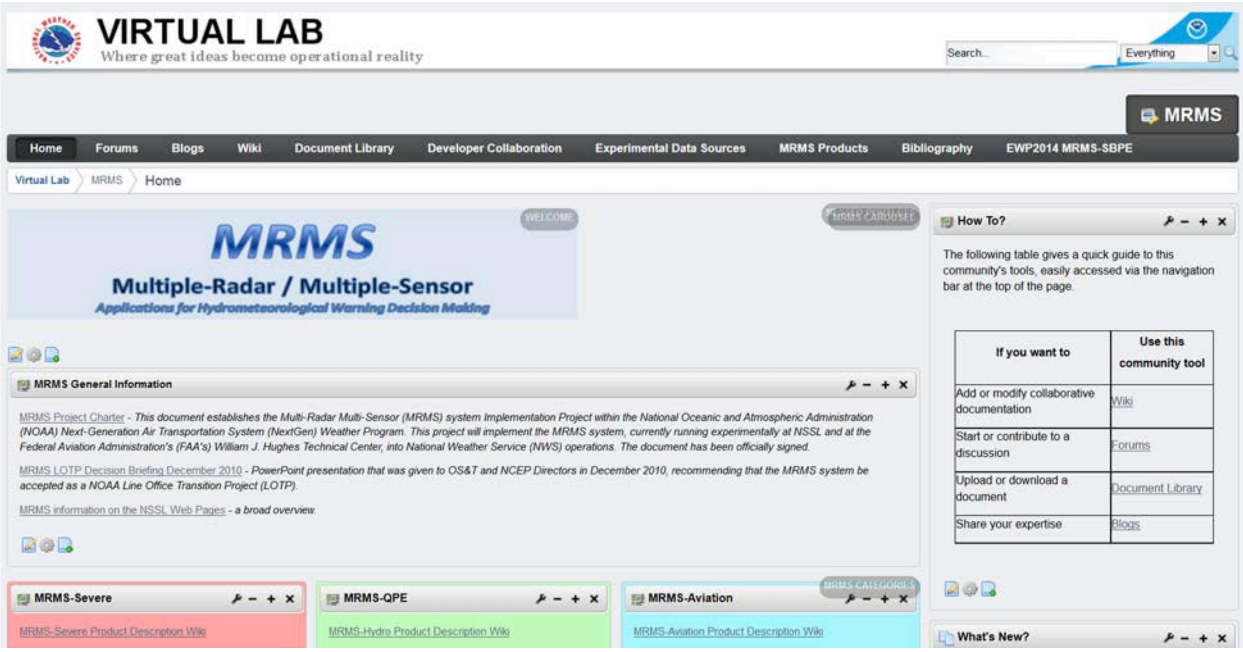


Advanced Weather Interactive Processing System II (AWIPS-II) depiction of MRMS products. Shown in the large panel is an image combination of instantaneous Maximum Estimate Size of Hail (MESH) and 60-minute MESH Tracks.

4. MRMS in the NOAA Virtual Laboratory (VLab)

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB)

The CIMMS/MDL scientist is the site owner of the MRMS community in the NOAA Virtual Laboratory (VLab). He developed the design and layout of the collaboration community and manages the development community (the latter to be expanded in FY15 to include external MRMS developers of future applications). The scientist coordinated the development of an MRMS product Wiki in the VLab, designed as a basis for official NWS/WDTB training documentation. In addition, the CIMMS/MDL scientist served on the VLab Support Team, to help design, develop, and implement the NWS VLab as a whole.



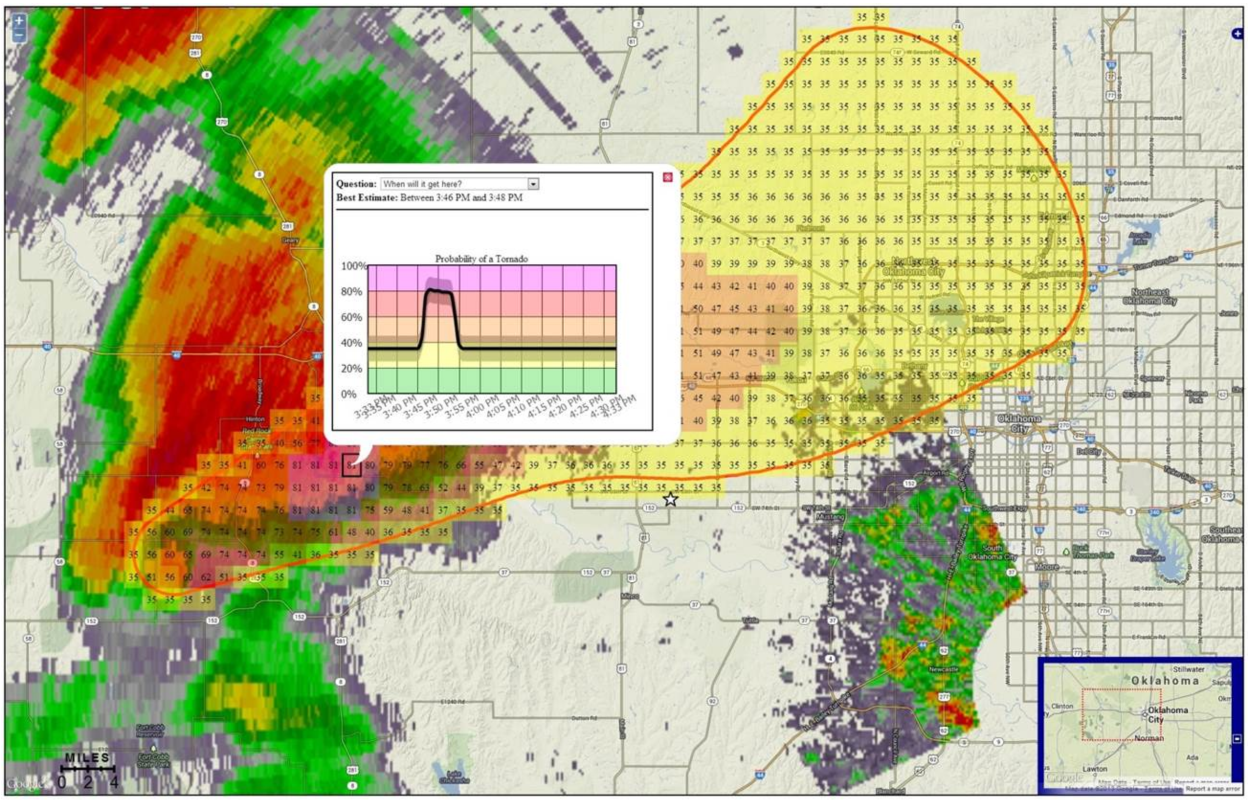
Screen capture of the MRMS community page in the NOAA Virtual Laboratory.

5. Probabilistic Hazard Information (PHI) Tool

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), Chris Karstens (CIMMS at NSSL), Chen Ling (formerly OU School of Industrial and Systems Engineering, now the University of Akron)

The CIMMS/MDL scientist continued to be involved with the AWIPS-II Hazard Services (HS) software project, in collaboration with the NOAA Global Systems Division (GSD). This included being co-principle investigator of a project to evaluate a new Probabilistic Hazard Information (PHI) Tool in the NOAA HWT with visiting NWS forecasters in May and June (conducted independently from the main HWT spring experiment). Collaborators included the NSSL, and human factors experts from the University of Oklahoma School of Industrial and Systems Engineering. The PHI Tool is a major

component of the Forecasting A Continuum of Environmental Threats (FACETs) initiative to change the severe weather forecast and warning paradigm for the NWS. MRMS products were available within the PHI tool to aid in the forecaster decision making process. Invited forecasters evaluated the browser-based PHI Tool application used to create probabilistic threat forecast information on the 0-2 hour time scale. Their comments were used to rapid prototype modifications to the PHI Tool; sometimes these new modifications were available the same day. Using human factors analysis, workload differences between the AWIPS-II WarnGen tool and the experimental PHI Tool were compared. Analysis is underway to verify the threat forecasts that were issued by forecasters using the PHI Tool in real-time severe weather warning situations. These projects are ongoing.



Screenshot of the Probabilistic Hazard Information (PHI) Tool that was evaluated in the HWT.

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

NOAA Technical Lead(s): John Ogren (NWSTC), Kim Runk (NWS/OPG), and Jim Poole (NWSTC)

Other Staff and Collaborators: Jeffrey Zeltwanger, Teresa Murphy, Jim Jones, Jerry Griffin, Dave Rowell, Heather Galan, Dave Cokely, Marco Bohorquez, Doug Streu,

Cathy Burgdorf, Tom Burgdorf, and Hattie Wiley (all NWSTC), Chad Gravelle (CIMSS-Wisconsin), Jack Richardson (NWSTC Contractor), Eli Jacks and Andy Horvitz (both NWS/OCWWS), Mark Mitchell (NWS/EAX), Somer Erickson (FEMA), Jim Keeney (NWS/CRH), Julie Adolphson (EAX – MIC), Derek Deroche (NWS/CRH), Bill Bunting (SPC), and Jennifer Zeltwanger and Kelsey Angle (NWS/CRH)

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

Funding Type: CIMMS Task II

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

Accomplishments

1. Forecast Systems Optimization

a. AWIPS Tools Distance Learning

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

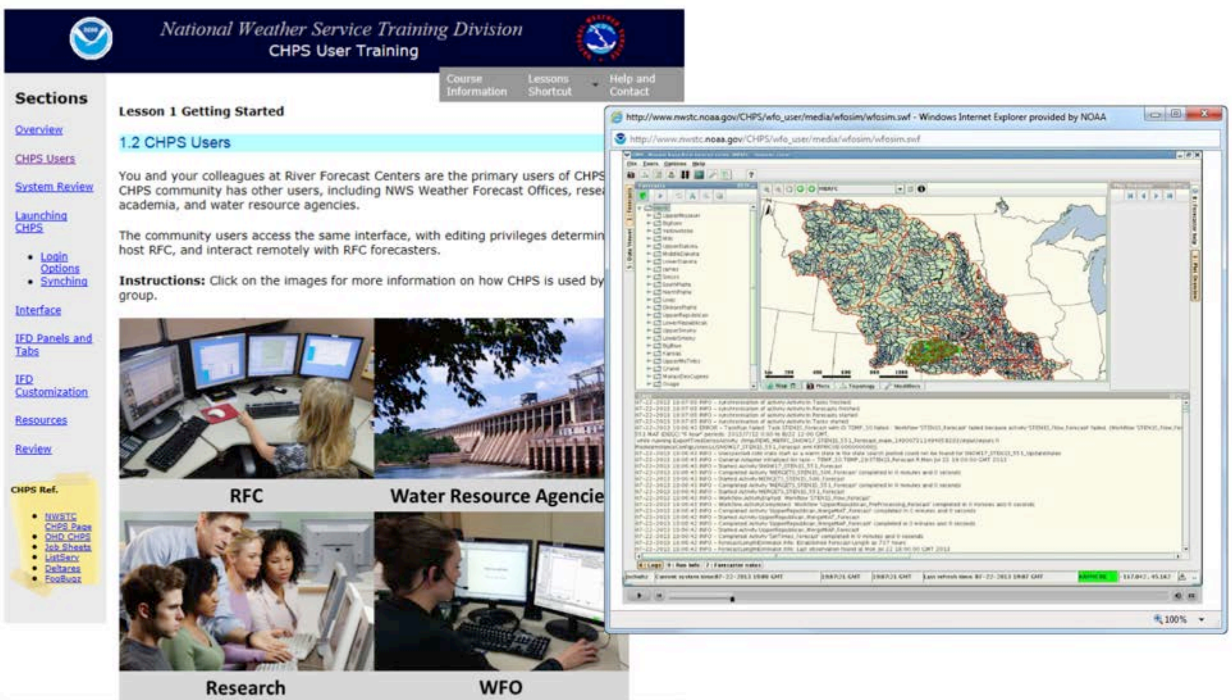
During the period from July 2013 through the present, two separate distance learning training modules were developed (or in the process of being developed) for AWIPS. The first was developed in mid to late 2013 training NWS forecasters on the AWIPS Collaboration Tool. This training included a fully interactive online simulation. The second was the Data Delivery Tool. Due to setbacks in the development of this tool, this second piece of training is still pending. Also during the reporting period, CIMMS Justin Schultz revamped several AWIPS-II transition courses and added more descriptive and representative media pieces and images to more effectively present the content.

Screen captures from two live courses from this project and one in progress (Data Delivery Tool) as seen in the NWSTC Distance Learning template.

b. Community Hydrologic Prediction System (CHPS)

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

During the reporting period additional courses were developed for the CHPS training curriculum. In order to develop this training, an upgrade to version 3.0.1 was made to the NWSTC CHPS in early July 2013. Training modules developed included RFC User and WFO User Training. Each module included a simulation module that was developed by Justin Schultz.

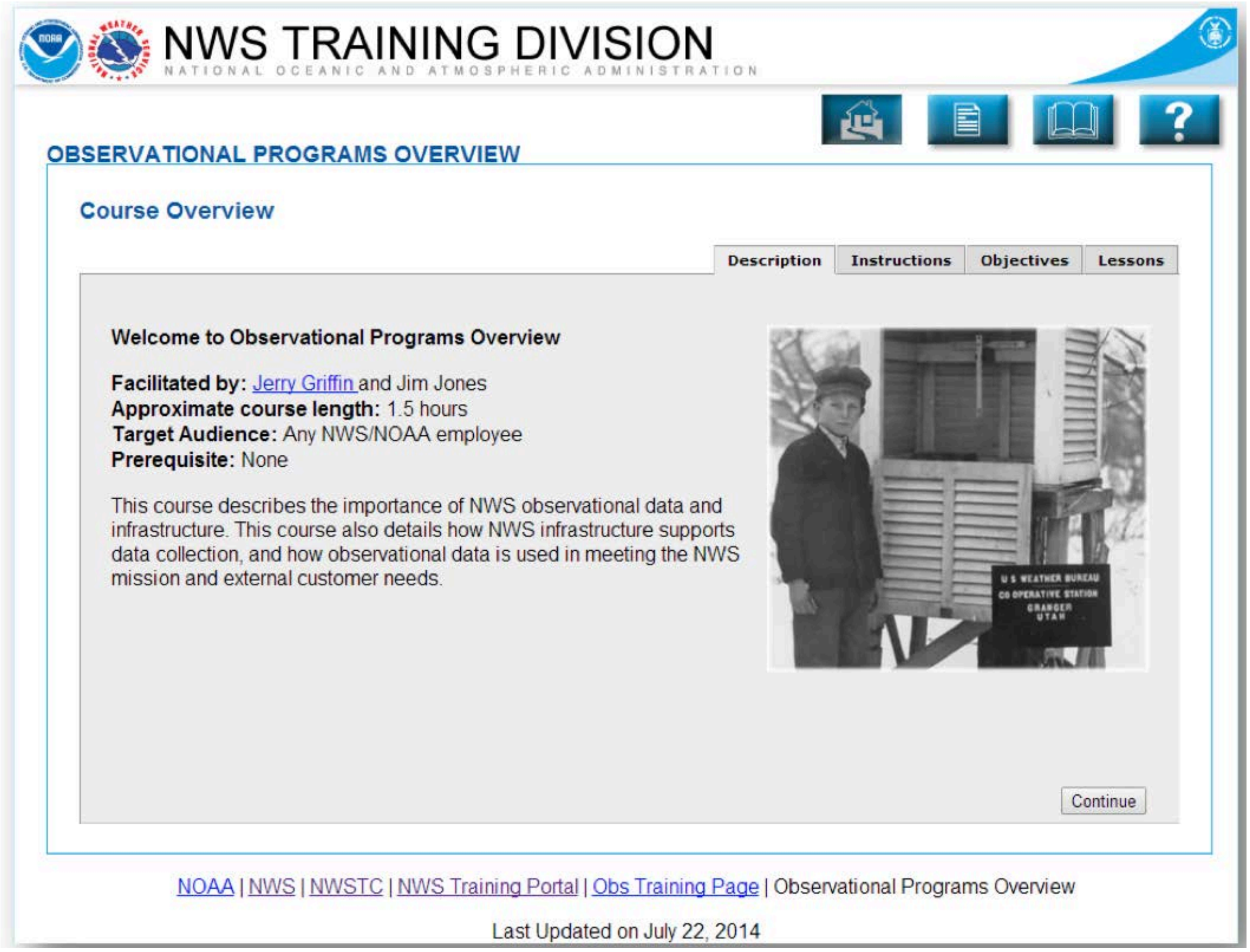


Screen captures from CHPS WFO and RFC user training distance learning course, including an image from the interactive simulation (right).

c. Observational Programs Overview

Megan Taylor and Justin Schultz (both CIMMS at NWSTC), and Jim Jones, Jerry Griffin, and Hattie Wiley (all NWSTC)

Beginning in summer of 2013, a revamp of the old Data Acquisition for Managers distance learning course began. Originally assigned to Jim Jones and Justin Schultz, the goal of this course was to use the existing course to provide a more general synopsis of the NWS Observing Programs for anyone in the NWS or NOAA. In September 2013, Megan Taylor was added to the project. The project continued through the reporting period and officially launched for the NWS and NOAA personnel to begin viewing in August 2014. This project also marked the first usage of the new NWSTC distance learning course design.



Screen capture of the Observational Program Overview distance learning course start page.

d. Cooperative Observer Program (COOP) Distance and Residence Courses

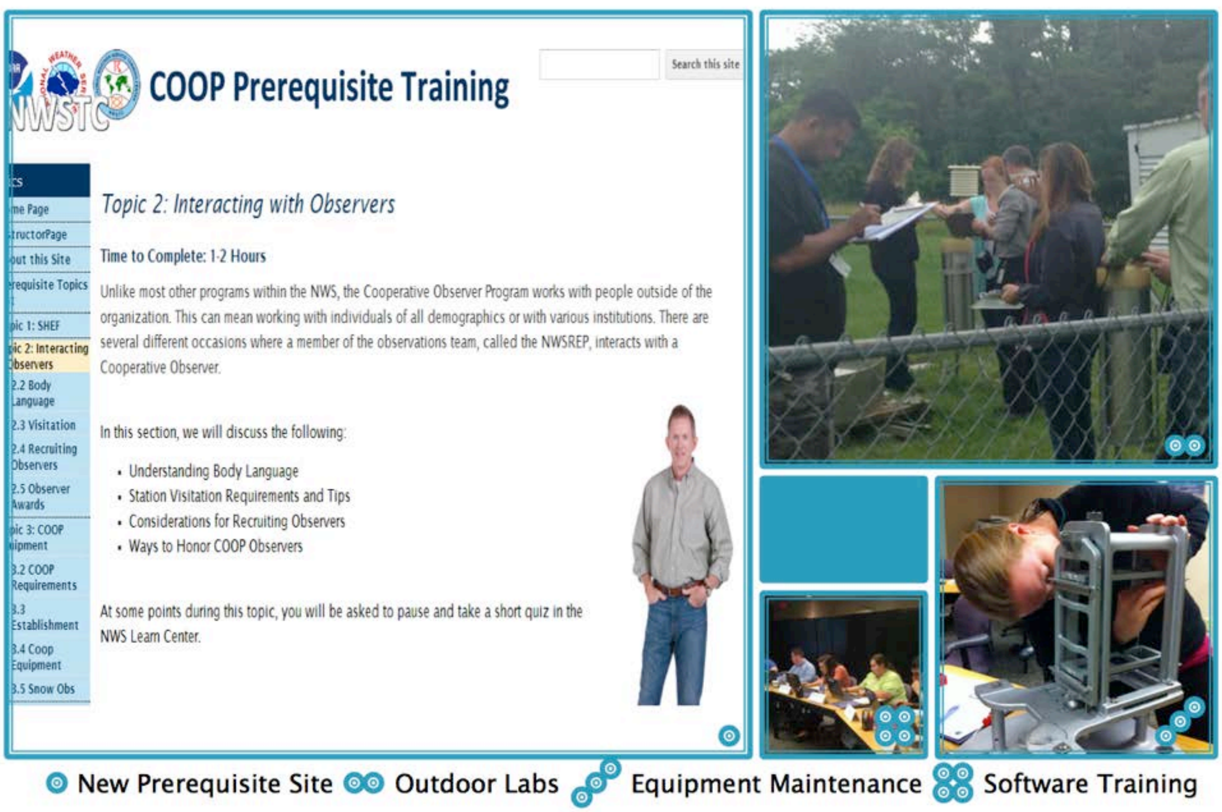
Megan Taylor and Justin Schultz (both CIMMS at NWSTC), and Jim Jones (NWSTC)

Considerable ground has been covered during the reporting period for the Cooperative Observer Program and its related training. In August 2013, Megan Taylor was added to the project to consult on designs for the September 2013 course presentations. Both she and Justin Schultz attended this course – Justin as a means of professional development and Megan to help absorb information to help further the development of COOP training. After discussion with Lead Instructor Jim Jones, it was decided to take a bold step and use the flipped style of instruction on this course. This method takes basic classroom instruction and puts it as prerequisite and/or online material and saves the homework or activity materials for the in class portion.

Development for the new style of learning began in October 2013 with Megan Taylor building a Google Site to act as the COOP Residence Course Prerequisite Site. This

was finished by January 2014 for students attending the March 2014 class to begin their work. The March 2014 class was considered the beta test of this program and was overall proven successful in accomplishing all objectives. Some adjustments were made, and the method was used once again in the June 2014 COOP class. Megan Taylor has also joined in facilitating presentations and activities during this residence course.

Also during this period two other developments occurred. The first is a reorganizing of proposed distance learning. This would fit into the design of the flipped class design and would provide additional training for those unable to come to the residence course. Secondly, Jim Jones announced his intention to retire. Through the end of the reporting period, Megan Taylor continues to collect information and files in order to inherit materials to pass to the next lead instructor. She will also facilitate the next course and its guest field instructors while the NWSTC makes arrangements for another instructor.



Images from the residence course including a screen shot from the new prerequisite site, the outdoor labs, equipment maintenance sections, and software labs.

e. Safety/Environmental Focal Point Training

Megan Taylor (CIMMS at NWSTC), and Hattie Wiley and Jim Poole (both NWSTC)

Continuing from last reporting period (late 2012), the distance learning courses are designed to prepare Safety and Environmental Focal Points for their duties in the NWS. The course was finalized and released in January 2014.

Safety/Environmental Focal Point Training course announcement flyer created for social media and any email distribution requested.

f. Linux Essentials Curriculum

Megan Taylor and Justin Schultz (both CIMMS at NWSTC), and Hattie Wiley, Dave Rowell, and Heather Galan (all NWSTC)

Megan Taylor consulted on a Linux Essentials distance learning curriculum that was being designed by Hattie Wiley, Dave Rowell, and Heather Galan (September 2013 – March 2014) The curriculum is ongoing, but John Ogren felt that Megan should help out with other concurring communication projects instead given her background. Before leaving the project, Megan created a KDE simulation tour, with the help of Justin Schultz, and passed it along to Hattie Wiley.

2. NWS Proving Ground Operational Service Delivery Simulations

a. Develop Operational Proving Ground (OPG) Awareness Display

Andrew Ansorge (CIMMS at NWSTC) and Kim Runk (NWS/OPG)

Andrew Ansorge created a webpage that provided forecasters/meteorologists with real-time updates that incorporated watches, warnings, social media, and current AWIPS displays in the Operational Proving Ground (OPG). This webpage is expanded to full functionality and used across several screens during courses and events in the OPG. This allows instructors also to see what is on students' screens without looking over their shoulders, as well as provide more effective simulation activities. One display is also enabled as a touchscreen to allow students/instructors to make annotations and notes.

Andrew Ansorge operating OPG computers and his creation the OPG Awareness display.

b. Hazard Simplification Demonstration (HazSimp)

Andrew Ansorge (CIMMS at NWSTC), Kim Runk (NWS/OPG), and Eli Jacks and Andy Horvitz (both NWS/OCWWS)

After the 2012-2013 demonstration of HazSimp, Andrew Ansorge and the other members of the team on this project used the feedback along with other ideas that are being done within the NWS to prototype what the next phase could look like (graphics, colors, numbers, etc). The NWS has a contract with a social science group called Eastern Research Group (ERG) and they have been doing focus groups in four different parts of the country with random public and also partners (emergency managers, TV meteorologists, etc). The social scientists are trying to learn the understanding of the public and if these prototypes may fit their needs. Andrew co-authored a one pager on next steps of the HazSimp project to NWS director and social science team prototyping ideas for next iteration of this project and future implementation. The next report has not come out yet.

c. First Operational Readiness Evaluation

Andrew Ansorge (CIMMS at NWSTC), Kim Runk (NWS/OPG), Chad Gravelle (CIMSS-Wisconsin), and Jack Richardson (NWSTC Contractor)

In May 2014, the Operational Proving Ground (OPG) completed the first Operational Readiness Evaluation (ORE) where the NASA SPoRT tracking tool was tested. Andrew Ansorge was involved with re-processing data to ingest archived satellite, radar, observations, and LMA data into AWIPS-II with the help of NASA.

NASA, the NWS, and the OPG engage in the first Operational Readiness Evaluation for the Operations Proving Ground.

d. Analyzed Data for Point-and-Click Forecast Survey

Andrew Ansorge (CIMMS at NWSTC), Mark Mitchell (EAX), and Andy Horvitz and Eli Jacks (NWS/OCWWS)

Andrew Ansorge was enlisted to help put raw survey data in a usable format for survey analysis for the new NWS Point-and-Click forecast icons. He assisted with analyzing some of the 6000+ survey comments.

3. Impact Based Decision Support Services Research and Development

a. Warning Coordination Meteorologist (WCM)/Service Coordination Hydrologist (SCH) Residence Training

Megan Taylor and Andrew Ansorge (both CIMMS at NWSTC), Jerry Griffin, Dave Cokely, and Jeff Zeltwanger (all NWSTC), Chad Gravelle (CIMSS-Wisconsin), John Ogren (NWSTC), and Kim Runk (NWS/OPG)

Both Andrew Ansorge and Megan Taylor helped facilitate the WCM/SCH training course in December 2013. Andrew helped with the ICS review and planning and participation of the full-day incident simulation. Megan began preparations in November by creating a whiteboard animation video with Kim Runk that explains key leadership and culture change points. This video was shown and used as a discussion point in one of the class sessions. Megan also helped during communication and media labs and played the role of reporter during the full-day incident simulation.

Front Row: Logan Johnson (Monterey, CA); Anthony Cavallucci (Morristown, TN); Noelle Runyan (Bohemia, NY); Christopher Foltz (Great Falls, MT) Leslie Wanek (Salt Lake City, UT); James Paul (Tulsa, OK)
Middle Row: Ernesto Morales (Carolina, PR); Bill Parker (Shreveport, LA); Marco Bohorquez (Oklahoma, City, OK; Michelle Mead (Sacramento, CA); Cindi Preller (Anchorage, AK); Doug Streu (Oklahoma City, OK)
Back Row: Tony Edwards (Jackson, KY); Andrew Brown (Spokane, WA); **Instructor - Dave Cokley**; Mark Strobin (Midland, TX); Jay Breidenbach (Boise, ID); **Instructor - Jerry Griffin**; Daniel Berc (Las Vegas, NV)

Class picture from WCM/SCH training course in December 2013.

b. Decision Support Services (DSS) Boot Camps

Andrew Ansorge and Megan Taylor (both CIMMS at NWSTC), Kim Runk (NWS/OPG), John Ogren and Jeffrey Zeltwanger (both NWSTC), Chad Gravelle (CIMSS-Wisconsin), Marco Bohorquez and Doug Streu (both NWSTC), and numerous Guest instructors from the NWS Regions

Andrew Ansorge and Megan Taylor helped facilitate both the March and April 2014 DSS Boot Camps that are part of the WRN initiative. Andrew helped with the ICS review and full-day incident simulation. Megan presented the Media Review section, helped run communication-based labs, and participated in Simulation Day activities (played the role of reporter).

DSS Boot camp photos showing the types of interactions and activities involved in preparing the NWS for disasters and event coordination.

c. FEMA Watchstanders Training Course

Andrew Ansorge (CIMMS at NWSTC), Jeffrey Zeltwanger (NWSTC), Kim Runk (NWS/OPG), Somer Erickson (FEMA), Jim Keeney (NWS/CRH), Chad Gravelle (CIMSS-Wisconsin), Julie Adolphson (NWS/EAX), Derek Deroche (NWS/CRH), Bill Bunting (SPC), and Jennifer Zeltwanger and Kelsey Angle (NWS/CRH)

The FEMA Watchstanders course is designed to help educate FEMA Watchstanders on general meteorology, as well as the products and services available from the NWS. This is in effort to strengthen the partnership between the two agencies. Andrew Ansorge

helped facilitate FEMA Watchstanders course in August and April by leading NWS Web Resources (Aug only), Winter Weather, Jeopardy and the Web Scavenger hunt.

4. Advanced Training Development

a. CIMMS Staff Gain Field Experience to Help with Training

Andrew Ansorge and Justin Schultz (both CIMMS at NWSTC)

In effort to gain more field experience to help with developing training, Andrew Ansorge and Justin Schultz spent time taking training and spending time in the field. Both Andrew and Justin completed the Distance Learning Operations Course (DLOC) between October 2013 and February 2014. They also attended the DLOC Workshop in February 2014. Additionally, Justin Schultz worked several shifts job shadowing at the Topeka and Pleasant Hill NWS Forecast Office.

b. Create Training Awareness in NWS through Online Media

Megan Taylor (CIMMS at NWSTC), and Jeffrey Zeltwanger, Cathy Burgdorf, Tom Burgdorf, Dave Rowell, John Ogren, Jim Poole, and Hattie Wiley (all NWSTC)

An effort has been made during the reporting period to reach out to the NWS employees to create training awareness and provide multiple platforms for announcements and download of information. While the primary dissemination platform continues to be the NWS Training Portal, these media serve as supplementary platforms for information. The following have been utilized:

- NWSTC Facebook and YouTube: Megan Taylor continues to serve as the Social Media Team lead. This position entails calling meetings, monitoring posts, and serving as Point of Contact for external inquiries. During the reporting period, the Social Media Team has begun meeting more frequently in efforts to step up social media presence.

- NWSTC Internet: Megan consulted on the design of the new NWSTC public facing internet page constructed by Hattie Wiley (September-December 2013). The purpose of this redesign was to create a more effective, detailed site that enables students and NWSTC visitors to find the information they are looking for.

- NWS Week of Service video project: In September and October 2013, Megan Taylor wrote, edited, and shot three videos to create awareness for the NWS Week of Service for 2013. The goal for getting involved in this program was to show the video abilities of the Training Center in hopes to spawn more projects as well as initiate more employees to join the cause.

- Megan Taylor was contracted to work with the Office of Marine and Aviation Operations (OMAO) from April to June 2014 (through the NWSTC) to help build a

training portal for OMAO with Chief Learning Officer (CLO) Scott Tessmer. The project took 2 months and around 40 to 50 hours of work. The goal was to provide a one-stop shop for OMAO employees to find training.

Examples of media used to spread awareness about training opportunities, activities, and events at the NWSTC.

c. CIMMS Employees Assist with NWSTC Staff Training

Justin Schultz and Megan Taylor (both CIMMS at NWSTC), and Hattie Wiley (NWSTC)

In effort to create more effective distance and residence training, the NWSTC staff must complete training as it is available. The NWSTC Instructional Designer, Hattie Wiley, is primarily responsible for this training. However, as CIMMS are highly involved in the training process, they are typically enlisted to help. During the reporting period, the following internal training sessions were conducted by CIMMS:

- Justin Schultz developed an online Adobe Captivate Simulation training module.
- Megan Taylor led the following three sessions: Using eLearning Bros., Camtasia Studio Basics, Creating Flipbooks with Captivate.
- Megan Taylor also facilitated many of the sessions for the Webinar Development series conducted from summer 2013 to late fall 2014. She turned these sessions into an intranet resource page.

Additionally, Megan Taylor remains the NWSTC Intranet Team Lead. The NWSTC has proven over the last year to be an excellent place to post internal training resources including instructional design resources, webinar creation resources, professional development opportunity listings, and additional staff announcements.

d. CIMMS Staff Attend Professional Development Training to Continue to Push the Boundaries of Instructional Design, Training, and Technology

Andrew Ansorge, Justin Schultz, and Megan Taylor (all CIMMS at NWSTC)

The OU CIMMS stationed at the NWSTC have made it a priority to attend professional development events in effort to gain more knowledge. The purpose is to push the limits of instructional design, training development, and technology. The following reflects this project:

- The Summer Institute for Design, Learning, and Instructional Technology (SIDLIT) 2013: Both Justin Schultz and Megan Taylor attended this conference. Megan Taylor also presented on performance techniques during meetings, presentations, and filming instructional videos.
- The 2014 KC Diversity Workshop: Justin Schultz and Megan Taylor attended this conference in effort to learn more about methods to reach all audiences in training and communication. Also, Megan Taylor presented on two topics: Generational Diversity and Self Expression in the Workplace.
- NWSTC Instructional Design Sessions: Hattie Wiley conducts monthly (sometimes weekly) instructional design sessions. These sessions include, but are not limited to:
    - Designing with Visuals
    - Organizing Content
    - Plain Language
    - Technical Writing
    - Easily Confused Words
    - Software Demonstrations and Training
    - Instructional Design
- Megan Taylor completed the ASTD Advanced eLearning Instructional Design Certificate in November 2013.

Photo of Megan Taylor giving a presentation at SIDLIT (top) and sample of topics from the 2014 KC Diversity Workshop (bottom).

CIMMS Task III Project – GOES-R GLM Lightning Jump Algorithm: A National Field Test for Operational Readiness

Kristin Calhoun, Darrel Kingfield, and Kiel Ortega (all CIMMS at NSSL), Lawrence Carey, Themis Chronis, and Elise Schultz (all University of Alabama-Huntsville), and Christopher Schultz (NASA/MSFC)

NOAA Technical Lead(s): Dan Lindsey and Andy Heidinger (GOES-R Risk Reduction – GOESR3 Program)

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

Funding Type: CIMMS Task III

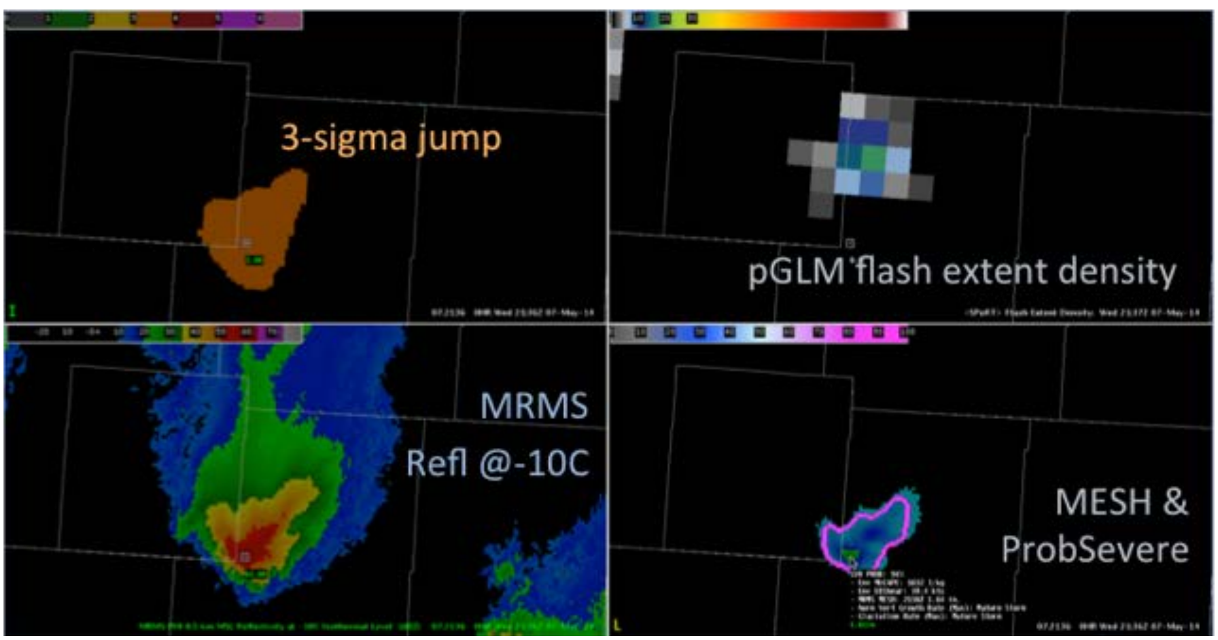
Accomplishments

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. The operational implementation of the Lighting Jump Algorithm (LJA) pre-GLM in the 2014 HWT experiment was produced using Lightning Mapping Array (LMA) data and a merged radar data set over five locations: Washington D.C., central and northeastern Colorado, northern Alabama, Oklahoma and west Texas. The LJA used fully automated methods for storm cell identification, tracking, and lightning jump detection. Initial testing was completed in the HWT during the 2014 spring experiment to assess if the LJA had impact on situational awareness, diagnosing convective trends, and the short-term prediction of severe weather.

The initial visual implementation of the LJA was produced as gridded storm object, colored by sigma (standard-deviation) level (figure below). The colorization of the jump was based on a stoplight- scale: no jump was indicated by gray and moved from green for a 1-sigma jump through yellow to orange and red with increasing sigma levels. Initial feedback on the color scale was positive as the increasing intensity (i.e., higher sigma levels) corresponded with brighter colors commonly used to indicate severity of a storm. The LJA was provided to forecasters at two different scales to see if there was any utilization of the product for lines in addition to smaller storm objects. Scale 1 required storms were at least 200 km^2 in size, the larger 600 km^2. The smaller scale was more heavily utilized in operations, although forecasters did find utility in having access to both scales, particularly for comparative purposes. On days of operations within one of the LMA domains, the LJA was heavily utilized in warning operations, usually in conjunction with local radar products. A couple of factors influenced the heavy use:

(1) Rapid Update – the 1-min update filled in gaps in both time and distance from the radar.
(2) Simplicity – the LJA display provided a view of rapid intensification in a way that was easy to integrate into the storm interrogation process and easy differentiate between storms.
(3) Correspondence with other metrics – multiple forecasters noted extra confidence in warning decisions with the LJA matching or preceding corresponding increases in radar intensity.

Additionally, during the reporting period, we have successfully run a real-time national demonstration of the LJA using flash data from lightning mapping arrays (LMAs) in multiple locations throughout the CONUS, conducted enhanced verification of the demonstration results using a variety of means, began initial testing of Earth Networks Total Lightning Network (ENTLN) flash data in the LJA, and disseminated our results at several. We successfully completed the 2013 real time field test during late summer/early fall 2013 and began another test in spring 2014, which is ongoing. Verification of the results was conducted using radar intensity proxies (e.g. MESH, VIL) and SHAVE hail reports that were collected during the 2013 season for the project. Results of the ongoing verification were reported at the NWA Annual Meeting, 2014 AMS Annual Meeting, 15th ICAE, and in a manuscript submitted to *Weather and Forecasting*. In this article, the LJA was implemented with both LMA and ENTLN flash rates (in the vicinity of LMAs for comparison) and validated against radar metrics.



AWIPS2 screenshot from the 2014 Spring Experiment real time operations in the HWT on 7 May 2014 at 2136 UTC. Top Left: Representation of LJA, shaded by sigma level – 3-sigma level shown. Top right: pseudo-GLM flash extent density. Bottom left: Reflectivity at -10 C. Bottom right: MESH and UW-CIMSS Probability of Severe (ProbSevere) product (94%).

Publications

Stano, G. T., C. J. Schultz, L. D. Carey, D. R. MacGorman, and K. M. Calhoun, 2014: Total lightning observations and tools for the 20 May 2013 Moore, Oklahoma supercell. *Journal of Operational Meteorology*, **2**, 71-88.

CIMMS Task III Project – Developing and Testing of Probabilistic Hazard Information Weather Tools for Forecasting a Continuum of Environmental Threats (FACETs)

Chris Karstens (CIMMS at NSSL)

NOAA Technical Lead(s): Lans Rothfusz (NSSL)

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

Funding Type: CIMMS Task III

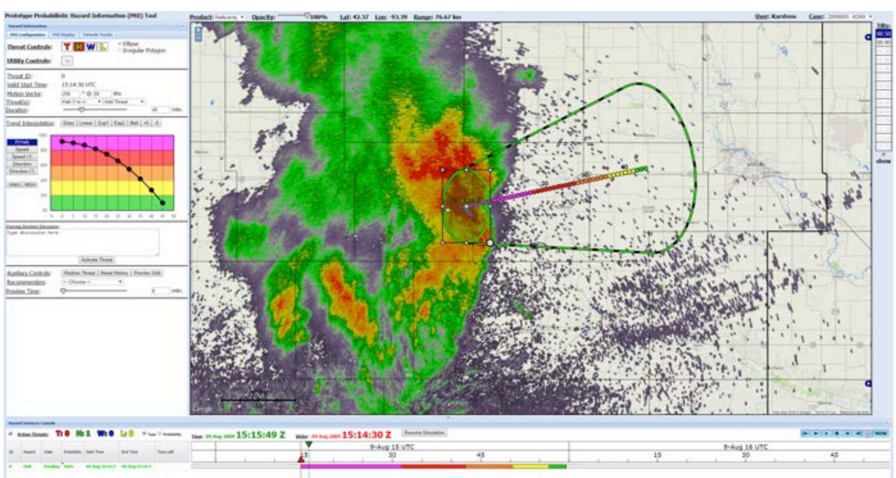
Objectives

Forecasting A Continuum of Environmental Threats (FACETs) is a new paradigm proposed by NSSL for NWS generation of hazardous weather information. The element of this paradigm upon which this project focuses is the existence of effective tools for converting numerically-derived forecast guidance into Probabilistic Hazard Information (PHI) that will be useful to decision makers. PHI is the probability of specific high-impact weather/water phenomena occurring at grid points across a temporal continuum of days to minutes. The activities of this project explore, develop, and test the framework, tools, and underlying science necessary for NWS forecasters to turn mesoscale and storm-scale statistical and numerical model output of severe convective phenomena into understandable and readily-applicable, grid-based PHI. Specifically, the objectives of this project include:

1. Development of forecaster-enabling tools to bridge the gap between guidance sources and end-user PHI needs.
2. Establishment of a variety of guidance sources from which PHI can be automatically derived and presented to the forecaster (e.g., Warn-on-Forecast).
3. Collaborate with NOAA's Global Systems Division (GSD) Hazard Services development team for beginning the process of transitioning tool functionality into the Advanced Weather Interactive Processing System (AWIPS-II).
4. Collaborate with human factors and behavioral scientists within the OU School of Industrial and Systems Engineering throughout the development process.
5. Conduct joint testing and evaluation between NSSL, GSD, OU, NWS, and the Storm Prediction Center (SPC) in the 2014/15 NOAA Hazardous Weather Testbed (HWT) Spring Experiments.

Accomplishments
Initial development of a new prototype web-tool began in May 2013, with efforts bolstered in June of 2013. This tool expands upon the original PHI tool (Ortega 2008) by including more Graphical User Interface (GUI) functionality for real-time previewing and more real-time Geographic Information Systems (GIS) functionality. Six development cycles have occurred, with more development iterations planned. In each development cycle, scientific methodologies for PHI creation/interpretation are incorporated along with recommendations from human factors and behavioral scientists. The goal of this process is to create a tool flexible enough to allow for multiple methodologies and/or guidance sources to be rapidly prototyped and tested, while maintaining core functionality, logical user-interface design, and mirrored functionality of the Hazard Services software (with some limitations). The projects described below are ongoing.

A screen capture of the most recent version of the prototype PHI tool is shown in the figure below. The interface is comprised of five main panels, including an information panel (top), hazard information configuration/display panels (left), map panel (center), quick-access controls panel (right), and a hazard services console panel (bottom). To reiterate, the panels have been designed to mirror functionality present in the AWIPS-II Hazard Services software, especially the time and hazard event controls located in the hazard services console panel.

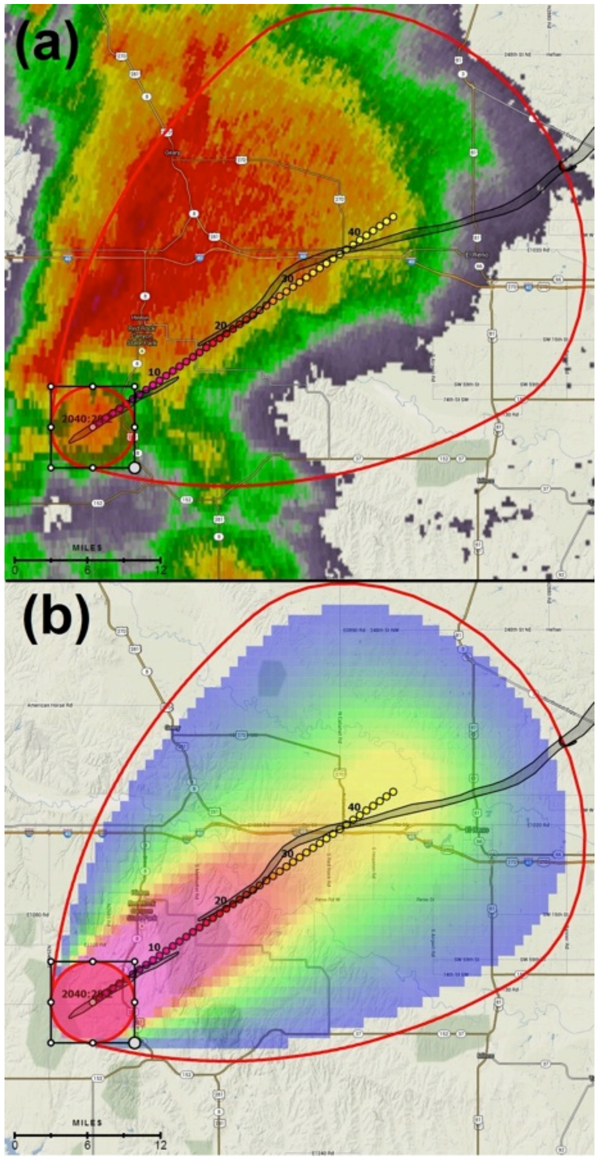


Screen capture of the new prototype web-based PHI tool for creating PHI.

1. PHI Objects

An example of a PHI object and its resulting PHI grid is given in the figure below, respectively. Conceptually, the PHI object's polygon geometry is intended to denote the region that is experiencing, or is forecast to experience, a particular threat or hazard over the forecast duration of the event (filled red polygon). The PHI threat object may be forecast to change location/speed/direction and/or expand using prognostic motion vectors and motion uncertainty values, respectively. This process is iteratively computed with increasing forecast times through the end of the forecast period, while

temporally and spatially integrating the PHI object polygon geometry to create a forecast strike swath (hollow red polygon). The PHI object and its associated forecast strike swath can be rendered at any time during the forecast period, thus giving the impression of a moving threat (i.e., Threats-in-Motion; e.g., Wolf et al. 2013).



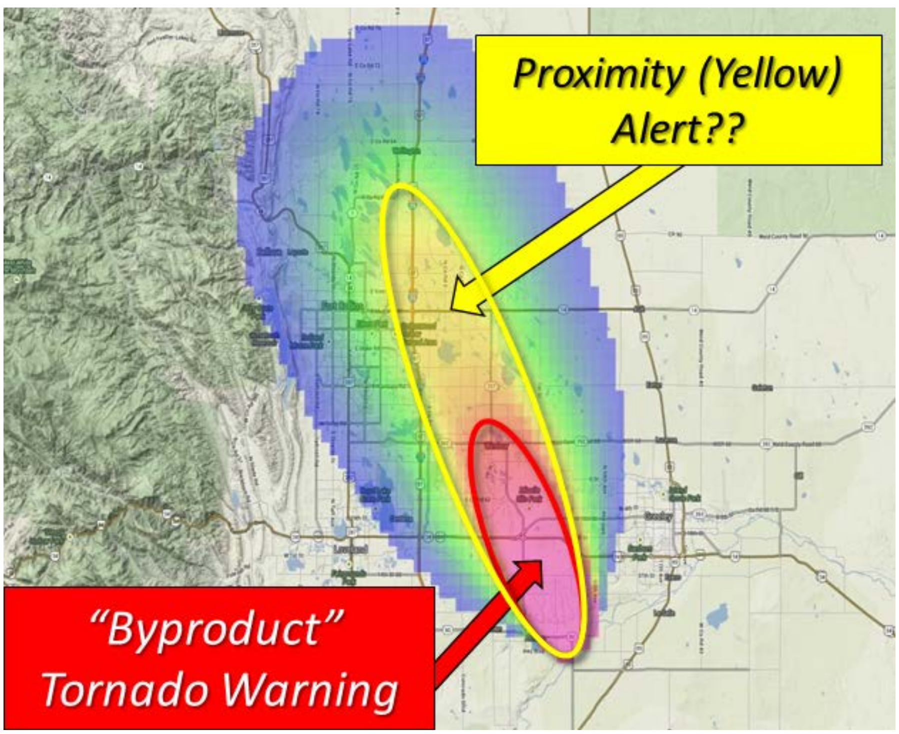
(a) Forecaster-initiated creation and modification of a PHI object (filled red polygon with bounding box that includes modification knobs) over base reflectivity data (24 May 2011, 2040:28 UTC). Large red hollow polygon is the forecast strike swath. Filled black polygon denotes the 24 May 2011 El Reno, OK tornado track. Positions of colored dots denote location of the centroid of the PHI threat object in 1-minute forecast intervals, and colors of dots denote forecast probabilities. (b) As in (a), except previewing the resulting accumulated PHI grid (filled grid cells; 1 km^2 resolution) that are generated by the PHI object.

Beyond spatially denoting the threat or hazard region (now and in the future), the purpose of the PHI object is to:

1. Calculate location- and grid-point-specific information such as its estimated current location, movement, time of arrival (TOA), time of departure (TOD), and duration.
2. Geospatially apply forecaster generated or approved prognostic probabilities of exceeding a severity threshold for a particular hazard.

Consequently, the forecast strike swath represents the area that is forecast to experience the threat or hazard during the forecast period. Additionally, the forecast strike swath denotes the region of accumulated probabilities from #2 above. Thus, the forecast strike swath boundary represents boundary between the regional probability fields (outer) and the enhanced, threat-based probabilities (inner).

It is important to note that the PHI threat object and its strike swath *do not* represent "the warning". Note that FACETs aims to modernize the binary product-centric watch/warning paradigm through the delivery of rapidly updating PHI optimized for effective, user-specific decision making in the proper societal contexts. Thus, a "warning" becomes end-user specific, based on exceeding preset probability thresholds. An example is given in the figure below, which shows two probability thresholds, and thus, two different derived warnings from the same PHI.



Example of end-user "warning" polygons (red and yellow ellipses) derived using probability thresholds from the underlying PHI grid (filled grid cells). Example is for the 22 May 2008 Windsor, CO tornado.

It is also important to consider resource limitations, specifically, bandwidth. One of the most important aspects of the PHI threat object is that it is an "object" (i.e., data). This allows it to be serialized into a data string for easy portability (typical size < 3 Kb). Much like using radar data to calculate and render a derived product (e.g., MESH), the PHI threat object relies on GIS modules to calculate its position, its forecast positions (i.e., forecast strike swath, threats in motion), and its underlying PHI. This can be produced at preset time intervals (e.g., 1 minute) and grid resolutions (e.g., 1 km), or rendered on the fly via more sophisticated real-time GIS applications.

2. Regional PHI

An additional component of the prototype PHI tool is providing forecasters with the ability to generate, evaluate, and manipulate automated PHI derived from NWP model diagnostics for time and space scales beyond that of warnings (i.e., 1 h +). We refer to these probabilities as "regional probabilities" because in most cases they would be issued prior to observed or near-observed threat formation and would cover relatively broad regions over which particular threats are expected to eventually develop. Under the FACETs vision of a time and space continuum, probabilities generated using PHI threat objects would blend into these background probability fields.

Development related to this aspect of the project has been somewhat limited thus far, but will be of focus in the near future with a planned real-time implementation of a Warn-on-Forecast system for 2015. The ultimate goal is to build functionality that allows the forecaster to derive PHI using the following as inputs:

1. NWP model/ensemble diagnostics
2. Time period for threat guidance
3. Radius of influence (e.g., probability that threat will occur within X miles of a point)

From these inputs, the derived PHI would be presented to the forecaster for further evaluation and modification prior to public dissemination. To accomplish this task, recently developed methods (e.g., Jirak et al. 2012; Marsh et al. 2012) in the HWT Experimental Forecast Program (EFP; e.g., Clark et al. 2012) Spring Experiments were incorporated into the PHI tool.

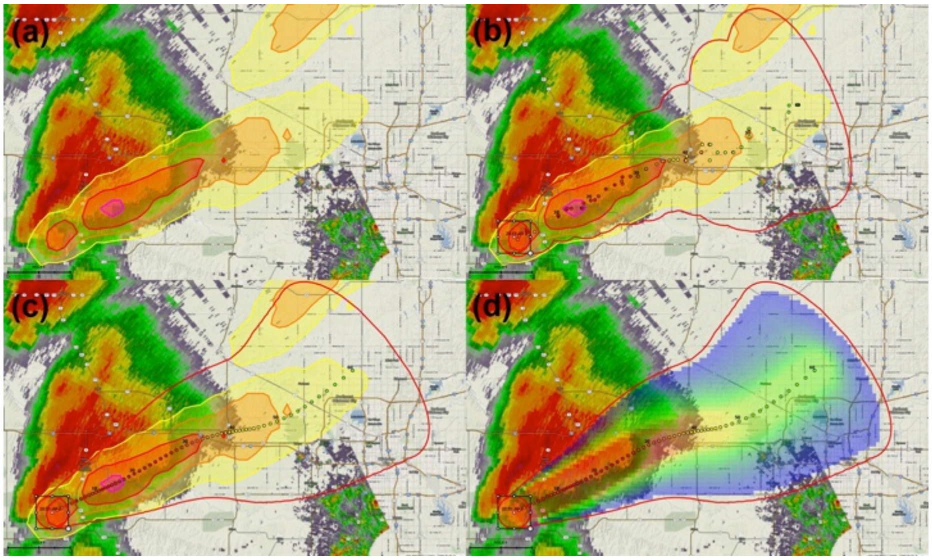
3. Guidance PHI

Perhaps one of the most critical components to the prototype PHI tool is the establishment and presentation of guidance PHI to the forecaster for incorporation into PHI threat objects or regional PHI. Examples of PHI guidance sources include the Multi-Radar Multi-Sensor (MRMS; e.g., Cintineo et al. 2011) data stream, the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS) project that would be offered via a storm identification and tracking algorithm (Humphrey et al. 2014), and PHI derived from Warn-on-Forecast (e.g., Stensrud et al. 2009; 2013) probabilities. For background probabilities at "Day 1" time scales (i.e., 12 to 36 hour forecasts), examples of guidance

sources include forecasts of storms and storm attributes (e.g., hourly maximum updraft helicity) from convection-allowing ensembles (e.g., Correia et al. 2014) and the High-Resolution Rapid Refresh (HRRR) model. For longer time scales (e.g., 2-8 days), guidance could be derived from environment-based severe weather parameters forecast by coarser ensemble systems like the SREF system and the GEFS global ensemble.

Efforts toward incorporating these automated PHI sources into the tool are still quite preliminary and will be the focus of near-future development, especially since that capability is at the heart of this project. An example of incorporating Warn-on-Forecast probabilities (Wicker et al. 2014) into a PHI threat object is provided in the figure below. It is important to note that the concept of PHI guidance sources is not limited to any particular project or methodology. It is our intent to design the prototype tool with the capability of incorporating new PHI guidance sources, when such sources are developed within the broad research community. Thus, we are striving to establish a tangible research-to-operations infrastructure (following the Hazard Services "recommenders" concept).

Another important consideration is the involvement of the forecaster in monitoring and updating PHI offered from guidance sources. The prototype PHI tool is being designed to integrate the forecaster into every decision that is made. However, we could explore ways in which guidance products are used to allow PHI for some low-impact events to be automatically generated while forecaster time is freed up to concentrate on higher-impact events and enhanced decision support services.



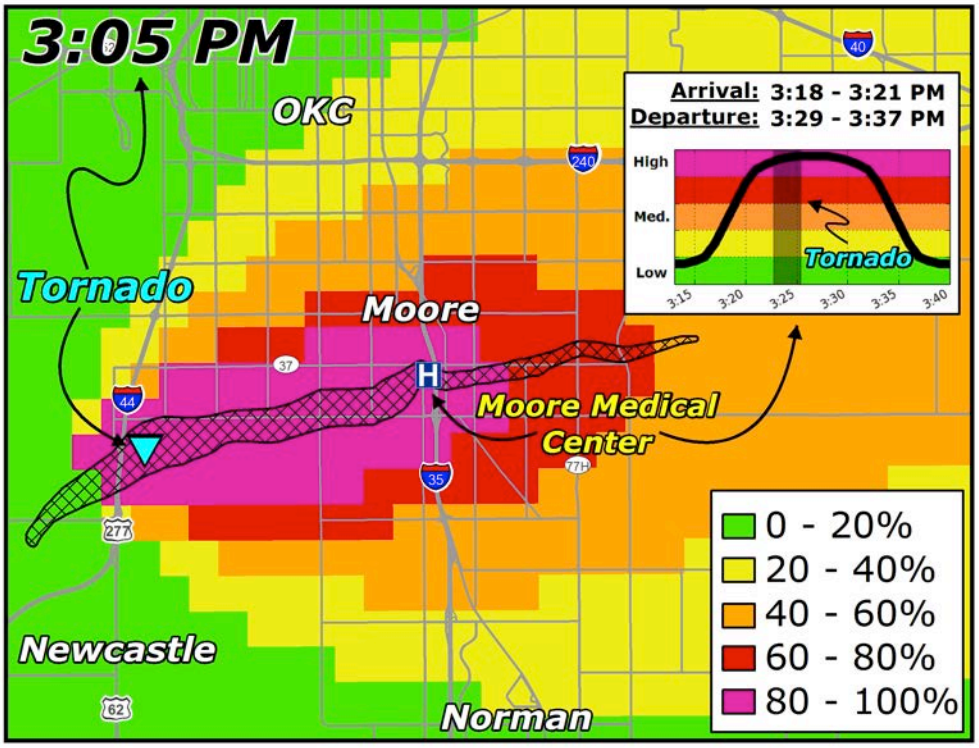
Mock-up Warn-on-Forecast guidance incorporated into a PHI threat object. (a) Probabilities of modeled strong rotation overlaid on Phased-Array Radar (PAR; Heinselman et al. 2009), (b) raw incorporation of probabilities into a PHI threat object, (c) cubic-spline interpolation of raw probabilities, and (d) preview of output PHI grid.

4. End-User PHI

Once PHI is generated by the forecaster for a given threat or hazard, the output information can be specifically tailored in a variety of ways to meet various end-user needs. In particular, approximations to the following example fundamental questions can derived based on location:

1. When will the hazard arrive?
2. When will the hazard be over?
3. How long will the hazard last?
4. What is the probability of the hazard occurring?
5. Where is the hazard currently?
6. What direction and how fast is the hazard moving?
7. How intense is the hazard (observations)?

An example display of this information is provided in the figure below. It is important to note that these questions are only examples and do not represent the full spectrum of questions that could be asked. We foresee this as an opportunity for the weather enterprise to deliver customized or personally tailored information to meet the diversity of end-user needs.



Mock-up of PHI that could be provided to end-users. Color-filled grid cells are the PHI grid. The popup window in the upper-right shows the probability time series associated with this particular PHI threat object forecast, along with the forecast TOA and TOD (35% probability threshold) for the Moore Medical Center compared to the estimated observed tornado duration (using TDWR and damage width; Ortega et al. 2014).

5. HWT Spring Experiment

Expanding upon efforts from 2008, the 2014 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted in the Experimental Warning Program (EWP) during the weeks of 5-9 May, 19-23 May, and 2-6 June. Each week, two forecasters participated by issuing probabilistic forecasts for severe convective phenomena (tornado, wind, hail, and lightning) using a prototype web tool. The objectives of this experiment included understanding how forecasters use the PHI system, comparing probabilistic forecasts to traditional warnings for two control cases, collaborating with the HWT Experimental Forecast Program (EFP), and understanding forecasters' thoughts on a paradigm change (deterministic products to continuous probabilistic information).

To achieve the objectives of this experiment, forecasters were tasked with issuing probabilistic forecasts for a variety of real-time and displaced real-time severe weather events. These events were comprised of a variety of convective modes with varying convective evolution. The diversity of these events allowed the facilitators to gauge what aspects of the PHI system worked well versus those needing further improvements. It was found that events with discrete cells (pulse convection or supercells) were easiest for the forecasters to engage and manage, while multicells and linear structures were more difficult. Part of the difficulty was attributable to a large number of hazard areas or potential hazard areas requiring attention, and to the complex evolution of these events (splitting/merging cells, non-linear motion). It was also found that lightning and wind hazards, which can often reside outside of the radar-indicated convective regions, are more difficult to identify geospatially than tornado and hail hazards. To combat these difficulties, the incorporation of improved numerical weather guidance is planned for 2015. This will be achieved by supplying forecasters with improved radar-derived objects, based on recommendations from the 2014 experiment. Additionally, it is planned to incorporate preliminary guidance from a real-time Warn-on-Forecast system.

One of the main findings of the experiment is that "on-the-fence" decision points are significantly reduced using the PHI system, as opposed to issuing warnings in the current system. This finding is attributable to the PHI system's ability to allow forecasters to communicate low-probability hazard information, well before a traditional warning would be issued. The result should ultimately improve communication between NWS forecasters and the diverse groups of end users (to be tested in 2015). Although relinquishing "on-the-fence" decision points should result in faster communication, many more hazard areas or potential hazard areas require attention by the forecasters. It was found that forecasters could comfortably handle about 4-5 hazard areas simultaneously, and when the number exceeded that, mental workload issues arose. To address this issue, forecasters recommended to improve the infusion of automated first-guess numerical weather guidance in the PHI system in a way that allows forecasters to quickly adjust which areas are unmonitored (low-probability hazard areas) versus those areas requiring significant attention (high-probability hazard areas). Adjustments to the PHI system based on this feedback are planned for the 2015 HWT PHI experiment.

In addition to the experiment conducted in the EWP, an HWT experiment was conducted simultaneously in the EFP with several forecasters (8-10) per week for five weeks (May 5 – June 6). Forecasters used the prototype PHI tool to issue hourly probabilities of any severe weather (including tornado, wind, and hail hazards) occurring between 18-03 UTC and within 25 miles of a point. Forecasts from these nine periods were issued initially by 18 UTC and the last six periods were updated by 21 UTC. Forecasters were given the ability to create their own probabilistic forecasts, with tool functionality similar to that of NMAP (GEMPAK software), or could use exceedance probabilities derived from the NSSL WRF ensemble. Subjective feedback indicated that forecasters liked having the ability to issue PHI on these time and space scales, but needed improved numerical weather guidance to inform their decision-making. Thus, future efforts will expand and improve the presentation of numerical weather guidance to forecasters in this experiment.

FACETs projects are ongoing.

Publications

Rothfusz, L., C. D. Karstens, and D. Hilderbrand, 2014: Next-generation severe weather forecasting and communication. *EOS Transactions*, **95**, 325-326.

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.

Awards

Chris Karstens – Technology disclosure filed with the University of Oklahoma (March 2014).

Chris Karstens – Third place at the Institute of Industrial Engineers' South Central Regional Conference Technical Paper competition (collaboration with Dr. Chen Ling, February 2014).

Chris Karstens – Award of Distinction in Undergraduate Research at the University of Oklahoma Undergraduate Research Day (collaboration with Dr. Chen Ling, April 2014).

CIMMS Task III Project – Development of Short-Range Realtime Analysis and Forecasting System Based on the ARPS for Taiwan Region – Years 3 and 4

Ming Xue, Fanyou Kong and Keith Brewster (all CAPS at OU), and Chong-Chi Tong and Rong Kong (CAPS at OU and OU School of Meteorology)

NOAA Technical Lead: Fanthune Moeng (NOAA/GSD)

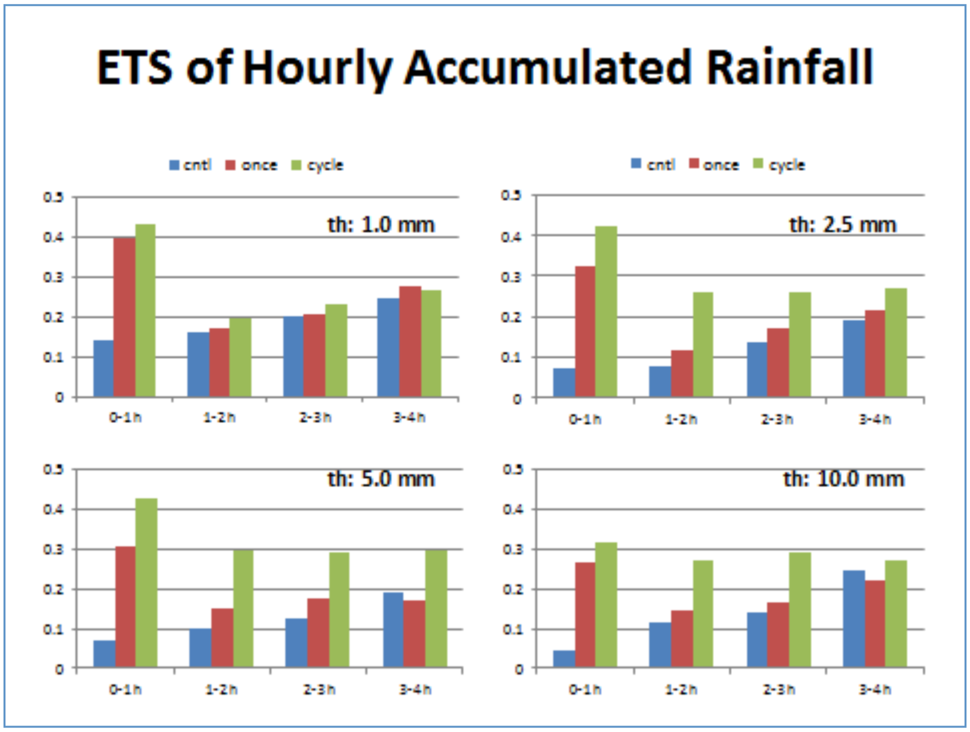
NOAA Strategic Goal 2 – *Weather Ready Nation: Society is Prepared for and Responds to Weather-Related Events*

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 performed experiments by adding partial cycling to the DA procedure using real cases including both the Typhoon Saula case and the Mei-yu front case, in an effort to explore ways to improve storm forecasting skill. Several sets of experiment were conducted to investigate the performance of different partial cycling strategies and model initiation time windows. For Typhoon Saula case, three sets of experiments with different initial times were selected: 12 UTC, 15 UTC, and 18 UTC on 1 August 2012. These times were selected because during these time periods, the typhoon was of “moderate” intensity, and significant precipitation was expected. Also, and rather importantly, the typhoon was close enough to Taiwan at these times to ensure good coverage from CWB radars for the purpose of data assimilation. For each of the three initial times, three experiments are performed, corresponding to no data assimilation, one-time assimilation, and partial cycling. It was demonstrated that for the Typhoon Saula case, the accuracy of the TC location prediction is crucial for rainfall forecast. The degree of data assimilation benefit depends on the data analysis strategy as well as observation coverage. When the radar data coverage is sufficient (i.e. the critical location around the TC center is well within the radar observing range), the momentum field is able to be adjusted (or corrected) by the data assimilation process through ARPS 3DVAR with radial wind and reflectivity analyses. One time 3DVAR analysis often leads to some imbalance between the wind field and the pressure filed in the analysis, resulting in less degree of improvement on precipitation forecast. Through the partial cycling analysis procedure with the presence of adequate radar coverage, the hourly rainfall forecast can be significantly improved with longer lasting impact to ETS scores, especially when the TC was getting closer to the land and its movement was insignificant. For the Mei-yu case, it is also demonstrated that the longer the partial cycle, the better the recovery of the convections over southwest of Taiwan Island. However, the recovered radar echo still dissipates too quickly compared with the observations, which is presumably caused by the lack of observations (both the conventional and radial velocity data from radar data) in the area of interest, it is difficult for the model to capture the low level boundary lines that may initiate new cells along it at later times. The performance of the partial cycles can be further improved by adopting the Milbrandt-Yau multi- or triple-moment microphysical scheme, which enables the water particles to evaporate slower at low-levels due to size sorting, and thus retain buoyant air at the surface that can support continued convection.

CAPS met all deliverable requirements for the reporting period, including one code delivery including model package update, one annual report due October 2013, and one PowerPoint presentation for the annual review. CAPS performance during this reporting period has been accepted in the annual review meeting held in CWB in November 2013.



ETS of 0-4 hour forecast hourly-accumulated rainfall of three experiments with 18 UTC initial time.

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 CAPS at OU)

NOAA Technical Leads: Andy Heidinger and Dan Lindsey (NESDIS)

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
This project is collaboration between three institutions: CAPS, CIMSS, and CIRA. The proposed project employs 4-km storm-scale ensemble forecasts (SSEFs) produced by CAPS for the NOAA 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.

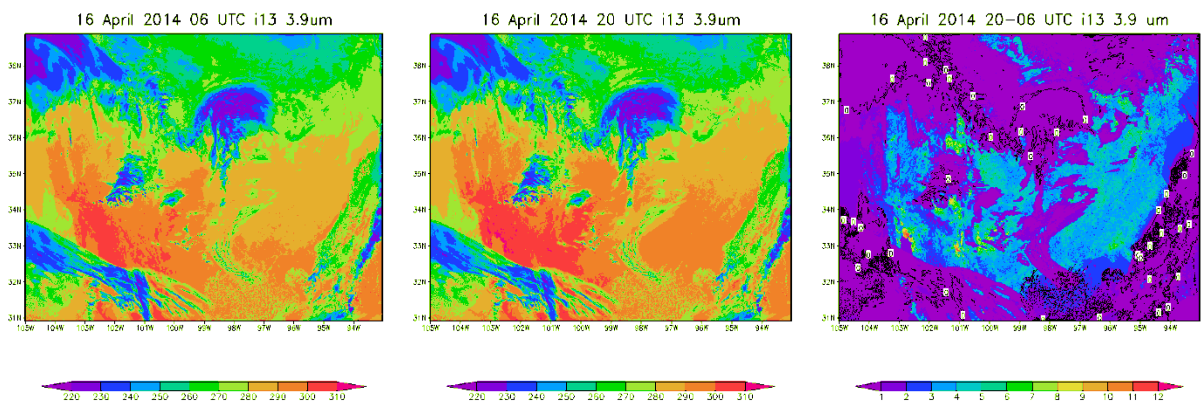
Accomplishments

During the 2014 NOAA HWT Spring Experiment season in May through early June, CAPS produced, in realtime, synthetic GOES-13 brightness temperature product using CRTM for all WRF-ARW members in its storm-scale ensemble forecast (SSEF) system. The CAPS SSEF was consisted of multiple physics options in microphysics, PBL, land-surface model, and radiation, as well as perturbations in initial and lateral boundary conditions. Two IR channels, 6.48, and 10.7µm Brightness Temperature (BT) were produced. BTs of individual members and the ensemble mean and probability were made available to HWT participants in realtime (http://www.caps.ou.edu/~fkong/sub_atm/spring14.html).

The CIMSS team completed a study that examined the ability of several cloud microphysical and planetary boundary layer (PBL) parameterization schemes in the Weather Research and Forecasting (WRF) model to accurately simulate cloud characteristics within 4-km grid-spacing ensemble forecasts performed over the contiguous United States during the 2012 NOAA Hazardous Weather Testbed (HWT) Spring Experiment. This was accomplished through comparison of synthetic and observed Geostationary Operational Environmental Satellite (GOES) infrared brightness temperatures. Four double-moment microphysics schemes and five PBL schemes were evaluated. Large differences were found in the simulated cloud cover, especially in the upper troposphere, when using different microphysics schemes. Overall, the results revealed that the Milbrandt-Yau and Morrison microphysics schemes tended to produce too much upper-level cloud cover, whereas the Thompson and the WRF double-moment 6-class (WDM6) microphysics schemes did not contain enough high clouds. Smaller differences occurred in the cloud fields when using different PBL schemes, with the greatest spread in the ensemble statistics occurring during and after daily peak heating hours. 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. Finally, large differences between the various microphysics and PBL schemes indicate that large uncertainties remain in how these schemes represent subgrid-scale processes. Results from this study were recently published in *Monthly Weather Review.*

A test was conducted by the CIRA team to determine whether or not solar reflection is computed by the CRTM_V2.1.3 at 3.9 µm. Version 2.1.3 was used to generate synthetic GOES-13 imagery at 3.9 µm from output of the 4 km NSSL WRF-ARW. For reference, the domain is the continental United States. Output was generated from a model output

that was initialized on 00Z 16 April 2014. For this test, synthetic imagery was generated from the 20-hour forecast or 20 UTC 16 April 2014. Initially imagery was generated without sun by setting the UTC time in the CRTM to 06 UTC (left panel below). This process was repeated with only the UTC changed from 06 to 20 UTC (center panel below). A comparison of these indicates an increase in brightness temperatures occurring in the lower left region of the image from 06 to 20 UTC. This region is the clear-sky portion of the southwest portions of the US. Cold cloud tops (220 < Tb < 230) show little if any difference between the two times. To further demonstrate these differences, brightness temperatures at 06 UTC were subtracted from brightness temperatures at 20 UTC (right panel below). As suggested by the left and center panels, clear-sky regions exhibit a positive difference, even over the waters off the east coast. Cloudy regions, however, display values of the difference near zero. As an aid, the 0.0 contour was added to the figure. Thus, results of this test demonstrate that solar reflection is computed by the CRTM; however, such reflection is computed only over clear-sky regions. Cloud tops exhibit no solar reflection; a result that is at odds with observations. This project is ongoing.



Synthetic GOES-13 imagery at 3.9 µm for (left) 06 UTC, (center) 20 UTC, and (right) Tb (20 UTC) – Tb (06 UTC).

Publications

Cintineo, R., J. A. Otkin, F. Kong, and M. Xue, 2014: Evaluating the accuracy of planetary boundary layer and cloud microphysical parameterization schemes in a convection-permitting ensemble using synthetic GOES-13 satellite observations. *Monthly Weather Review*, **142**, 163-182.

Grasso, L., D. T. Lindsey, K.-S. Lim, A. Clark, D. Bikos, and S. R. Dembek, 2014: Evaluation of and suggested improvements to the WSM6 microphysics in WRF-ARW using synthetic and observed GOES-13 imagery. *Monthly Weather Review*, **142**, 3635-3650.

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, Yujie Pan, and Gang Zhao (all CAPS at OU)

NOAA Technical Lead: Stan Benjamin (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 ensemble Kalman filter (EnKF) and GSI-based EnKF/3DVAR hybrid data assimilation systems 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

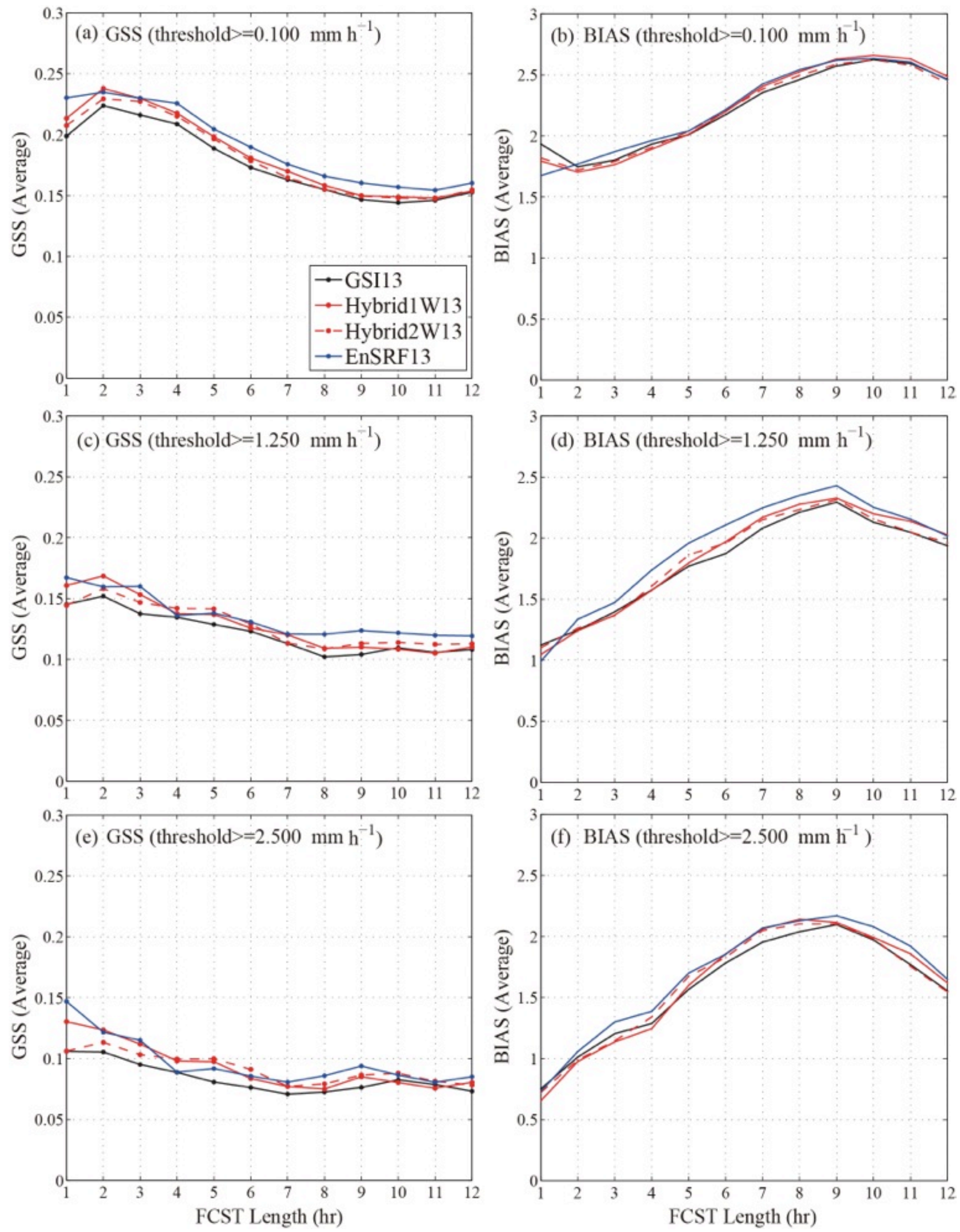
Two papers have been published in Monthly Weather Review on the results of this project. One paper (Zhu et al., 2013) documents the configuration and performance of the GSI-based EnKF DA system; another paper (Pan et al., 2014) reports on the development and testing the hybrid GSI DA system coupled with the EnKF, and compares the results of hybrid DA with those of EnKF and GSI 3DVAR.

More specifically, in Zhu et al. (2013), a regional ensemble Kalman filter (EnKF) system is established for potential Rapid Refresh (RAP) operational application. 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. All conventional observations that are used in the operational RAP GSI are assimilated. To minimize computational costs, 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 convectively active retrospective period from spring 2010. The EnKF performance was improved by extensive tuning, including the use of height-dependent covariance localization scales and adaptive covariance inflation. When the EnKF employs multiple physics parameterization schemes, forecast errors are further reduced, especially for relative humidity and temperature at the upper levels and for 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. (2014), a coupled EnSRF-En3DVar hybrid data assimilation (DA) system is developed for the operational Rapid Refresh (RAP) forecasting system. The three-dimensional ensemble-variational (En3DVar) hybrid system employs the extended control variable method, and is built on the NCEP operational Grid-point Statistical Interpolation (GSI) 3DVar framework. It is coupled with an ensemble square root filter (EnSRF) system for RAP, which was documented in Zhu et al. (2013). This EnKF system provides ensemble perturbations. Recursive filters (RF) are used to localize ensemble covariance in both horizontal and vertical within the En3DVar. The coupled En3DVar hybrid system is evaluated with 3-hour cycles over a 9-day period with active convection. All conventional observations used by operational RAP are included. The En3DVar hybrid system is run at 1/3 of the operational RAP horizontal resolution or about 40-km grid spacing, and its performance is compared to parallel GSI 3DVar and EnSRF runs using the same data sets and resolution. Short-term forecasts initialized from the 3-hourly analyses are verified against sounding and surface observations. When using equally weighted static and ensemble background error covariances and 40 ensemble members, the En3DVar hybrid system outperforms corresponding GSI 3DVar and EnSRF. When the recursive filter coefficients are tuned to achieve a similar height-dependent localization as in the EnSRF, the En3DVar results using pure ensemble covariance are close to EnSRF. Two-way coupling between EnSRF and En3DVar did not produce noticeable improvement over one-way coupling. Downscaled precipitation forecast skill on the 13-km RAP grid from the En3DVar hybrid is better than those from GSI 3DVar analyses (see Figure attached).

Additional works testing satellite data impacts within the EnKF and GSI systems and a dual-resolution hybrid DA system where the ensemble is run at a 40 km grid spacing while the hybrid En3DVar runs at the native RAP 13 km grid space have been performed. Results are been summarized for publication. This project is ongoing.



Average precipitation GSSs and BIASs of 13-km forecasts as a function of forecast length for thresholds (a) (b) 0.1 mm h^{-1}, and (c) (d) 1.25 mm h^{-1}, and (e) (f) 2.5 mm h^{-1} for control experiments.

Publications

Pan, Y., K. Zhu, M. Xue, X. Wang, M. Hu, S. G. Benjamin, S. S. Weygandt, and J. S. Whitaker, 2014: A regional GSI-based EnKF-variational hybrid data assimilation system for the Rapid Refresh configuration: Results with a single, reduced resolution. *Monthly Weather Review*, **142**, 3756-3780.

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 EnKF system for the Rapid Refresh configuration: Results with a single, reduced resolution. *Monthly Weather Review*, **141**, 4118-4139.

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, Guoqing Ge, and Tim Supinie (all CAPS at OU)

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.

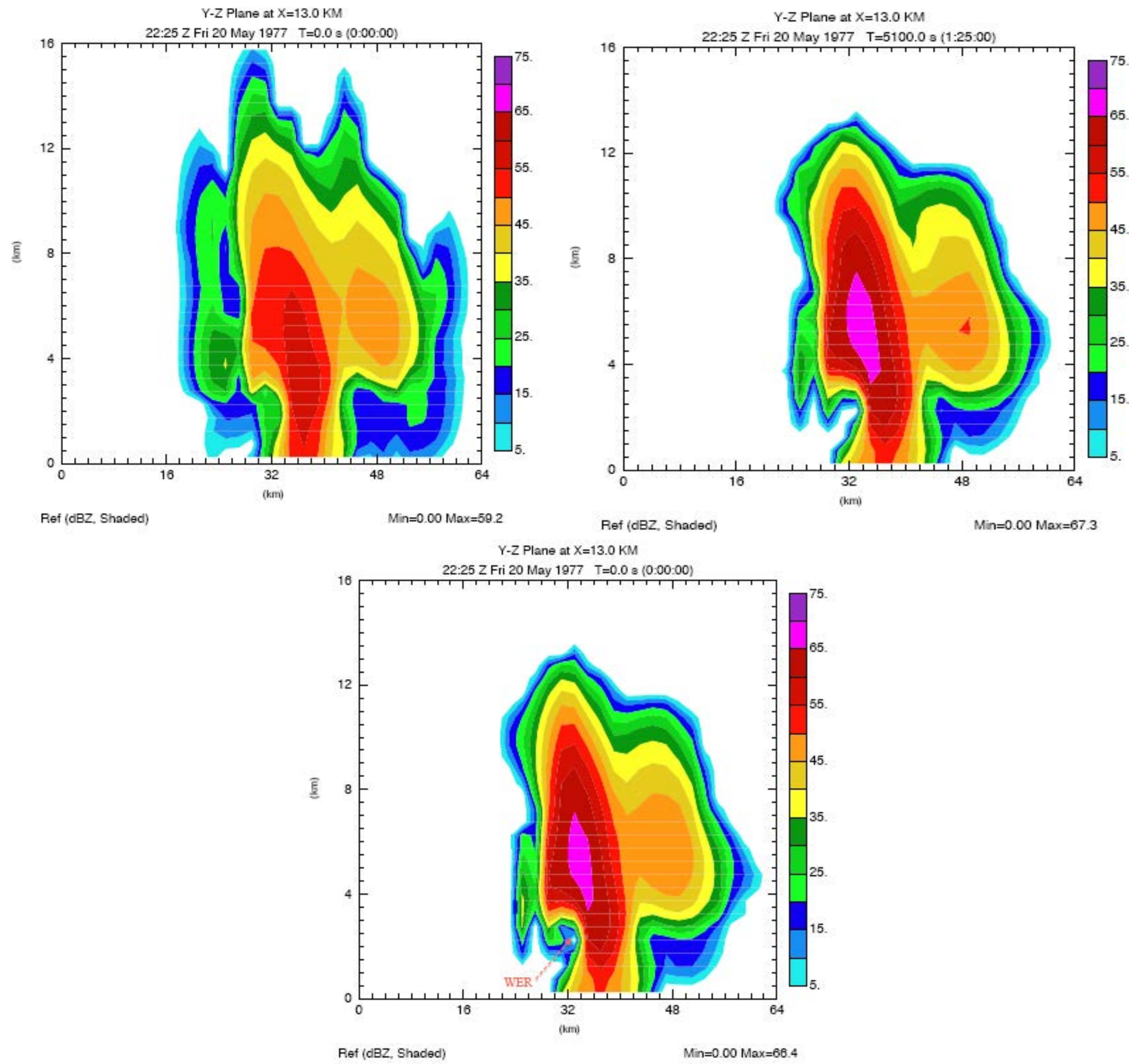
Accomplishments

Advanced data assimilation (DA) is the essential procedure for obtaining accurate initial conditions for thunderstorm forecasts, which is the key to the Warn-on-Forecast (WoF) vision. As a partner of the WoF project led by NSSL, CAPS is focusing its efforts on developing, refining, and applying ensemble-based data assimilation systems to storm-scale deterministic and probabilistic predictions. Efforts are also underway to develop a hybrid ensemble-variational data assimilation system that seeks to combine the strengths of both variational and ensemble methods.

Significant progress is being made in CAPS advanced data assimilation software and assimilation experiments. The ability to assimilate MPAR radar data has been developed within the parallel EnKF system using both a conventional ensemble square root filter (EnSRF) and a four-dimensional asynchronous EnSRF (4DEnSRF). A procedure to run a cycled EnKF analysis for the CONUS domain in real-time has been developed. In this procedure the CAPS parallel EnKF system, interfaced with WRF ARW model, directly assimilates conventional and radar observation within the domain to initialize 24-hour WRF forecasts. The procedure has been tested in post-realtime during the 2014 HWT Spring Experiment. This DA system has also been applied to a VORTEX2 case, the 5 Jung 2009 Goshen County, Wyoming, tornadic supercell case (Supinie et al. 2013), to determine the impact of the special VORTEX2 observations on supercell forecasts. The major findings are that the soundings produce updraft helicity tracks that are more consistent with the general weakening of the observed mesocyclone over the forecast period.

An update has been made to the ARPS 3DVAR system to assimilate radar radial velocity and reflectivity observations on the radar elevation levels. This update enables

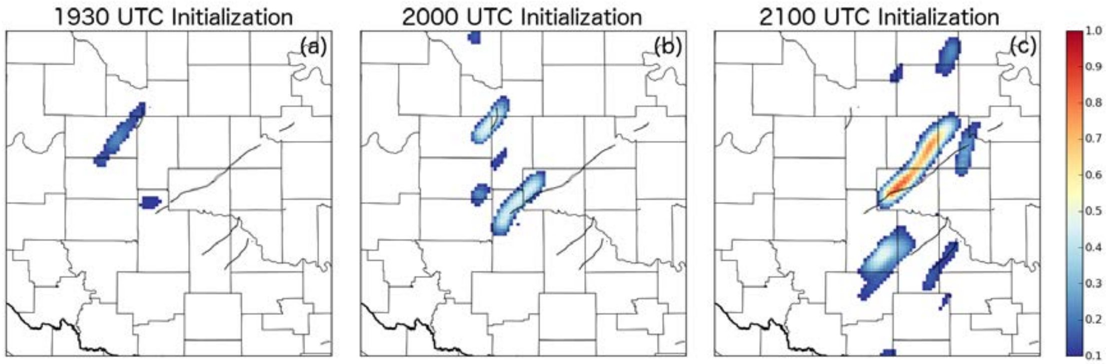
direct comparison of performance among EnKF, 3DVAR, and hybrid DA systems by assimilating the same observation dataset. An ensemble based hybrid DA system, 3DEnVar, and its time-extended version, 4DEnVar, have been developed within the ARPS 3DVAR framework (Liu and Xue, 2014) and applied to an idealized supercell simulation. Preliminary results show that 3DEnVar outperforms 3DVAR and is able to retrieve the storm structure and intensity much better than cycled 3DVAR (figure below).



Simulated reflectivity from (a) the truth and analyses of (b) cycled 3DVar and (c) En3DVar. Both radial velocity and reflectivity are assimilated in 3DVAR and En3DVar.

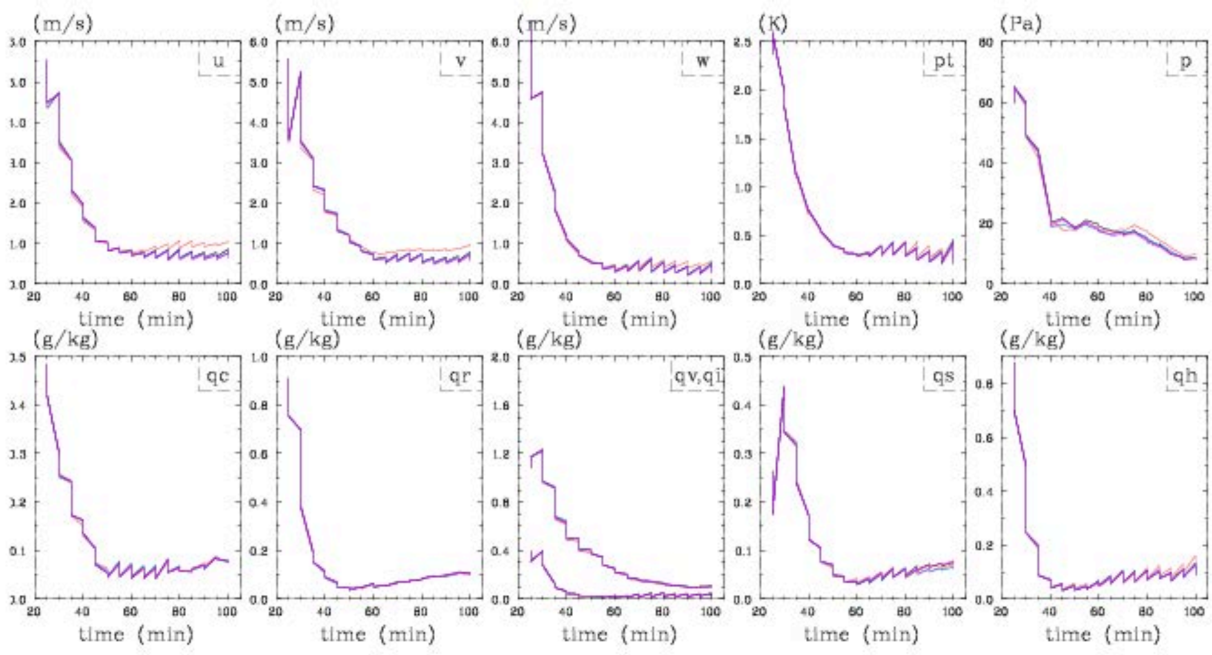
CAPS has been running inter-comparison studies: EnKF and 3DVAR have been applied to the 24 May 2011 tornado outbreak in Oklahoma. A 40-member ensemble was generated at 3 km grid spacing, assimilating data from 17 WSR-88D's, the Oklahoma Mesonet, and special sounding data from the ARM network every 5 minutes starting at 1800 UTC using EnSRF. Data from MPAR were also assimilated every 150 seconds from 2000 UTC on. One-hour forecasts were launched at 1930, 2000, and 2100 UTC to determine the benefit of additional assimilation time on the forecast (figure below).

Generally, the forecasts initialized later were closer to the observed tornado tracks. An experiment assimilating similar datasets using 3DVAR is underway.



Probability of UH > 75 m^2 s^{-2} for 1-hour forecasts initialized at 1930 UTC (a), 2000 UTC (b), 2100 UTC (c). Observed tornado tracks are plotted as black outlines.

The analysis incremental interpolation technique has been implemented within the ARPS-LETKF system, which significantly reduces the computational cost without degrading the quality of analysis (figure below). 4D-LETKF has been developed and tested with high-temporal frequency (1-min interval) observations. In OSSE, 4D-LETKF showed clear advantages for data batches spanning longer than 3 minutes of time period over the classic LETKF. This project is ongoing.



Root Mean Square Errors (RMSEs) of LETKF without interpolation (black) and with full variable interpolation (red), incremental interpolation (blue), and weight interpolation (purple).

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.

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Ge, G., J. Gao, and M. Xue, 2013: Impact of a diagnostic pressure equation constraint on tornadic supercell thunderstorm forecasts initialized using 3DVAR radar data assimilation. *Advances in Meteorology*, Article ID 947874, 12 pp.

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.

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. To be Submitted to *Monthly Weather Review*.

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.

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CIMMS Task III Project – National Sea Grant Weather & Climate Extension Specialist

Kodi Monroe (CIMMS at NSSL), Joe Ripberger (CIMMS/CRCM at OU), Kevin Kelleher (NSSL, now ESRL/GSD), Lans Rothfusz (NSSL), and Peter Lamb (CIMMS at OU)

NOAA Technical Leads: Leon Cammen (NOAA Sea Grant), Kevin Kelleher (NSSL, now ESRL/GSD), and Lans Rothfusz (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, and Weather-Ready Nation – Society is Prepared for and Responds to Weather-Related Events*

Funding Type: CIMMS Task III (NOAA Sea Grant)

Objectives

Connect NSSL research with the Sea Grant Extension Network; lead the Coastal and Inland Flooding Observation and Warning (CI-FLOW) project to predict total water level for coastal watersheds; assist in the evaluation of the end-to-end weather warning

process by studying the way in which members of the public prepare for, respond to, and recover from incidents of severe weather.

Accomplishments

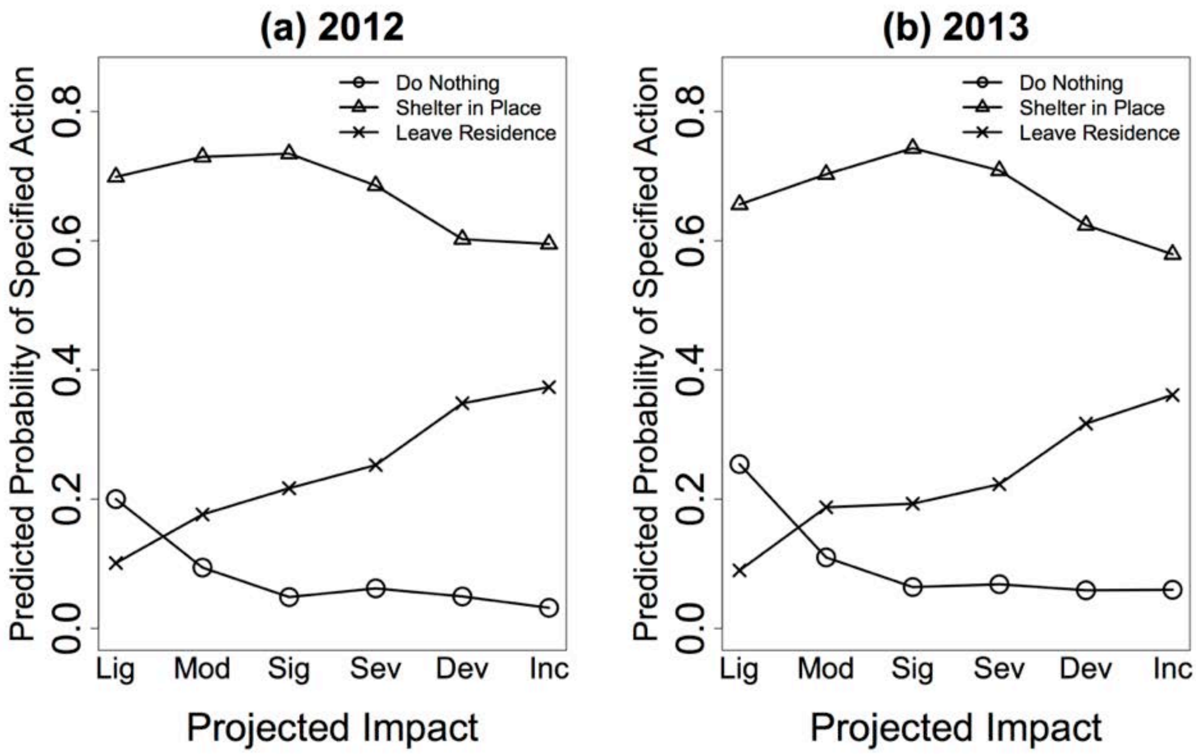
The Sea Grant Weather & Climate Extension Specialist at CIMMS/NSSL leads NOAA's CI-FLOW project and actively participates in NSSL's hydrometeorological research activities. During the 2013 and 2014 Atlantic hurricane seasons, the CI-FLOW collaborators continued real-time predictions of coastal water levels during Tropical Storm Arthur. This storm stayed off the North Carolina coast with minor impacts to the Outer Banks. Quantitative precipitation estimates produced by the NSSL MRMS/Q3 system provided input data to the 128-member ensemble of the National Weather Service (NWS) Hydrologic Lab-Research Distributed Hydrologic Model (HL-RDHM). Discharge information from HL-RDHM served as upstream boundary conditions for the ADvanced CIRCulation (ADCIRC) hydrodynamic model to incorporate freshwater contributions into coastal water level simulations. Real-time simulations of coastal water levels are available every six hours on the CI-FLOW (https://secure.nssl.noaa.gov/projects/ciflow/), NOAA nowCOAST (http://nowcoast.noaa.gov/ciflow/), and Coastal Emergency Risks Assessment (http://nc-cera.renci.org/) web sites.

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. This research will help design a coupled model system that can be more broadly implemented into NWS operations for the Gulf and Atlantic coasts. OU researchers collected data to set up the one-dimensional hydraulic model of the Tar River Basin and devised a data-passing scheme to transfer boundary conditions between models in a loosely coupled fashion. Hindcast and validation data are being collected for comparison of the current CI-FLOW coupled model system to the system that includes the hydraulic model. 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. As such this work is ongoing.

The Sea Grant Post-Doctoral Research Associate is continuing to assist in the evaluation of the end-to-end weather warning process. Quantitative and qualitative data were collected via multiple sources, including social media, the Hazardous Weather Testbed (HWT) 2014 Spring Experiment, and Internet surveys of US residents that live in tornado-prone regions of the country. In collaboration with the Center for Applied Social Research (CASR) and the Center for Risk and Crisis Management (CRCM),

these data are being used to study the way in which members of the public prepare for, respond to, and recover from incidents of severe weather.

The findings from this research have been used inform discussions about how to better connect the front (warning decision making) and back (public response) ends of the warning process in multiple venues, including the FACETs Science and Strategic Implementation Plan (SSIP) Development Team Workshop, a Brown Bag Seminar hosted by the NOAA Central Library, the Social Coast Forum, and a workshop hosted by the South Central Climate Science Center. These discussions have allowed us to share the results of our work with a wide variety of stakeholders, such as NWS, NOAA, and OAR affiliates, emergency managers, and members of the public. This work is ongoing.



The predicted influence of consequence-based messages (projected impact) on public responsiveness to tornado warnings.

Publications

Dresback, K. M., J. G. Fleming, B. O. Blanton, C. Kaiser, J. J. Gourley, E. M. Tromble, R. A. Luettich Jr., R. L. Kolar, Y. Hong, S. Van Cooten, H. J. Vergara, Z. L. Flamig, H. M. Lander, K. E. Kelleher, 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*, **71**, 78-94.

Ripberger, J. T., C. L. Silva, H. C. Jenkins-Smith, D. E. Carlson, M. James, and K. G. Herron, 2014: False alarms and missed events: The impact and origins of perceived inaccuracy in tornado warning systems. *Risk Analysis*, **34**, in press. doi: 10.1111/risa.12262.

Ripberger, J. T., C. L. Silva, H. C. Jenkins-Smith, and M. James, 2014: The influence of consequence-based messages on public responses to tornado warnings. *Bulleting of the American Meteorological Society*, **95**, in press. doi:10.1175/BAMS-D-13-00213.1.

Ripberger, J. T., H. C. Jenkins-Smith, C. L. Silva, D. E. Carlson, and M. Henderson, 2014: Social media and severe weather: Do 'tweets' provide a valid indicator of public attention to tornadoes? *Weather, Climate and Society*, **10**, in press. doi:10.1175/WCAS-D-13-00028.1.

CIMMS Task III Project – Prototyping and Evaluating Key Network-of-Networks Technologies (and Project Extension)

Jerry Brotzge (OU CAPS), and Fred Carr, Lee Carlaw, Nicholas Gasperoni, and Andrew Osborne (all OU School of Meteorology)

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) Dallas-Fort Worth Urban Demonstration Network to improve NOAA's understanding and use of in situ and remotely sensed observations. The specific objectives of this project are twofold: (i) evaluate observation sensor impact using Observation System Simulation Experiments (OSSEs); and (ii) evaluate observation sensor impact using Observation System Experiments (OSEs). The primary focus of the OSE work has been on evaluating the impact of data from surface networks for high-resolution analyses and forecasts. The OSSE work has focused on developing a data assimilation system that provides data impact estimates in real-time at the mesoscale.

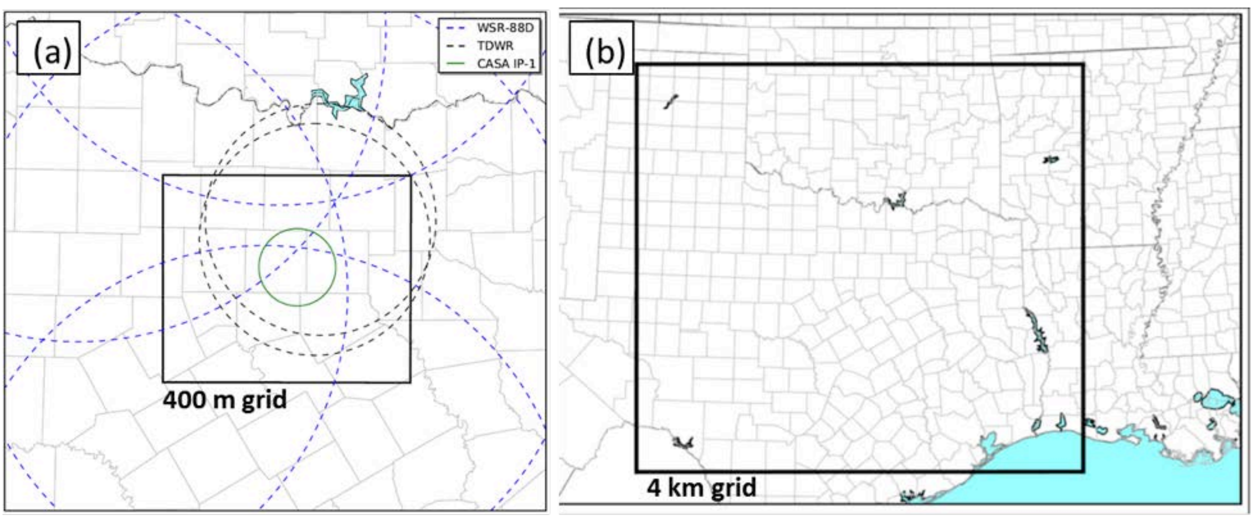
Accomplishments

1. Evaluate Observation Sensor Impact Using an OSE

Current work has proceeded in two parallel tracks with a primary focus on evaluating the effect of non-conventional surface networks, such as those provided by local and private sector sources. A single case study was examined first to quantify the sensitivity of analyses and forecasts during a high-impact event to the inclusion of non-conventional surface data. Then, statistics were collected over a month period over a much broader domain to quantify the contribution of non-conventional data to more general analysis statistics.

a. Case study – 15 May 2013

The case study portion of this work focused on the 15-16 May 2013 tornado outbreak, which produced 19 tornadoes, two of which were EF2 or higher and included the EF-3 tornado near Cleburne, TX. The Cleburne tornado caused 7 injuries and $124 million in damage (see http://www.srh.noaa.gov/fwd/?n=tornadoes051513). The ARPS (Advanced Regional Prediction System; Xue et al. 2000, 2001) forecast model and its three-dimensional variational data assimilation and cloud-analysis packages (ARPS 3DVAR) were utilized to analyze and model the event. The data assimilation experiments were performed on a 400-m horizontal-resolution grid with a domain 161 x 161 km in size (figure below). The domain covered the immediate Dallas/Fort-Worth metropolitan region and surrounding suburbs, and the analysis grid consisted of 53 levels and was stretched in the vertical according to a hyperbolic tangent function with minimum vertical grid spacing of 20 m near the surface.



(a) Dallas/Fort Worth data assimilation domain (inner nest). (b) Analysis domain across the south-central Plains region.

A single ARPS/ADAS simulation at 3 km grid spacing was run using the initial analysis from the Rapid Refresh model at 2100 UTC 15 May 2013. Hourly data assimilation incorporated conventional surface (ASOS/AWOS) stations along with RAOBs, profiler, and aircraft data. This simulation was forced at the boundaries by subsequent RAP forecasts at hourly intervals until 0400 UTC 16 May and provided boundary conditions for 400 m resolution runs on the inner domain at five-minute intervals.

A single 1-hour 3 km forecast valid at 0100 UTC was interpolated to a 400 m resolution domain that covered the immediate Dallas-Fort Worth Metroplex. Surface data from both conventional and non-conventional stations, profilers, aircraft, and Level-II WSR-88D radial velocities and reflectivity were assimilated every five-minutes in a high-frequency intermittent data assimilation cycle that lasted until 0145 UTC. Forecasts were released at 0145 UTC and were run out to 0400 UTC. The non-conventional data

evaluated in this study included data from the Citizen Weather Observer Program, or CWOP stations; EN Weatherbug® Network, and mobile platform data from GST.

A series of Observation Simulation Experiments (OSEs) were run to evaluate the impacts of the non-conventional data, as listed in the first table below. A control (CTL) experiment was run assimilating all of the above-described data sets. One OSE was run excluding all surface data (Nosfc), and another OSE was run excluding only the non-conventional surface data (NoNewSfc). A fourth OSE was run excluding all non-conventional surface data except for a select group of WeatherBug sites located in the inflow region of the supercell (WxBugAdd). This OSE ingested thermodynamic and kinematic data. A second set of OSEs was run to better understand the contribution of thermodynamics versus kinematics. One OSE (WxBugThermo) repeated the WxBugAdd OSE but included WeatherBug thermodynamic (T, RH) information only. A second OSE (WxBugWind) repeated the WxBugAdd OSE but this time used only WeatherBug kinematic (wind speed and direction) data only.

Results from the set of OSEs for the Cleburne tornadic supercell are summarized in the second table below. A set of ten ASOS sites was withheld from the data assimilation and used for analysis and forecast verification. The gridded analyses were interpolated to the ASOS site locations and compared against the ASOS observations (Table 2). Reviewing the equivalent potential temperature RMS error, bias, and mean absolute error showed that excluding all surface data gave the worst results. Including the conventional surface data reduced the RMSD slightly, but worsened the bias and MAE. Adding WeatherBug data located within the region of storm inflow to the conventional surface data improved all statistics slightly. However, including all conventional and non-conventional data throughout the domain improved the overall analysis most.

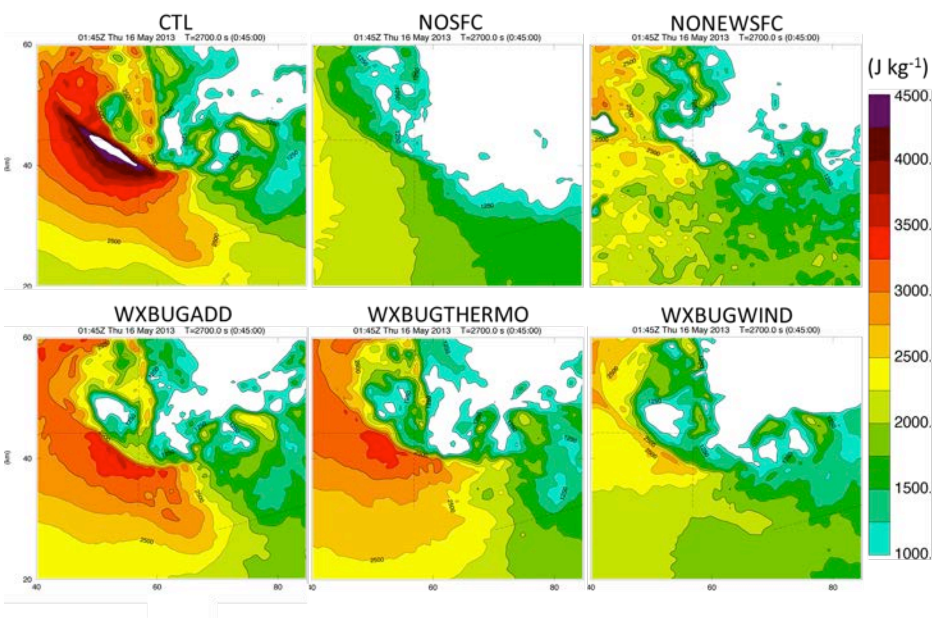
Details of the 400-m assimilation-forecast experiments

Name	**Brief Description**	**Surface data**
CTL	Control	All
NOSFC	Surface station denial	None
NONEWSFC	Non-conventional denial	Conventional only
WXBUGADD	WeatherBug - Johnson County	Conventional and WXBUG in Johnson County, TX
WXBUGTHERMO	WeatherBug - Johnson County T,T_d,P observations only	Conventional and WXBUG thermodynamic variables in Johnson County, TX
WXBUGWIND	WeatherBug - Johnson County wind obs. only	Conventional and WXBUG wind in Johnson County, TX

Equivalent potential temperature root mean square error, bias, and mean absolute error calculated at 10 ASOS stations at 0145 UTC 16 May 2013 for various experiments

Experiment	**RMSD (°C)**	**BIAS (°C)**	**MAE (°C)**
CTL	3.1	0.7	2.7
NOSFC	6.3	0.2	5
NONEWSFC	5.8	3.8	5.3
WXBUGADD	5.5	2.8	4.7
WXBUGTHERMO	5.6	3.1	4.9
WXBUGWIND	5.9	3.8	5.3

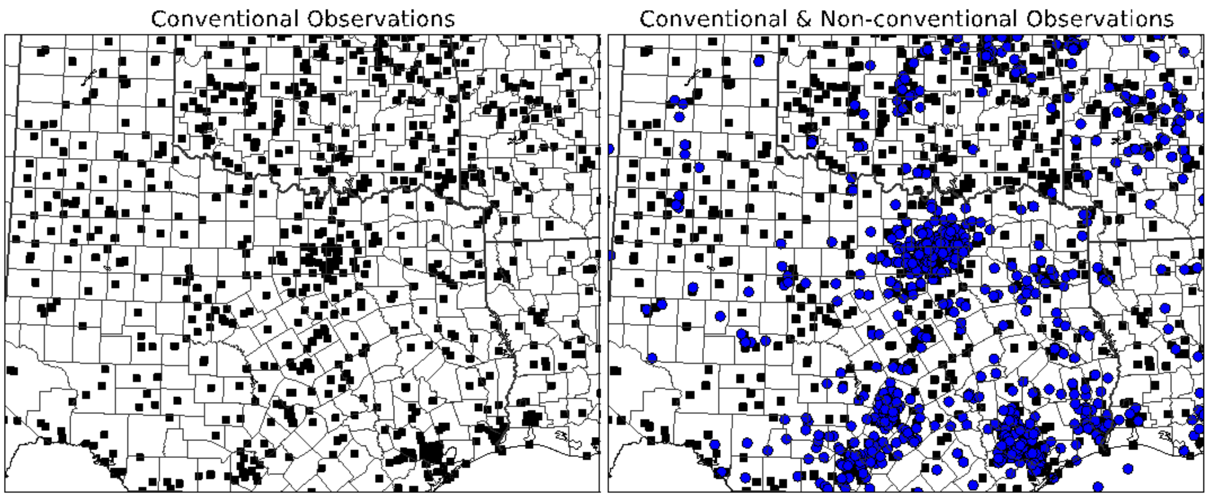
A series of forecasts were generated using each of the above analyses as the initial conditions. A review of these storm forecasts showed that *the thermodynamic information from a few select WeatherBug stations located within the storm inflow region had a significant impact on the storm evolution*. The initial forecast time analysis of CAPE (J kg^{-1}) is shown in the figure below. For experiments without surface data included, values of CAPE were much lower than the control. The inclusion of conventional surface data improved CAPE values slightly, but still underestimated surface thermodynamics. These experiments produced only very weak vortex circulations. However by adding thermodynamic information from a few select non-conventional sites (within Johnson County), CAPE values were much higher and closer to that estimated by the control. These forecasts generated much stronger and longer-lasting vortices that were much closer to the strength and path of the vortex observed. In summary, this single case study demonstrates the rather substantial sensitivity of storm-scale prediction to initial conditions. More importantly, this case highlights the value and opportunity presented by utilizing non-conventional data for high-impact events. A manuscript describing this case study is now being written and will be submitted to *Monthly Weather Review*.



Convective available potential energy (color fill, J kg^{-1}). CAPE is plotted at 0145 UTC.

b. Real-Time, Continuous Analysis System

In order to better understand the quantitative impact of non-conventional data on a broader scale, a continuous, hourly-cycled analysis system was run at 4 km grid spacing using ARPS and 3DVar. The system was run for over a month period (1 March – 3 April) over a regional domain. Two versions of the system were run with one using only conventional data and the second using both conventional and non-conventional (amateur surface and WeatherBug) data (figure below). Regional ASOS sites were withheld from both analyses and used for verification.

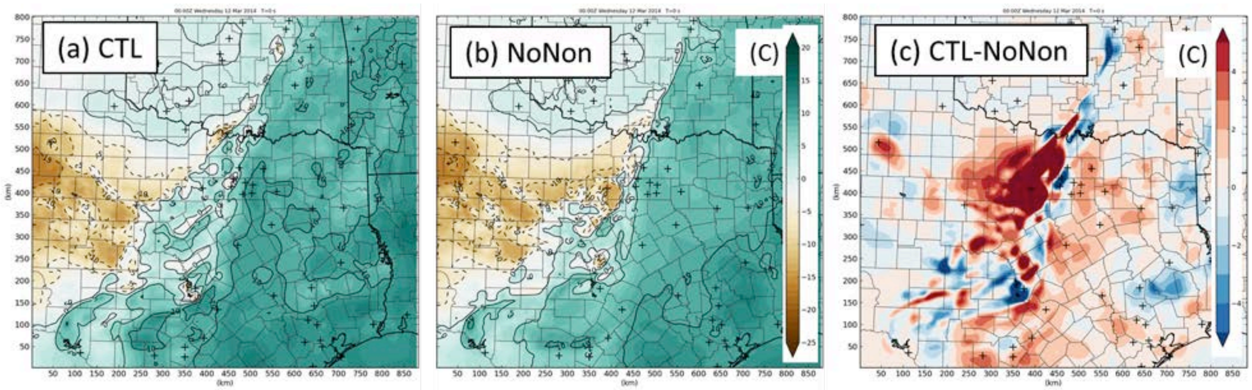


The site locations of data used from the (left) conventional only and (right) conventional and non-conventional stations.

Initial results show that the use of non-conventional data has a significant positive influence on the analyses. Comparing the difference fields between analyses and the ASOS verification, the use of non-conventional data reduced the overall analysis bias, reduced the Interquartile Range (IQR), and reduced the number of outliers. A low wind bias was noted with the non-conventional data, and this is likely due to relatively poor siting of many of these stations. However, the siting did not appear to negatively impact other measurements.

The use of additional, non-conventional data allows for a more rigorous, detailed surface analysis. For example, the exact placement of surface boundaries, such as drylines, is often difficult to discern in areas with limited surface information. One example from the real-time analysis demonstrates how the non-conventional data can correct, or refine, boundary placement (figure below). In this case analysis on 12 March 2014, at 0000 UTC, a dryline was located across central Oklahoma and north-central Texas. The analysis using only conventional data had the dryline just to the immediate west of the DFW Metroplex. However, the control analysis shifted the dryline over 100 km west with higher moisture gradients to the east. This difference in dryline placement and overall moisture availability has profound impacts on forecasts of convective initiation, storm evolution, and overall situational awareness. *This work highlights the*

promise of high-resolution analysis and forecasting, but as importantly, showcases the limitations of Warn-on-Forecast without an adequately dense observational network to support it.



The surface analysis of dew point (ºC) of a dryline case on 12 March 2014, at 0000 UTC. The control run including both conventional and non-conventional data (a), experimental run with no non-conventional data (b), and the difference field (control – no non-conventional data) (c).

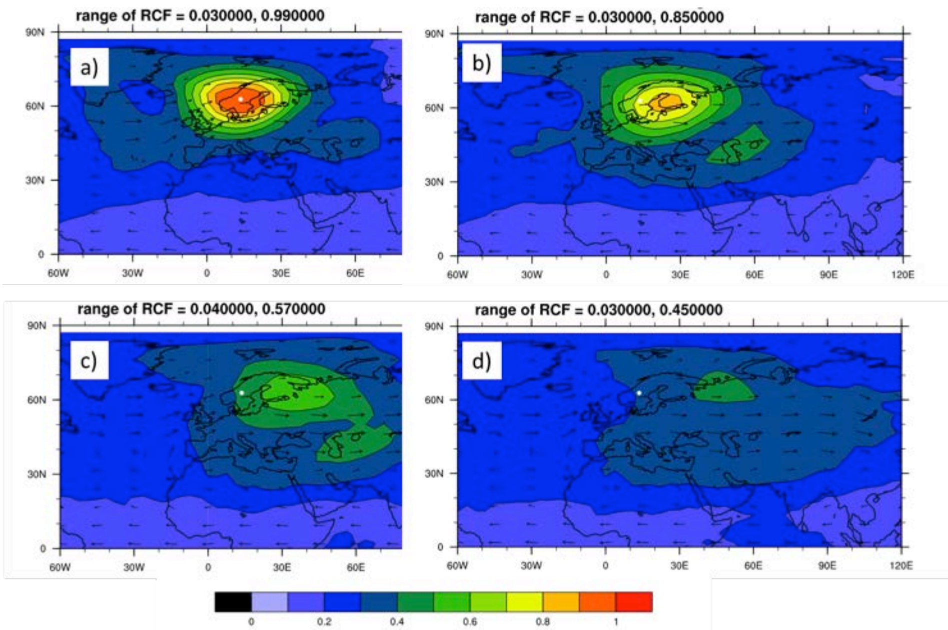
2. Evaluate Observation Sensor Impact Using an OSSE

To evaluate and explore methods to improve the ensemble based observation impact, we first conducted 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 (e.g. Wang et al. 2007, 2009; Holland and Wang 2012).

Following Holland and Wang (2012), a two-level global model run at T127 resolution served as a nature run, or true state. The assimilation-forecast cycles were 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 as defined in Wang et al. (2007), and assimilated via LETKF (Local Ensemble Transform Kalman Filter) every 24 hours. There are 362 equally spaced observations distributed over the global domain. We employ a Monte Carlo 'group filter' (GF) technique to limit the effects of sampling error. For each group, a regression coefficient, β, is calculated between the analysis and a forecast of some length. Then a regression confidence factor (RCF) is computed to minimize expected RMS differences between sample β's. An envelope of RCF values is then applied to the observation impact estimate. An example of the impact of a single observation to a very simple global forecast is demonstrated by its RCF in the figure below.

Our results have shown that the shape, location, time-dependency and variable-dependency of the localization function are consistent with underlying dynamical processes of the model. When applying the GF localization to the impact estimates,

there is an improvement in skill as forecast time increases over the static Gaussian-like localization that is traditionally used. This improvement is primarily due to the ability of the GF method to capture both the time-dependent shift of the localization as well as the diminishing magnitude of the signal as forecast time increases. Additionally, results have shown that the proper choice of localization used for the forecast impact estimate is inherently linked to the localization function used at the assimilation time.



The regression confidence factor (RCF) of a single observation of height as it evolves in time: (a) analysis; (b) 1-day forecast; (c) 2-day forecast; and (d) 3-day forecast.

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 (CIMMS at OU), 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

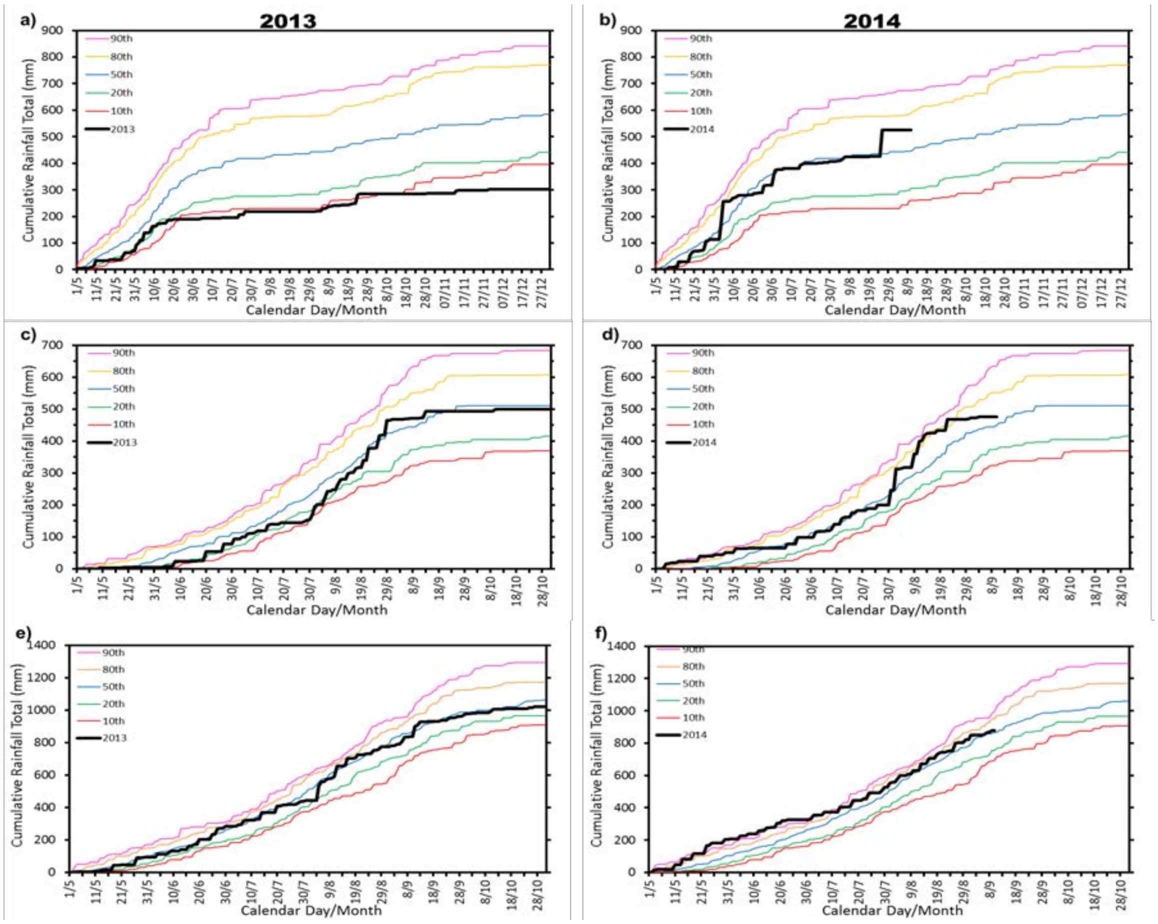
Objectives
Building climate resilient management systems across the West African Sahel.

Accomplishments
Recurrent drought affecting Sub-Saharan Africa continues to increase the risk of food insecurity for many households, and jeopardize their ability to meet their household food needs. The recurrent food crises since 2010 continue to affect more than 31 million people in the Horn and Sahel regions (Boyd et al. 2013), and the situation is becoming increasingly desperate due to the fact that short-term weather and seasonal climate forecasting have limited skill for West Africa. Thus, building resilience in communities for future crises is indispensable for people in the region, to adapt to an increasing and potentially irreversible global sustainability challenge. The Rainwatch project coupled with the African Climate Exchange (AfClix) aims to integrate the expertise and actions of relevant institutions, agencies and stakeholders to broker ground-based dialogue to promote resilience in the face of recurring crisis.

Rainwatch works on the principle of analogues -- by allowing users to compare the evolution of the rainy season with indicator years of good or poor rainfall or with any other year or station of their choice. Knowing that a particular rainy season is evolving in a manner similar to another year with which users have experienced provides them insight as to likely outcomes or what to expect. Real-time monitoring of the 2014 monsoon season for eight stations in Burkina Faso, fifteen in Ghana, twelve in Mali, and nine in Niger was accomplished using Rainwatch-AfClix interface. These forty four stations are distributed across, and represent fully, the economically vital agricultural region of the respective countries. Rainwatch website (http://cimms.ou.edu/rainwatch/) was developed at OU to build African capacity to minimize the adverse impacts of Sahelian rainfall variability by allowing users and decision-makers 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. Periodic Rainwatch-AfClix Bulletin is issued and distributed to more than 400 users around the globe. Rainwatch-AfClix 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 Accra (Ghana), Niamey (Niger), and Bougouni (Mali) for 2013–2014: a, b) comparison of progression of 2013 and 2014 rainy seasons in Accra (thick black lines) versus indicated historical percentiles for 1950-2012; c, d, and e, f; same as a, b but respectively for Niamey relative to historical percentiles for 1965–2000; and for Bougouni relative to historical percentiles for 1974-2003.

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: David Legler (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)

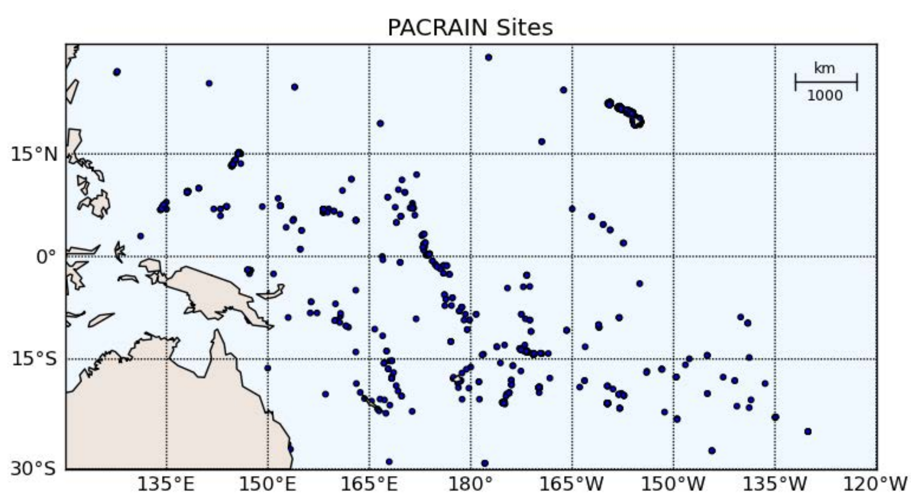
Objectives

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 National Weather Center 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 remain actively involved in research of the tropical rainfall process using data obtained from this project.

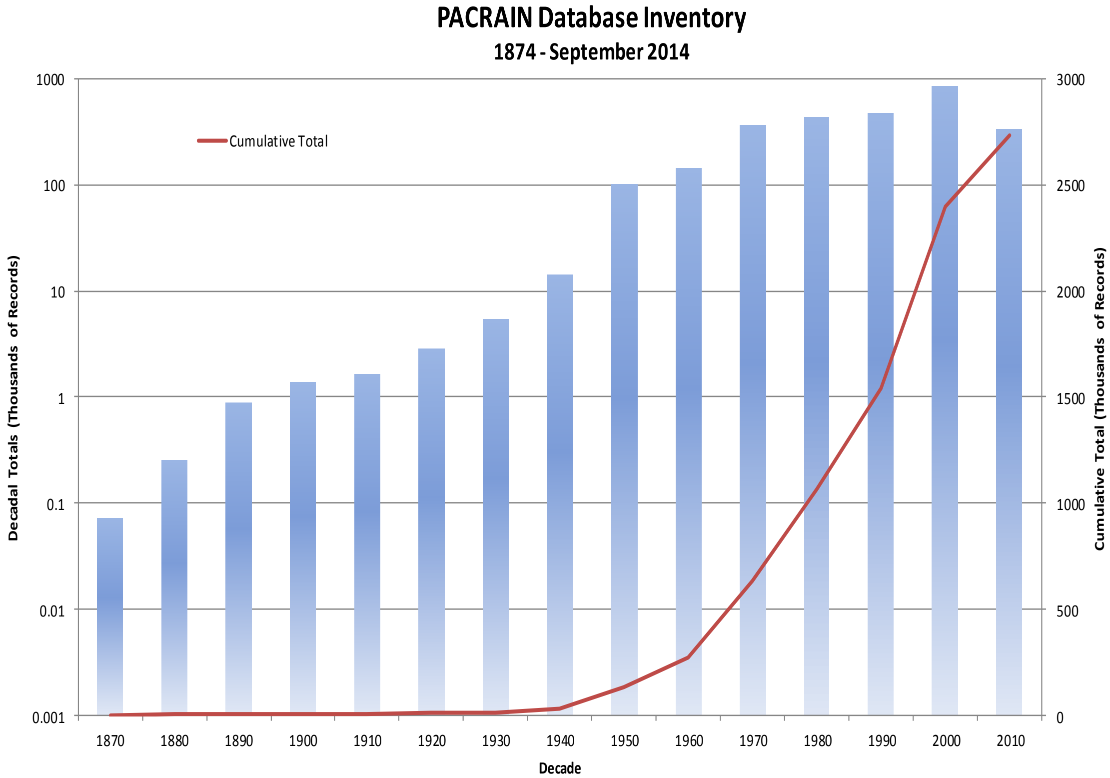
Accomplishments

1. PACRAIN Database Status

As of September 2014 the database contains 2.74 million observations from 990 sites. Data begin in January 1874 (see first two figures). All data are available at http://pacrain.evac.ou.edu. The database was last updated on September 2 with data through July 2013. Data availability varies by site. Data access is verified at least monthly with each regular update. Users are encouraged to report access problems so that they can be corrected as soon as possible. Database availability for the past year has been over 99.99%. For the 12-month period ending September 2014, PACRAIN users retrieved nearly 35.5 million records. Approximately one-third of users made multiple queries.



All sites represented in the PACRAIN database.



The current PACRAIN database inventory showing records counts by decade.

2. Database Enhancements

A hardware and software upgrade of the PACRAIN data server is underway. The database has been migrated to the new server, a new web site is being developed, and the data ingest/processing software is being rewritten to take advantage of the new server and database capabilities. Once the upgrade and internal testing is complete, the new server will take over for the existing server.

3. Investigation into Differences Observed Between the PACRAIN Data and the Global Historical Climate Network

The Global Historical Climate Network (GHCN) dataset is maintained by the National Climatic Data Center as a compilation of climate data from around the world. The GHCN-Daily dataset is NCDC's data set of record for global daily climate observations. GHCN replaces a number of NCDC data sets, including the TD3200 Cooperative Summary of the Day data set. While both of these data sets use the same source data, they have different quality assurance schemes that lead to differences between the two data sets in some cases. Also, TD3200 was limited to the US first-order and cooperative observation networks so the geographic scope of GHCN is much greater.

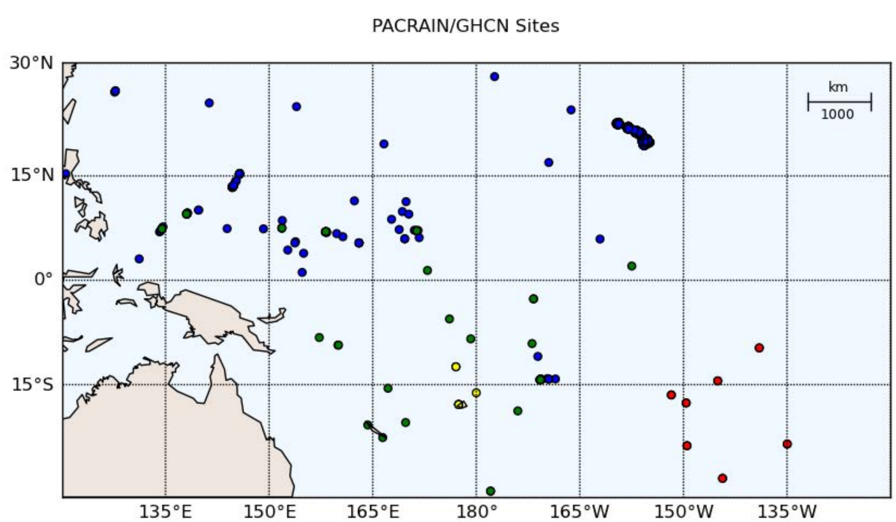
The PACRAIN database includes a mix of GHCN and TD3200 data depending on when the data were ingested. Starting with the 2011 data year, when TD3200 was

discontinued, all values for NCDC data are from GHCN; prior to then most values are from TD3200 except for cases where a correction to an existing observation was issued in the GHCN data feed. While GHCN data are available for the South Pacific—primarily for ICAO aviation observation sites—PACRAIN currently uses NIWA data for this region. The existence of redundant data provides an opportunity to compare GHCN to the PACRAIN database with the goal of identifying discrepancies between the two data sets.

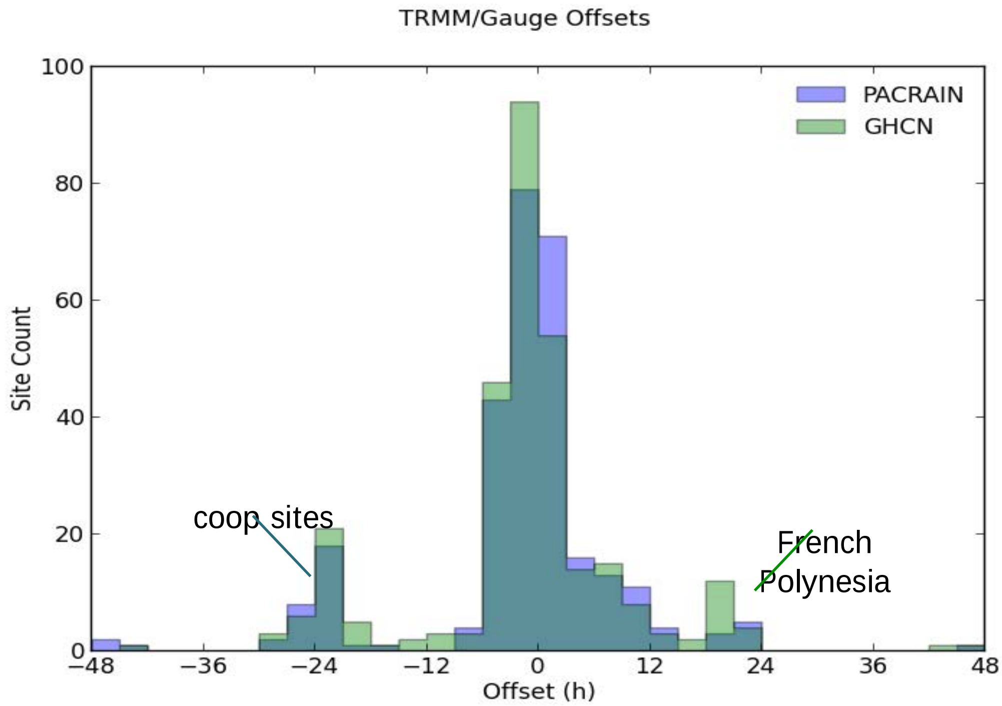
The 670 PACRAIN sites were matched against 812 GHCN sites in the region to produce 498 site pairs for comparison (see first figure below). PACRAIN has more extensive coverage in the South Pacific. Notably, GHCN does not include any data for Cook Islands, Niue, Pitcairn Islands, Samoa, or Wallis and Futuna, but data for these areas are included in PACRAIN. The site matching process identified some metadata errors in both the PACRAIN and GHCN datasets; these errors have been corrected.

The cross-correlation was calculated for the data at each matched GHCN/PACRAIN site to identify date/time discrepancies. The PACRAIN and GHCN data were also compared individually to satellite estimates from the TRMM 3B-42 product as a sanity check on the reported date/time values. The overall PACRAIN/GHCN and gauge/satellite agreement is good, with some exceptions (see second figure below). The GHCN data for French Polynesia appears to be offset from PACRAIN and satellite estimates by ~1 day, possibly due to a misinterpretation of the reporting conventions used for these data. There is also a cluster of US cooperative sites for which PACRAIN and GHCN agree, but are offset from the satellite estimates by 24 hours. This offset might be explained by incorrect reporting by those observers.

Work continues to examine the discrepancies between the GHCN and PACRAIN data, with the goal of collaborating with NCDC to identify and correct errors in both datasets.



Matched PACRAIN/GHCN sites used for comparision. The color indicates the PACRAIN data source: blue for NCDC, green for NIWA, yellow for the the Fiji Met Service, and red for Meteo-France – French Polynesia.



Comparision of the reported PACRAIN and GHCN observation times to TRMM 3B-42 satellite estimates. The 3B-42 resolution is 3 h.

4. Schools of the Pacific Rainfall Climate Experiment (SPaRCE)

Our Pacific educational program, SPaRCE (http://sparce.evac.ou.edu/) 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 results 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. Ongoing activities include:

1. SPaRCE schools continual to be recruited
2. SPaRCE rain gauge data entered in PACRAIN database
3. Islands data continually input into the PACRAIN database
4. Analysis of observed differences in rain gauges in PACRAIN and NCDC.

Publications

Morrissey, M.L., E. Cook, and J. S. Greene, 2014: *Satellite and Surface Validation: Theory and Methods.* Textbook for upper level undergraduates and graduates in Meteorology. J. Wiley & Sons. Manuscript to be completed November 2014.

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: 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

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. Participation in the FACETS Discussions and Meetings

James J. Correia, Jr. (CIMMS at SPC)

The NSSL FACETS project has had several meetings at the AMS Annual Meeting Town Hall meeting, the SSIP meeting in Norman, and many pre-meeting discussions about how FACETS will be shaped and run. We identified physical and social science goals, issues to be addressed for NWS and specifically SPC, as well as how to address these issues relevant to the HWT.

2. Special Projects in Effective Communication

James J. Correia, Jr. (CIMMS at SPC)

I am serving as a liaison to many different groups within and concerning social science activities including the Weather and Water social science working group within NOAA, a local social science group between NOAA, OU CIMMS, CASR, and CAPS, working with the SPC communications team including Dr. Susan Jasko (University of California – Pennsylvania), Dr. Laura Myers (University of Alabama - Tuscaloosa) 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 2013) and work towards clarifying the language used in the outlooks in the NWS survey in 2013. Additionally, we solicited Dr. Myers to

analyze and report back on the Day 1 outlook change survey for user feedback. 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.

3. HWT EFP-EWP Collaboration

James J. Correia, Jr. (CIMMS at SPC)

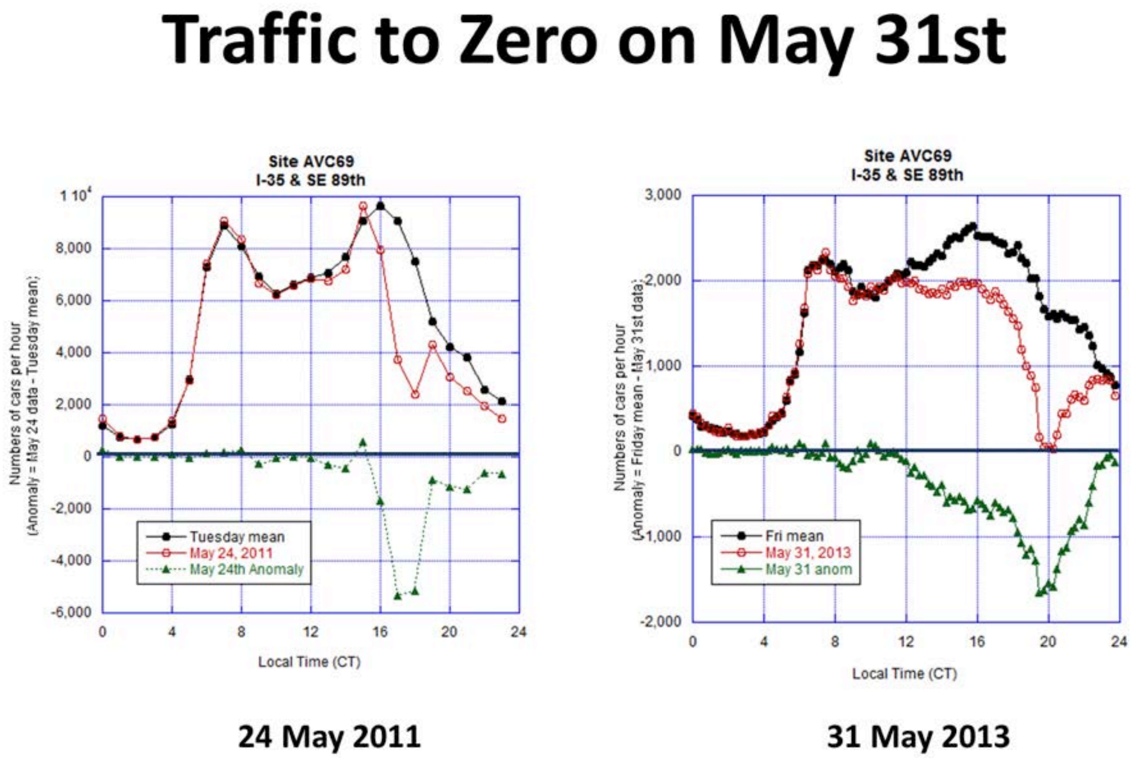
The Experimental Forecast Program's desire to issue frequently updating short-period convective outlooks fit well within the Experimental Warning Program's Probabilistic Hazard Information experiment. I collaborated with the PHI group to do multiple afternoon briefings of EFP products including all updated high-resolution convection allowing model guidance and our 3-hour hazard specific outlooks. These briefings were meant to simulate aspects of the SPC watch collaboration call and offer risk assessments as needed to the warning forecasters in the PHI experiment. The briefings ran between 5 and 15 minutes, occurred at least 3 times per week (the experiment ran every other week), and roughly twice per day. Both EFP teams products and risk assessments were briefed and a Q&A period was used to foster discussion. This work is ongoing.

4. El Reno Tornado – Traffic Study

Gabriel Garfield (CIMMS at OUN)

On 20 May 2013, an EF5 tornado ravaged Moore, Oklahoma, a southern suburb of Oklahoma City (OKC). Just 11 days later, another powerful tornado formed on the outskirts of El Reno, Oklahoma, just west of the OKC metropolitan area. As the El Reno supercell continued eastward toward OKC area, substantial traffic jams developed. It appears that the dread caused by the recent tornadoes induced many to flee their homes.

Using damage surveys, Doppler radar, traffic numbers, and first-hand accounts, the need for better communication of weather information during severe weather events was demonstrated. In particular, my collaborators and I noted that even as “lead time” increases, the non-linear nature of public response might not allow for a monotonic reduction in tornado fatalities (in the absence of communications research). With the advent of warning-improvement programs like “Warn-on-Forecast”, it will become necessary to understand the relationship between weather communication and public response. Additional research on this subject continues (regarding hypothetical tornado paths into Oklahoma City after the El Reno tornado).



Comparison of traffic sensor data during two violent tornadoes in central Oklahoma. The traffic sensor detects vehicle "flux", so a zero count indicates traffic has completely stalled. Notice how the traffic count decreases toward zero during the 31 May event.

5. Storm Observer Safety Video

Gabriel Garfield (CIMMS at OUN)

On 31 May 2013, a powerful tornado formed near El Reno, Oklahoma. Though the city was not directly impacted by the tornado, 8 people died – six of who were storm observers. Given the growing hobby of storm chasing, this kind of event may become more common. Thus, in an effort to reduce storm observer fatalities in the future, my collaborators and I set out to create a safety documentary related to the event. In 26 minutes, we present a forecast, a timeline, and a set of lessons learned / re-learned from the event. This video documentary was published to YouTube, and was shared hundreds of times on social media: http://www.youtube.com/watch?v=TBjr-nvA2Jg

El Reno tornado documentary.

6. Creation of Numerical Weather Guidance

Chris Karstens (CIMMS at NSSL)

Numerical Weather Guidance was provided to forecasters participating in both the Experimental Warning Program (EWP) and the Experimental Forecast Program (EFP) during the 2014 Hazardous Weather Testbed (HWT) Spring Experiment. Forecasters in the EWP Probabilistic Hazard Information (PHI) experiment were provided real-time and displaced real-time radar-derived objects through an implementation of the k-means clustering and object identification algorithm that tracked storms at the -10 C reflectivity isosurface on multiple length scales. The objects included the derived Maximum Estimated Size of Hail (MESH) value that was used to derive a probability of hail exceeding 1 inch in diameter, valid within the object, based on a correlation that was performed with MESH and high spatial and temporal resolution hail reports from the Severe Hazards Analysis and Verification Experiment (SHAVE). These objects could be used by forecasters to generate probabilistic forecasts, while optionally overriding the guidance probabilities to ideally add value to the forecast. The usage of this guidance information is currently being evaluated to inform future development. The subjective feedback received was positive, but highlighted a need for improved presentation within the web-based prototype tool for easier engagement by the forecasters across the continuum of guidance probabilities.

Secondly, forecasters in the EFP produced 9, one-hour probabilistic forecasts between the 18-03 UTC time period (updated 21-03 UTC forecasts later on in the day) for all severe convective hazards (combined tornado, wind, and hail hazards). The forecasters were provided guidance probabilities derived from the NSSL-WRF Ensemble, in the form of probability contours. These contours could be taken as-is, or edited by the forecasters interactively using a web-based prototype tool to ideally add value to the forecast. The forecasters enjoyed generating these forecasts, but found it to be somewhat laborious. Future efforts are exploring how to improve the presentation of the guidance information within the web-based prototype tool. Additionally, verification of these forecasts is being performed and will be presented at conferences in the near future.

7. Warning Decision-Making and Value to End Users

Chris Karstens (CIMMS at NSSL)

Expanding upon efforts from 2008, the 2014 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted during the weeks of 5-9 May, 19-23 May, and 2-6 June. Each week, two forecasters participated by issuing probabilistic forecasts for severe convective phenomena (tornado, wind, hail, and lightning) using a prototype web tool. The objectives of this experiment included understanding how forecasters use the PHI system, comparing probabilistic forecasts to traditional warnings for two control cases, collaborating with the HWT Experimental Forecast Program (EFP), and understanding forecasters' thoughts on a paradigm change (deterministic products to continuous probabilistic information).

One of the main findings of the experiment is that "on-the-fence" decision points are significantly reduced using the PHI system, as opposed to issuing warnings in the current system. This finding is attributable to the PHI system's ability to allow forecasters to communicate low-probability hazard information, well before a traditional warning would be issued. The result should ultimately improve communication between NWS forecasters and the diverse groups of end users (to be tested in 2015). Although relinquishing "on-the-fence" decision points should result in faster communication, many more hazard areas or potential hazard areas require attention by the forecasters. It was found that forecasters could comfortably handle about 4-5 hazard areas simultaneously, and when the number exceeded that, mental work-load issues arose. To address this issue, forecasters recommended to improve the infusion of automated first-guess numerical weather guidance in the PHI system in a way that allows forecasters to quickly adjust which areas are unmonitored (low-probability hazard areas) versus those areas requiring significant attention (high-probability hazard areas). Adjustments to the PHI system based on this feedback are planned for the 2015 HWT PHI experiment.

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

NOAA Technical Lead: Pamela 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

Research associated with this project will address three major research areas: (1) investigation of impact of radar scan time on NWS forecaster decision making, (2) develop NWRT PAR system design concepts that may aid forecaster decision making, and (3) analysis of how MPAR scan time captures mesoscale processes compared to operational and mobile research radars possibly leading to better warning decision by forecasters.

Accomplishments

1. Phased Array Radar Innovative Sensing Experiment (PARISE)

Darrel Kingfield (CIMMS at NSSL), Pamela Heinselman (NSSL), and Robert Hoffman (Institute for Human and Machine Cognition)

As the Phased Array Radar testbed was down during the time frame of the planned PARISE real-time data collection, no experiment was conducted in spring 2014.

Two formal publications were prepared and submitted to *Weather and Forecasting* based on analysis of prior years' experiments. The first paper focused on forecaster tornado warning decision-making using MPAR data (it has been accepted) while the second examined their performance during severe hail and wind events. This project is ongoing.

Publications

Heinselman, P., D. LaDue, D. M. Kingfield, and R. Hoffman, 2014: Tornado warning decisions using phased array radar data. *Weather and Forecasting,* accepted.

CIMMS Task III Project – Southern Climate Impacts Planning Program (SCIPP) Phase II

PIs: Mark Shafer (OCS at OU), Barry Keim (LSU), Harold Brooks (NSSL), Renee Edwards (LSU), Michael Haynes (National Drought Mitigation Center), Yang Hong (OU Department of Civil Engineering and Environmental Sciences), Renee McPherson (South Central Climate Science Center at OU), Randy Peppler (CIMMS at OU), Kevin Robbins (LSU), and Steven Quiring (Texas A&M University)

Senior Personnel: A. Billiot (LSU), M. Boone (OCS at OU), A. Krautmann (OCS at OU), H. Needham (LSU), and R. Riley (OCS at OU)

Staff: J. Bostic (OCS at OU), K. Brehe (LSU), G. McManus (OCS at OU), N. Richardson (OCS at OU), L. Romolo (OCS at OU), D. Sathiaraj (LSU), and A. Shih (OCS at OU)

Graduate Research Assistants: L. Becker (LSU), C. Kovacik (OU), C. Pavlowsky (OU), and Z. Zhang (OU)

Undergraduate Research Assistants: M. Brumfield (OU), K. Christian (OU), E. Day (OU), C. Kuhn (OU), T. Rodgers (OU), and K. Williams (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)

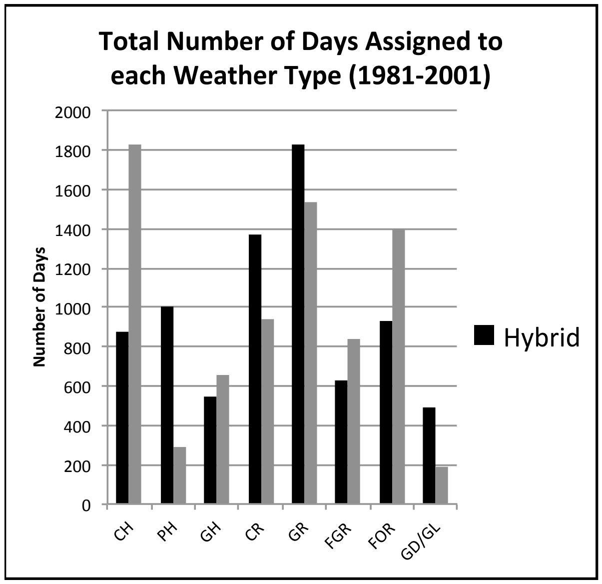
The SCIPP project is ongoing.

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 FY14, 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. SCIPP is ongoing.

1. A Hybrid Procedure for Classifying Synoptic Weather Types for Louisiana with an Application to Precipitation Variability

Louisiana experiences large shifts in weather conditions from year to year, especially with regards to precipitation. It is unclear how much large-scale (synoptic) weather variability affects the local weather in Louisiana. There is no widely accepted automated synoptic weather classification system for the Louisiana/Gulf Coast region; however, there is a manual classification system developed by Muller at Louisiana State University, called the 'Muller Weather Types for Louisiana'. The automated hybrid classification system can be used for seemingly endless applications in climate and climate impact research for Louisiana, including updates to older studies that used the Muller classification systems as well as new studies, such as synoptic climatological investigations of future climates using GCMs.



The hybrid procedure correctly matched the Muller weather types at one or more of the point locations for ***57%*** *of days.*

2. South Central U.S. Hazard and Climate Change Planning Assessment

SCIPP conducted an online assessment to better understand the needs of hazard planners across its region. A survey was administered in early 2013 to decision makers who were thought to be involved in hazard planning. Three hundred forty-two people participated. This was the 2nd time the survey was administered; the first was in 2009. The assessment focused on 1) hazard planning, 2) planning for climate change, and 3) information use and applications across the region.

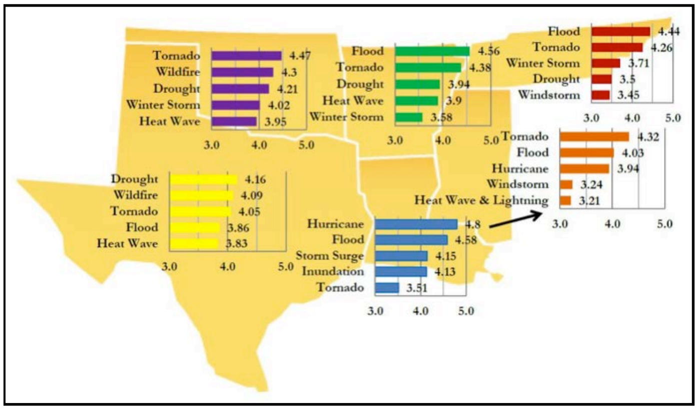
Seventy-nine percent of respondents (n = 269) were formally involved in hazard planning in their agency or organization. Of those, 45% were emergency managers or planners, and the rest comprised a variety of positions such as extension agents, administrators, environmental specialists, elected officials, and engineers. Over two-thirds of respondents (71%) said three or fewer staff in their department share hazard planning responsibilities for their area. Most commonly, however, only one person in a department is responsible for hazard planning.

The respondents were asked how important they think it is to plan for 14 weather and climate hazards on a scale from 1 “not important at all” to 5 “critically important”. The hazards were then ranked by their mean importance rating. Floods (from rain or rivers; M = 4.17) ranked the highest, followed closely by tornadoes (M = 4.13). Tornadoes slightly edged out floods in 2009 and the largest ranking change occurred with drought (it went from 8th to 3rd). A multi-hazard plan is the most common type of plan used for hazard planning.

The second section of the assessment focused on incorporating climate change into

hazard planning. About one-third of respondents (30%) had considered incorporating climate change into their hazard plans. Over half said the barriers to doing so included “limited or no funds to support climate change planning” (68%), “higher work priorities” (61%), “lack of community or political interest” (56%), and “limited or no staff available to support climate change planning” (56%).

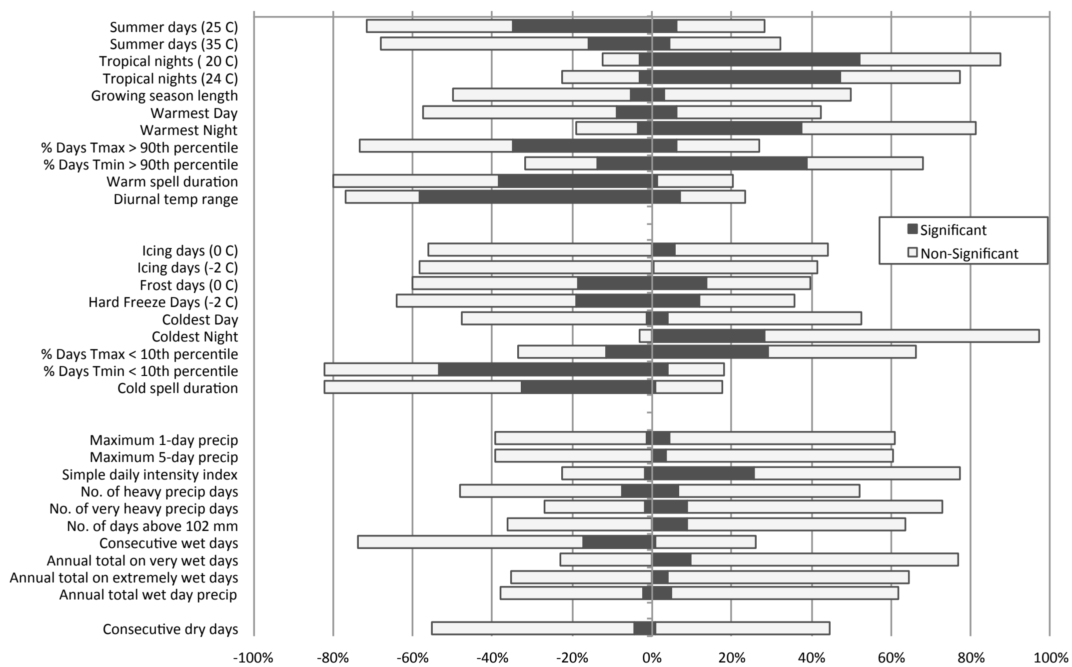
Finally, the respondents answered several questions pertaining to information use and needs. The top critical need for including climate change in hazard plans was “more climate information that is applicable to my particular area” (59%), although the spread between the first and last ranked need was less than 18%.



The five highest rated hazards, by state, in terms of how important the respondents think it is to plan for them. The scale ranged from 1 “not important at all” to 5 “critically important”.

3. Climate Extremes in the Southeastern United States: Observed Trends, Spatial Variability, and Related Planning

Extremes are particularly important elements of climate in the Southeastern United States. Since 1980, the Southeast has been involved in more billion-dollar weather and climate disasters than any other region in the country, largely due to hurricanes, floods, and tornadoes. Is this reflective of a changing climate, or increasing population and industry across the region? The objectives of this study were to 1) assess annual spatial and temporal trends in temperature and precipitation extremes from 1948 to 2012 for the Southeast, 2) examine seasonal trends in temperature and precipitation extremes, and 3) develop a regionalization of extreme variability across the region. The indices reflect increasing trends in warm and wet extremes for much of the region, with drier conditions evident in eastern portions, particularly South Carolina. Increases in extreme heat have been due to upward trends in minimum rather than maximum temperatures, and the rate at which minimum temperatures are increasing appears to be outpacing any increases in extreme maximum temperatures. The asymmetric changes in extreme daytime and nighttime temperatures are narrowing diurnal temperature ranges for most stations.



Proportion of stations in the Southeast showing positive and negative trends in extreme indices from 1948 to 2012; image concept borrowed from Insaf et al. (2012).

4. May 20 Newcastle/Oklahoma City/Moore Tornado: Post-Disaster Assessment of Preparedness, Planning and Recovery

The Oklahoma City metropolitan area has observed eight days with violent tornadoes in just the past 14 years. Given that tornadoes occur relatively randomly and infrequently, the 20 May 2013 tornado that struck three towns in central Oklahoma provides a unique opportunity to learn what impact “repeat” events have on city response and recovery mechanisms.

SCIPP researchers are conducting interviews with emergency managers and other key decision-makers involved in the tornado response and recovery. Under investigation are the institutional and structural policies related to this event in the areas of policy for disaster planning and emergency management. Questions that will be covered relating to emergency management include: What lessons learned from the 1999 and 2003 events were implemented for this event? What decisions were made on the fly to respond to the disaster? Policy questions include: What interagency relationships are most valuable? What factors were successful or a barrier to providing continuity of services? Additional topics covered in the assessment involve sheltering, managing resources and volunteers, and debris removal. A goal of this study is to promote planning and preparedness as important for mitigating, responding to and recovering from natural disasters.

Central Oklahoma emergency managers indicated that in the past interpreting FEMA rules on debris removal had been difficult, but they were very upfront and clear with this

disaster. For example, local officials were relieved during one of the first FEMA meetings in Oklahoma City right after the event to hear that foundation slabs were included by FEMA as storm debris and could go toward reimbursement costs. This had not been the case for previous disaster events. In general, if homeowners could get debris to the right of way along the curb, then the city or county could pick it up.

The outpouring of volunteers and donations were one of the hallmarks of this event that distinguished the response from past tornado disasters in Oklahoma. However, there were challenges and liabilities associated with supervising a large group of unskilled labor. Therefore municipalities are considering or are already implementing donation management and volunteer coordination plans to ensure better continuity during a future event.

One of the lessons learned a central Oklahoma emergency manager identified from 1999 and other events is the importance of getting people back into their neighborhoods and back to their homes as quickly as possible. It is mutually beneficial for the city and the residents to open the neighborhoods back up once utilities are turned off and the roadway is clear because the city can then focus resources elsewhere. Residents can also start the recovery process and move forward.

Full government response can take a while sometimes, so a local government like a county or municipality establishing relationships with local groups like churches or Tribal Nations is crucial to bridging the one to three day gap immediately after a disaster before more permanent solutions and enrollment in government aid can occur. These relationships that can be created before a disaster through the planning process end up being much more important than the plan itself. Going through a planning process helps to identify early on the natural command control coordination, support structure and expected roles and responsibilities for when a disaster arises. Mutual aid agreements with neighboring communities regarding police, fire and municipal staff are also essential to effective and timely local government response.

5. Responses to News Stories about Drought

Most people, including decision-makers, get information about extreme weather from news reports. They do not have training in climate science. Indeed, they have relatively low scientific literacy and must rely on preexisting beliefs and attitudes as well as their assessment of individual news stories to draw conclusions about the importance and consequences of weather events. Two theories rooted in social cognition address the process of responding to news stories about drought. Message Interpretation (MI) proposes that beliefs and personal experience influence meanings. Individuals with different backgrounds and beliefs may encounter the same information but draw different meanings from it. Story Appraisal Theory (SAT) states that individuals assess news stories for whether they have a point, are plausible, and are representative. If so, people are more likely to generate implications for what the story means for them personally, for others, and for society. Both MI and SAT suggest that meanings and implications lead to emotions, cognitions, and behaviors. Thus, individuals encounter

the same story but draw different conclusions from it.

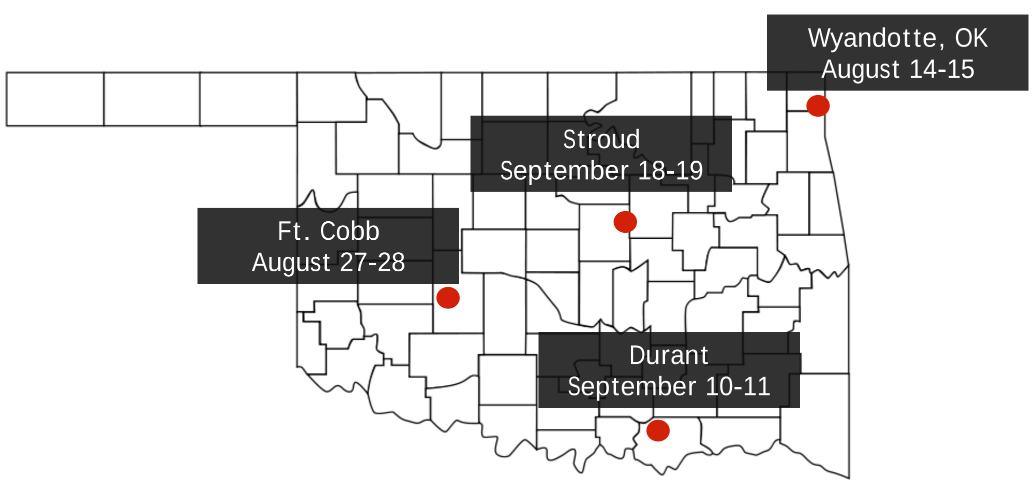
This project addresses three questions about what happens when individuals access news stories about drought: (1) What do they think? (2) Why do they have different thoughts? (3) What are the consequences for decision-making? The model proposes that thoughts or implications derived from news stories are influenced by experience with extreme weather, belief in climate change, and story appraisal. Implications (both quantity and type) lead to outcomes such as fear, sympathy, and endorsing action.

Background and Story Appraisal --> Implications --> Emotions and Action

In ongoing tests of the model, participants read a summary of a news story followed by open-ended and closed-ended questions about it. The questionnaire asks for implications and measures background information, story appraisal, emotions, and endorsement of action. Approximately 70% of participants generate implications for themselves, others, and society. The implications focus on issues such as what people and government should do about the drought, the importance of water, and how much people are suffering. Preliminary results are that beliefs about climate change and story appraisal, especially judging representativeness, are associated with constructing more implications. More implications are associated with stronger emotions (fear and sympathy) and endorsing actions such as requiring low-flow toilets.

6. Climate Training for Native American Tribes

Funded through supplemental RISA funds, four 2-day workshops will take place in August and September 2014 in Oklahoma. Tribal environmental professionals from Oklahoma and Texas will participate in the workshops. Material covered will include information on the basics of climate science and climate change, climate planning tools, and how to conduct a basic vulnerability assessment. Workshop planning and content development began in September 2013. The purpose of the workshops is to educate on the basics of climate science, assist tribes in addressing climate science needs, and introduce how a vulnerability assessment could be useful for planning.



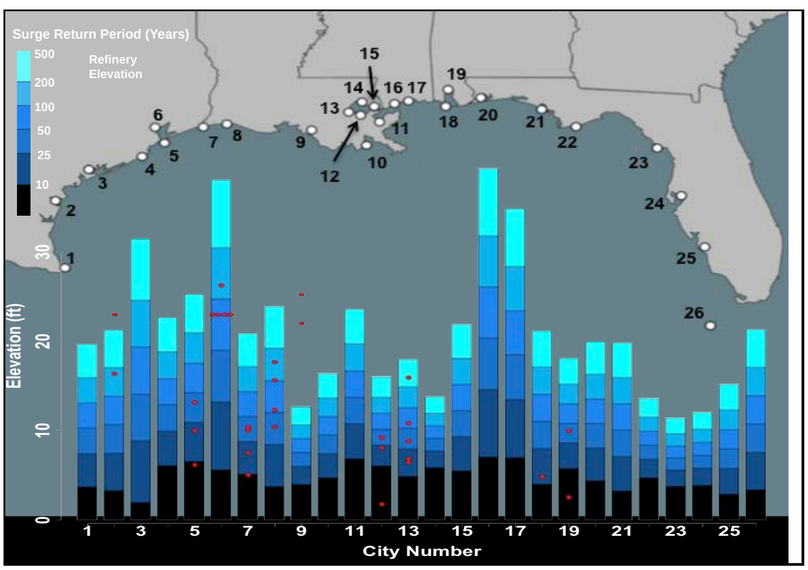
Workshop locations and dates.

7. Intertribal Workshops on Climate Variability and Change

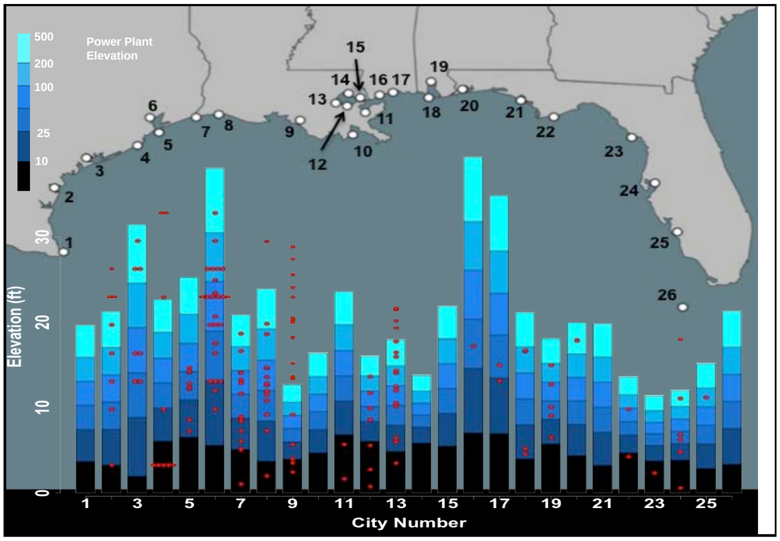
SCIPP, through the leading of the DOI South Central Climate Science Center, helped plan and host four workshops in Oklahoma for tribal environmental professionals and cultural preservation officers in June and July 2013. The workshops 1) educated tribal representatives across the region about climate adaptation-related products and services, especially related to drought; 2) documented climate impacts on the tribal nations and their peoples, lands, resources, and economies; and 3) fostered dialogue between tribal citizens and government representatives, climate scientists, indigenous geographers, and U.S. government representatives that was previously initiated through three related meetings.

8. Gulf Coast Energy Infrastructure Project

SCIPP has been working closely with the Speed Center at Rice University on a project that will provide critical flood protection for the Houston Ship Channel. This project proposes to construct The Centennial Gate, a flood-control device that would protect this dense industrial area from high storm surges. SCIPP is providing historical storm surge data for Galveston Bay and the region close to the Houston Ship Channel, as well as storm surge statistics, such as the height of the 100-year storm surge in this area. SCIPP has also collaborated with Oak Ridge and Pacific Northwest National Labs on a project that assessed the vulnerability of critical energy infrastructure to storm surge inundation. This project utilized SCIPP's storm surge data from the SURGEDAT project, along with location and elevation data for oil refineries and power plants along the U.S. Gulf Coast. The project found that the 100-year storm surge would inundate 72% of the coastal refineries and 63% of the coastal power plants in the region, without the protection of local levees and other flood control devices.



Storm Surge Return Levels and Refinery Elevations for the U.S. Gulf Coast.



Storm Surge Return Levels and Power Plant Elevations for the U.S. Gulf Coast.

9. State of Oklahoma Hazard Mitigation Plan

FEMA has required each state to update their Hazard Mitigation Plans every three years in order to receive funding and assistance after a disaster declaration. Over the past year, SCIPP has been influential in the updating of the State of Oklahoma Hazard Mitigation Plan. Alek Krautmann, SCIPP Research Associate, reviewed and updated the Risk Assessment portion of the plan, which includes the state hazard descriptions, hazard climatology and descriptions of notable past hazard events or disasters. The review involved making sure the weather and climate information provided is accurate and offering additional suggestions as needed. As part of SCIPP's involvement with the State of Oklahoma Hazard Mitigation Plan, SCIPP members attended several of the quarterly Oklahoma Hazard Mitigation Team meetings. The meetings involve partners from the Oklahoma Department of Emergency Management, as well as Emergency Managers from various counties and Tribal Nations.

10. State of Louisiana Hazard Mitigation Plan

FEMA requires each state to update their Hazard Mitigation Plans every three years in order to receive funding in case of a disaster. Over the past year, SCIPP has been influential in the writing and updating of the State of Louisiana Hazard Mitigation Plan. Lynne Carter, SCIPP Program Manager at LSU, played an influential role in adding sections to the Hazard Mitigation Plan regarding climate variability and climate change in Louisiana, especially with regards to sea level rise. The State of Louisiana Hazard Mitigation Plan was approved by FEMA on 2 April 2014, and is now available online at http://www.getagameplan.org/mitigateplanupdate.htm.

11. Houston Yacht Club

SCIPP developed a comprehensive storm surge database and analysis for the

Galveston Bay area, which is important for understanding coastal flooding vulnerability in this region. Such data are important to assess the vulnerability of industrial complexes, residential communities, and specialized infrastructure, such as yacht clubs, marinas and ports. The Houston Yacht Club is an example of a coastal facility that has taken the initiative to adapt infrastructure to minimize losses from storm surges. The facility invested in more than $1 million in adaptations that will likely offset $5 million in losses during the next large storm surge event.

SCIPP conducted a storm surge risk assessment for the western end of Galveston Bay, near the Houston Yacht Club at Shoreacres. Such assessments are helpful to validate the need for substantial adaptations in areas at high risk from extreme hazards. This analysis indicates that adaptations along this portion of coastline are worthwhile, as the 100-year storm surge in this location is 17 feet and the 50-year storm surge is 13 feet. Long-term losses in such locations will likely far outweigh the investment to adapt for large storm surges.

12. Houston Ship Channel

SCIPP provided historical storm surge data and analysis to the Centennial Gate Project initiated by the SSPEED Center at Rice University. These data are critical because they indicate that storm surge vulnerability at the Houston Ship Channel is higher than previously thought. Our data-driven analysis indicates that the 100-year storm surge level is 25 feet near the Houston Ship Channel and 18 feet near Galveston. These results are considerably higher than most modeling analyses. For example, a recent probabilistic model indicated an 18-foot surge near Galveston would be an 8,000-year event. Therefore, our work has shown that important industrial complexes in this region are more vulnerable to storm surge inundation than previously thought, and provide crucial data to improve infrastructure planning.

Key Publications

Mullens, E. D., M. Shafer, and J. Hocker, 2013: Trends in heavy precipitation in the southern USA. *Weather*, **68**, 311-316.

Needham, H.F., B.D. Keim, D. Sathiaraj, and M. Shafer, 2013: A global database of tropical storm surges. *EOS Transactions,* **94**, 213-214.

Key Non-OU Project Publications

Ford, T. W. and S. M. Quiring, 201: Comparison and application of multiple methods for the interpolation of soil moisture observations. *International Journal of Climatology,* **34**, 2604-2621.

Needham, H. F., and B. D. Keim, 2014: Correlating Storm Surge Heights with Tropical Cyclone Winds at and before Landfall. *Earth Interactions,* **18**, 26 pp.

Needham, H. F., and B. D. Keim, 2014: An Empirical Analysis on the Relationship between Tropical Cyclone Size and Storm Surge Heights along the U.S. Gulf Coast. *Earth Interactions,* **17**, 15 pp.

Other Publications involving OU Authors

Konrad, C. E. C. W. Fuhrmann, A. Billiot, B. D. Keim, M. C. Kruk, K. E. Kunkel, H. Needham, M. Shafer, and L. Stevens, 2013: "Climate of the Southeast USA: Past, Present, and Future." Chapter 2 in *Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability* (K. Ingram, K. Dow, L.Carter, and J. Anderson eds.), pp. 8-42. Island Press, Washington, D.C.

CIMMS Task III Project – Local Assessment of Drought Impacts and Climate Change Adaptation

Mark Shafer (OCS at OU) and Gregg Garfin (University of Arizona)

NOAA Technical Lead: David Brown (NOAA Regional Climate Services Director for the NWS Southern Region)

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

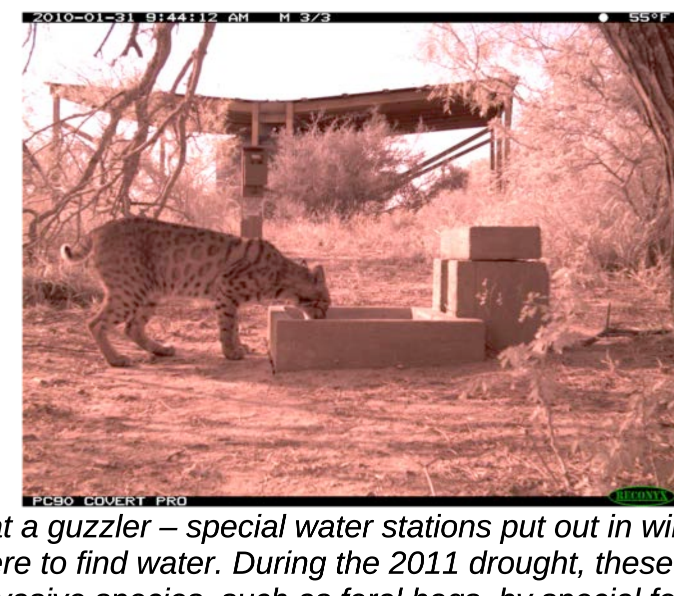
Funding Type: CIMMS Task III (NOAA/RISA)

Objectives

Document impacts and management strategies related to the ongoing (since 2011) drought in the Southern Plains by examining economic, ecological, and water management impacts and strategies. An additional element looks at impacts in the Rio Grande/Rio Bravo region and develops scenarios for drought from the short-term (ongoing) to the long-term (climate change scales).

Accomplishments

The project team concluded surveys of drought impacts on special ecological regions (particularly national wildlife refuges and other managed landscapes) and has developed an economic and social impacts survey that will be distributed to residents in Tillman County, Oklahoma. The project team developed a prospectus for a regional meeting on drought, including cross-border participation from several agencies in Mexico, with a workshop planned for 10-11 September 2014 in El Paso, Texas.



An ocelot drinks at a guzzler – special water stations put out in wildlife refuges to give wildlife somewhere to find water. During the 2011 drought, these guzzlers had to be protected from invasive species, such as feral hogs, by special fencing that would let protected wildlife such as ocelots reach the water while keeping others out. Photo by Mitch Sternberg, South Texas Wildlife Refuge Complex.

CIMMS Task III Project – Rio Grande/Bravo River Basin Climate Outlook

Mark Shafer (OCS at OU) and Gregg Garfin (University of Arizona)

NOAA Technical Lead: David Brown (NOAA Regional Climate Services Director for the NWS 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)

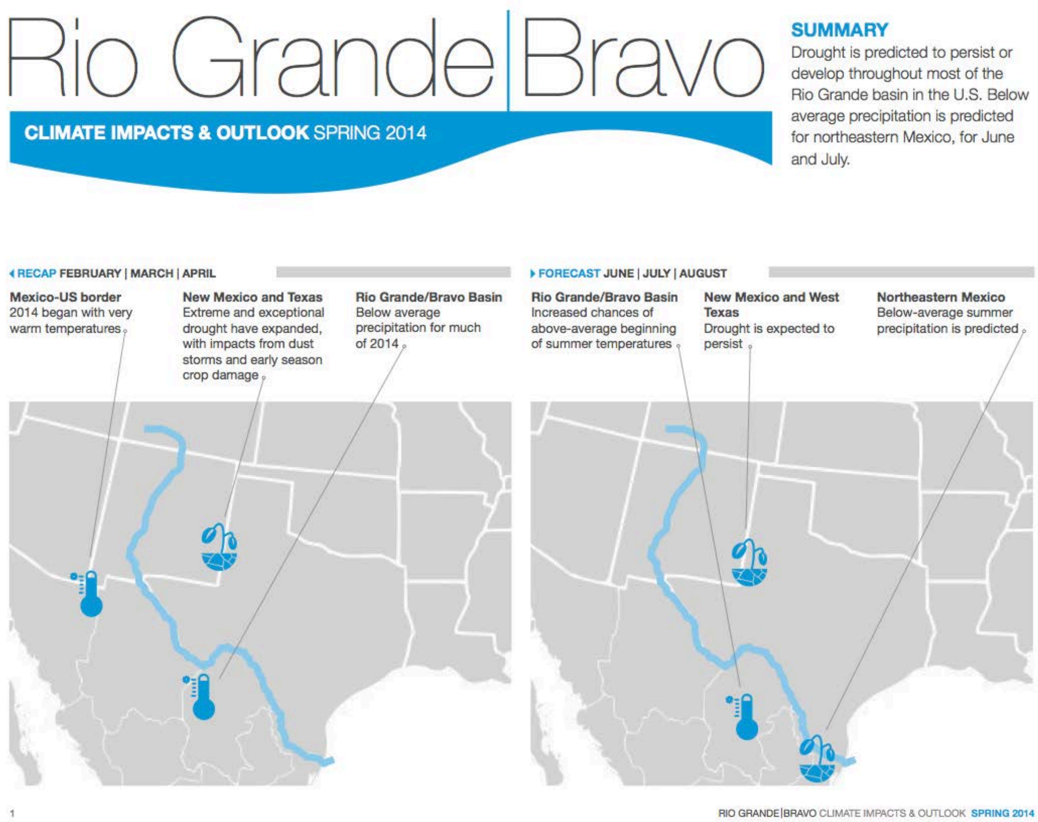
Objectives

The Rio Grande/Bravo River Basin (RGB) of the United States and México, is exposed to tornadoes, severe storms, hurricanes, winter storms, wildfire, and drought. The combination of these weather and climate-related hazards has resulted in impacts, such as wildfire, crop loss, water supply reduction, and flooding, with exceedingly high economic costs ($13 billion in 2011 alone). In order to contribute to increased binational preparedness, information flow, and knowledge exchange in the region, the project investigators propose the development of a prototype quarterly RGB Climate Outlook. The RGB Outlook will feature a synthesis of climate products, impact data and analysis, and will be expressed in user-friendly language. The RGB Outlook will be co-produced with colleagues from the U.S. and Mexico, in conjunction with the North American Climate Services Partnership. Using an online survey, the project team will perform an evaluation of the uses of the RGB Outlook, and will report basic use statistics and recommendations for improvement of the prototype.

Accomplishments

The project team designed and produced two issues of the Rio Grande | Bravo Climate Impacts and Outlook bulletin, produced in January and June 2014 and posted on the U.S. Drought Portal, http://www.drought.gov/drought/content/resources/reports. The bulletin is produced in English and translated into Spanish. A survey has been designed to solicit information on the utility of the information contained in the bulletin and preferences for layout and delivery mechanisms. The survey is currently being fielded. The bulletin and other climate information, tools and scenarios will be discussed at a workshop in El Paso, Texas on 10-11 September 2014, co-hosted by the International Boundary Water Commission.

The Rio-Grande – Rio Bravo river basin includes parts of 3 states in the United States and 4 states in Mexico.


Rio Grande|Bravo

CLIMATE IMPACTS & OUTLOOK SPRING 2014

SUMMARY
Drought is predicted to persist or develop throughout most of the Rio Grande basin in the U.S. Below average precipitation is predicted for northeastern Mexico, for June and July.

RECAP FEBRUARY | MARCH | APRIL

Mexico-US border
2014 began with very warm temperatures

New Mexico and Texas
Extreme and exceptional drought have expanded, with impacts from dust storms and early season crop damage

Rio Grande/Bravo Basin
Below average precipitation for much of 2014

FORECAST JUNE | JULY | AUGUST

Rio Grande/Bravo Basin
Increased chances of above-average beginning of summer temperatures

New Mexico and West Texas
Drought is expected to persist

Northeastern Mexico
Below-average summer precipitation is predicted

1

RIO GRANDE|BRAVO CLIMATE IMPACTS & OUTLOOK SPRING 2014

Cover page from the Spring 2014 issue of the Rio Grande | Bravo Climate Impacts & Outlook.

Public Affairs and Outreach

NOAA Communications, Public Affairs, and Outreach

NOAA Technical Leads: Lans Rothfusz (NSSL) and 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. NOAA and OAR Data Calls – Susan Cobb (CIMMS at NSSL)

- Reported on significant papers by alerting NOAA leadership to published papers determined to be significant by NSSL leadership. This involves working with the authors to write a summary of the significant paper. NSSL reported 10 significant papers in FY2014.
- Fact check total publication numbers against NOAA Headquarters for accuracy
- Managed, edited, and wrote “Overview of NOAA’s Collaborative Research on Tornadoes and Associated Severe Weather Events” in response to the FY13 Commerce-Justice-Science Appropriations Bill and FY14 Consolidate Appropriations Act
- Reported numbers for Quarterly Education performance taskers
- Wrote the paragraph on updraft helicity pathcasts as an NSSL accomplishment for the NOAA Blue Book
- Wrote major accomplishments and talking points for visiting NOAA leadership
- Compiled, edited, wrote the NOAA Hazardous Weather Testbed Annual Report
- Reviewed the DOC Gold Medal Nomination from NSSL

2. Legislative Affairs – Steve Koch and Lans Rothfusz (both NSSL), and Susan Cobb (CIMMS at NSSL)

- Each year the OAR Legislative Affairs team provides a template for fact sheets used to brief members of the U.S. Congress and their staffers. Work was done with NSSL management to revise this in preparation for their **NOAA Day on The Hill**.
- **NOAA In Your State** – Legislative Affairs maintains a spreadsheet of NOAA Activities in each state to use when briefing the U.S. Congress. This list is updated each year.
- Worked with legislative affairs to develop an annual Congressional Plan for NSSL

3. NOAA and OAR Communications – Susan Cobb (CIMMS at NSSL)

- **OAR Hot Items** describe new NSSL and CIMMS research and activities and are posted on the OAR Hot Items site. The OAR Communications team reviews the articles and chooses significant topics to be included in the Department of Commerce Secretary's Weekly Report. Working with NSSL researchers, 18 NSSL OAR Hot Items were authored in FY2014.
- **Department of Commerce Secretary's Weekly Report** – Significant OAR Hot Items are condensed into a few sentences to be included into the Department of Commerce Secretary's Weekly Report. In FY2014, **4** NSSL OAR Hot Items were included in the Weekly Report; coordination with Headquarters ensured the accuracy of these items.
- **OAR Editorial Board** – Susan Cobb serves on the OAR Editorial Board that meets each Monday to review the accuracy and clarity of items to be sent to the Executive Management Team and the Secretary of Commerce. We also discuss potential social media items.

4. NSSL Project Fact Sheets – Susan Cobb (CIMMS at NSSL)

- Fact Sheets are 2-4 page handouts on NSSL projects used to give visitors and guests a "take-away" message, designed, written, edited, and updated by Cobb. Eight such NSSL Fact Sheets were produced in FY2014.

5. Publicize NSSL Research and Projects through Social Media – Susan Cobb (CIMMS at NSSL)

- NSSL's Facebook and Twitter accounts are very popular. Almost every morning, Cobb "shares" weather stories from other NWS offices that are educational or interesting. She tweets and retweets as appropriate. NSSL also has Flickr and Instagram accounts. Cobb also maintains the CIMMS Facebook page.
- **Facebook "likes"** (other accounts include CIMMS, CI-FLOW, HWT, mPING, FACETs):
  - NSSL
    - 2014: 38248
    - 2013: 25782
    - 2012: 16,002

- **Twitter** (other accounts include FACETs and HWT)
  - NSSL
    - 2014 18,900
    - 2013 12,600
    - 2012 6189

6. NSSL Briefings Online – Susan Cobb (CIMMS at NSSL)

- All OAR Hot Items are posted on NSSL News, and online news blog. NSSL successes, significant publications, photos of the month and people stories are all posted here. In FY2014 there were 28 stories posted.

7. NSSL Outreach emails – Susan Cobb (CIMMS at NSSL)

- The public submits questions to NSSL via the NSSL Outreach email account. In FY2014, 97 emails were answered and two written letters.

8. NSSL Website – Vicki Farmer (ACE) and Susan Cobb (CIMMS at NSSL)

- Reviewed and updated NSSL website content as needed, including tracking and posting staff awards

9. Serve on NSSL Leadership Team – Steve Koch and Lans Rothfusz (NSSL) and Susan Cobb (CIMMS at NSSL)

- Managed content and designed the NSSL Strategic Plan, including management of outlines and content, attendance at weekly team meetings via phone, and provided writing assistance when needed

10. Back-Up NOAA Weather Partners Public Affairs – Keli Pirtle (NOAA Public Affairs) and Susan Cobb (CIMMS at NSSL)

- Fielded media calls and questions while the NOAA Public Affairs Officer is unavailable
- Fielded 70 media calls and interview requests during April 27-May 4 tornado outbreak including The Weather Channel, NY Times, CNN, Al Jazeera, Reuters, NPR, NBC, FOX, BBC, USA Today, ABC, China National News, and AP.

11. Preserve Historic NSSL Photos, Film, and Documents – Susan Cobb (CIMMS at NSSL)

- Successfully applied for and won a small National Film Preservation Foundation grant to preserve film from the Union City, OK tornado, which occurred on May 24, 1973

12. Other Education and Outreach – Susan Cobb (CIMMS at NSSL)

- Served on the Science Olympiad Committee
- Worked with Time For Kids on weather content

CIMMS Staff at WDTB Outreach

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

CIMMS staff at WDTB regularly engaged in various outreach activities during the past year. Some of the activities involved partnerships with other organizations in the National Weather Center. Some of these outreach activities included:

- Volunteering to work support “shifts” at the NWS Norman Weather Forecast Office (WFO) during severe weather events;
- Facilitating a short course for the OU School of Meteorology on using dual-polarization radar data in warning operations;
- Mentoring a Research Experience for Undergraduates student for their summer project;
- Volunteering in the planning and presentation of the National Weather Festival;
- Participating in Norman Public Schools Tornado Safety Plan Review team;
- Volunteering with other National Weather Center organizations during the Norman United Way Day of Caring.

Other outreach activities involving CIMMS staff at WDTB included:

- Visiting with elementary school students to talk about meteorology and
- Attending a Girl Scouts Western Oklahoma community event involving disaster preparedness and weather awareness.

CIMMS scientist participates in a site visit at Roosevelt Elementary School in Norman, OK to assess the school’s safety plans during a tornado.

Appendix A

AWARDS AND HONORS

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

- Presidential Early Career Award for Scientists and Engineers (PECASE): **Adam J. Clark (CIMMS at NSSL)**

- 2014 Dean's Award for Excellence in Research and Scholarship in the University of Oklahoma's College of Atmospheric and Geographic Sciences: **Adam J. Clark (CIMMS at NSSL)**

- Young Scientist Travel Award, International Symposium on Data Assimilation, Munich, Germany: **Corey Potvin (CIMMS at NSSL)**

- Nominated for the Presidential Early Career Award for Scientists and Engineers (PECASE) in July 2014: **Corey Potvin (CIMMS at NSSL)**

- 2011 OAR Outstanding Paper Award (Awarded in November 2013): **Matt Kumjian and Alexander Ryzhkov (both CIMMS at NSSL)** for "Storm-Relative Helicity Revealed from Polarimetric Radar Measurements". *Journal of the Atmospheric Sciences*, 66, 667-685.

- AGU Editor's Award (Geophysical Research Letters), January 2014: **Alexandre Fierro (CIMMS at NSSL)**

- National Weather Associate Annual Meeting, October 2013: Best Graduate Student Oral Presentation – Ben Herzog; Best Graduate Student Poster Presentation: **Race Clark (CIMMS at NSSL)**

- AGU Annual Meeting, December 2013: Outstanding Student Paper Award: **Sean Waugh (CIMMS at NSSL)**

- Significant Papers Award – NSSL Director, January 2014: **Kim Elmore, Zac Flamig, Valliappa Lakshmanan, Brian Kaney (all CIMMS at NSSL), Vicki Farmer (INDUS), Heather Reeves (CIMMS at NSSL), and Lans Rothfusz (NSSL)**, "mPING Crowd-Sourcing Weather Reports for Research". *Bulletin of the American Meteorological Society*, Early Online Release 2014. doi: 10.1175/BAMS-D-13-00014.

- Third place at the Institute of Industrial Engineers' South Central Regional Conference Technical Paper competition (collaboration with Dr. Chen Ling, February 2014): **Chris Karstens (CIMMS at NSSL)**

- College of Atmospheric and Geographic Sciences/National Weather Center Photo Contest, 2013: “Pure Oklahoma” – First and Second Place, **Steve Martinaitis (CIMMS at NSSL)**, Honorable Mention, **Brandon Sullivan (OU School of Meteorology)**; “World Travels” – First Place, **Bethany Hardzinski (OU School of Meteorology)**, Honorable Mention, **Steve Martinaitis (CIMMS at NSSL)**

Appendix B

PUBLICATION SUMMARY*

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2006-07	2007-08	2008-09	2009-10	2006-07	2007-08	2008-09	2009-10	2006-07	2007-08	2008-09	2009-10
Peer Reviewed	55	55	52	32	15	16	13	25	33	37	45	40

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2010-11	2011-12	2012-13	2013-14	2010-11	2011-12	2012-13	2013-14	2010-11	2011-12	2012-13	2013-14
Peer Reviewed	28	31	32	***57***	22	13	8	***9***	44	35	45	***44***

**Publication numbers are approximate.*

Appendix C

PERSONNEL SUMMARY – NOAA FUNDED RESEARCH ONLY

Category	Number	B.S.	M.S.	Ph.D.
Research Scientist	65	1	34	30
Visiting Scientist	4	1		3
Postdoctoral Fellow	6			6
Research Support Staff	13	6	7	
Administrative	2	2		
Total (>50% support)	**90**	**10**	**41**	**39**
Undergraduate Students	41			
Graduate Students	50	25	25	
Employees that receive <50% NOAA Funding (not including students)	**37**	**9**	**4**	**25**
Located at Lab	NWSTC-3, NSSL-100, ROC-7, SPC-4, WDTB-11, OUN-1			
Obtained NOAA employment within the last year	7			

Appendix D

COMPILATION OF CIMMS-RELATED PUBLICATION 2013-14

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.

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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.

Burgess, D., K. Ortega, G. Stumpf, G. Garfield, C. Karstens, T. Meyer, B. Smith, D. Speheger, J. LaDue, R. Smith, and T. Marshall, 2014: 20 May 2013 Moore, Oklahoma tornado: Damage survey and analysis. *Weather and Forecasting*, **29**, in press. doi:10.1175/WAF-D-14-00039.1

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.

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Clark, R. A., J. J. Gourley, Z. L. Flamig, Y. Hong, and E. Clark, 2014: CONUS-wide evaluation of National Weather Service flash flood guidance products, *Weather and Forecasting*, **29,** 377-392.

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.

Curtis, C. and S. Torres, 2014: Adaptive range oversampling to improve estimates of polarimetric variables on weather radars. *Journal of Atmospheric and Oceanic Technology*, **31**, 1853-1866.

Dresback, K. M., J. G. Fleming, B. O. Blanton, C. Kaiser, J. J. Gourley, E. M. Tromble, R. A. Luettich Jr., R. L. Kolar, Y. Hong, S. Van Cooten, H. J. Vergara, Z. L. Flamig, H. M. Lander, K. E. Kelleher, 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*, **71**, 78-94.

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Karimkashi, S., and G. Zhang, 2013: A dual-polarized series-fed microstrip antenna array with very high polarization purity for weather measurements. *IEEE Transactions on Antennas and Propagation*, **61**, 5315-5319.

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Appendix E

NOAA COMPETITIVE AWARD RECIPIENT REPORTS

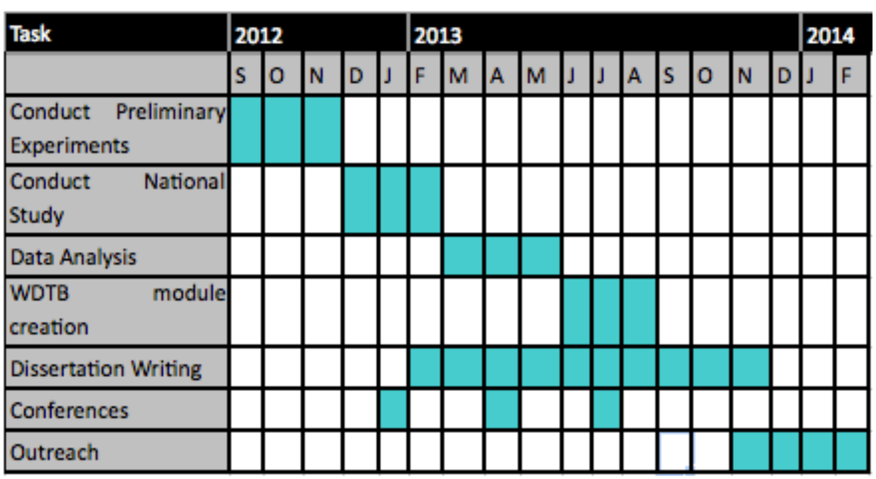
These reports are presented largely in the format provided by the PIs to relevant NOAA Program Managers and to CIMMS – In some cases only the summary is provided for space considerations.

SSWR Project: 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 – August 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.

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 that are backed up daily, as well as on the laptop and backup device of PI McPherson.

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)*** **–** As a result of sequestration and the defunding of one of their key courses by National Weather Service Headquarters, the Warning Decision Training Branch (WDTB) had staff reductions that forced them to narrow the scope of their activities. Although we had funding in this grant to cover a portion of one of their developers to work with Klockow on content for a learning module, WDTB was no longer able to collaborate on this project. That is, **as of March 17, 2014**, there was no developer available to work with us, even with the funding. **On March 18, Ms. Liz Quoetone, WDTB's lead instructor and our SSWR collaborator, lost her battle to cancer. At that time, we intended to close this grant and return the remaining funding. By May, however, NWS Headquarters changed its decision and we have added a new WDTB collaborator, Ms. Jami Boettcher. We submitted a no-cost extension to this grant and work on completing the uncompleted training module objectives.**

Objective 6 ***(completed February 2014)*** **–** Klockow has led the first-draft preparation of a manuscript that summarizes key findings from this work entitled "The Effects of Geospatial Risk Representations on Decision-Making for Tornado Hazards." The manuscript will be submitted to the Annals of the Association of American Geographers. 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 ***(partially completed)*** **–** The majority of the outreach for this grant was to be conducted through the Advanced Warning Operations Course (AWOC) Core Track that WDTB was to create in collaboration with us for Objective 6. Unfortunately, National Weather Service Headquarters defunded AWOC in early 2014 and we were unable to proceed as designed. In conversations with WDTB management **in early March 2014**, there were no other options, as social science was a component of only the AWOC Core Track, and their staff has been reduced significantly. **Following the bold notations in Objective 5 above, we submitted a no-cost extension to this grant and work on completing the uncompleted outreach objectives.** Klockow provided an overview of findings from her entire dissertation to the National Weather Center community in Norman at a departmental colloquium on August 23, 2013. Consistent with this grant but beyond the funded project period, Klockow presented this work in a variety of forums, including at NOAA Headquarters, the University of Ohio, and at a specialty group meeting of the American Association for the Advancement of

Science in Washington, D.C. in March 2014. She also highlighted key findings of this work on the WeatherBrains Internet radio show, with a national audience of over 10,000 weekly listeners, in April 2014. The portion of the funds that were dedicated to Objective 8 is unspent and will remain at NOAA.

SSWR Project: 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
Dr. Burrell E. Montz, Co-PI, East Carolina University
Jessica Losego, Co-PI, University of North Carolina
Rachel E. Riley, Co-PI, University of Oklahoma
Dr. James Correia, Jr., University of Oklahoma

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 (1 September 2013-28 February 2014)
Four iterations were undertaken during the reporting period:

Iteration #8 – June 2013-end of reporting period: Prototyping via EM interviews and surveys

- Attended Kansas EMA conference in September to talk with EMs about examples in our 4 main areas of prototyping that we've established during the project. See "4 Main Areas of Prototyping" section below for details.

- Prototyping continues through the development of surveys that will be administered to EMs.

Iteration #9 – October 2013-end of reporting period: Development of project page on Drupal (wxem.org)

- It is from this page that our surveys will be launched. Users will create a profile and be assigned a token that will allow their responses to stay anonymous and prevent them from having to fill out demographic information for each survey they complete.

Iteration #10 – January 2014-end of reporting period: Survey development (surveys to be administered in March/April)

- A series of short surveys are being developed to test hypotheses and prototypes established throughout the project. The first survey to EMs (to be administered in March/April) will be about one of the six critical elements to decision-making, confidence.

Iteration #11 – Summer 2013-end of reporting period: Tulsa Messaging Experiement

- Since summer, we have worked with Steve Piltz, NWS Tulsa MIC, to connect with emergency managers at various venues around the Tulsa area. The goal is to study how using a combined messaging system (with NWS and EM messages) would work. A visit to OK will occur in March to talk face-to-face with the venue EMs.

Presentations

- Montz, B.E., K. Galluppi, J.L. Losego, J. Correia Jr., R. Riley, Social and Behavioral Influences on Weather-Driven Decisions of Emergency Managers, National Weather Association 38th Annual Meeting, October 2013, Charleston, SC.
- Montz, B.E., K. Galluppi, J.L. Losego, J. Correia Jr., R.E. Riley, Social and Behavioral Influences on Weather-Driven Decisions: Prototypes for Severe Weather, Ninth Symposium on Policy and Socio-Economic Research, AMS 94th Annual Meeting, February 2014, Atlanta, GA.
- Mills, B., K. Galluppi, J. Demuth, Societal Aspects of Weather Forecast Information: Applications to Marine Weather, Environment Canada-NWS Marine Forecasting Workshop, February 13, 2014, Webinar.

Other

- Publication from related work funded by NWS accepted for publication: Montz, B.E., K.J. Galluppi, J.L. Losego, C. Smith, 2014: Winter Weather Decision-Making: North Carolina School Closings, 2010-11, *Meteorological Applications*, accepted.

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:

- All milestones for this task were completed during first reporting period

Task 2. Characterize the influences, when they occur, who or what causes them, and how they manifest themselves within the risk paradigm

Milestones:

- All milestones for this task were completed during the second reporting period

Task 3. Define a scale of relative importance and priority for assessment of influences on decisions

Milestones:

- All milestones for this task were completed during the second reporting period

Task 4. Demonstrate through prototyping, what changes to products and services can be made to incorporate positive influences on decisions

Milestones:

- Completed: Workshop to define prototypes prior to severe weather season – July 2013
    - o No formal workshop was held due to travel restrictions. Prototypes were not developed until after severe weather season so that all current practice information collected during interviews could be considered.
- Completed: Define second round of prototypes
- Completed: Completion of first round of prototype testing – August 2013 (OK EM conference)
- Ongoing: Completion of additional iterations of prototyping
- Ongoing: Complete analyses of prototyping
- Completed: Workshop to discuss results and make recommendations for year 2
    - o No workshop will be held due to travel restrictions, but ongoing discussion occurs at each project meeting (held every other week)
- Completed: Prepare abstracts for AMS and NWA conferences – August 2013

Task 5. Repeat process used for severe weather for a tropical weather use case to verify influences

Milestones:

- Ongoing: Prototyping addressing product and service changes – Fall 2013
    - o Did not formally undertake, as resources were concentrated on prototyping (and no tropical events occurred), however findings about social and behavioral influences are applicable to tropical weather events as well. For example, we're currently exploring confidence and its impact on decision-making. What we learn about confidence from the EMs will be applicable to tropical weather as well.
- Ongoing: Focus groups, interviews and surveys on prototypes – Fall 2013
    - o The first round of feedback was collected at the Kansas EMA Conference in September and is ongoing
- Completed: Workshop to define year 2 – Fall 2013
    - o No workshop was held due to travel restrictions, but ongoing discussion occurs at each project meeting (held every other week)
- Conduct real or simulated case studies – Spring 2014

<u>Four Main Areas of Prototyping</u>

The major focus of our activities is prototyping based on the decisions, influences, and actions of EMs we've established so far in the project. The purpose of prototyping is to learn the reasoning behind actions and words used by the NWS and EMs. We want to understand what correctly and efficiently conveys knowledge to EMs.

Four main areas for prototyping we focused on through the end of 2013 are listed here. Starting in January, we narrowed our focus to informal/formal cues given by forecasters, specifically forecaster confidence.

1. Informal and formal cues from NWS to EM: ways to express tone, confidence, and thinking, all of which have a major influence on EM decision-making.
    - What are these cues and what happens if we formalize them?
    - What do the informal cues convey in terms of meaning and confidence?
    - Examples:
        - o Tulsa "Chiclet" page and other ways to express elevating the event
        - o Words and phrases used on calls and NWSChat
        - o Words and phrase used on briefing slides or EM pages
        - o Test us of DEFCON 1-5 idea proposed by several EMs
2. Outlook – Watch-Warning Continuum
    - What is the critical timing of this information? What actions are they prompting?
    - We hear from EMs that more updates are needed throughout the continuum. What is missing?
    - EMs tell us they want to know what the forecasting is thinking. How can this be expressed?
    - Ways to convey consistent and clear information along the time continuum, graphics and text. Use of probabilities or words or are both really needed?
    - What do EMs do with this information? Reinterpret, or simply pass it along?

- Examples:
    - Ideas for what to do between watch and warning?
    - How to get information from NWS forecaster to EMs about what to be concerned about? NWSChat map to share with people in chat room?

3. Post-warning while event is in progress – alert of what's next, what to expect
    - What information is needed, time and location?
    - Want to know NWS "best guess" versus a box
    - How to convey what is needed to know
    - Examples:
        - FACETS grid example
        - Graphical tornado warning example from 2011 BAMS article
        - Pleasant Hill forecast office drawing
4. Messaging
    - Goal is clear, concise and consistent message from NWS to EM
    - Focus on packaging knowledge to be conveyed
    - Focus on modes (media), what attributes exist that modes can take advantage of?
    - Examples:
        - Text with mixed case and/or colors for emphasis
        - Simplified to basic information only
        - Eli Jacks winter weather wording changes

<u>Upcoming Activities (1 March 2014-30 August 2014)</u>

- Administer series of short surveys to EMs in the central, southern, and eastern U.S. to examine various hypotheses, ideas, and prototypes that have developed over the project
- Visit EMs at various venues around Tulsa to carry out messaging experiment.
- Attend EM conferences as needed to gather data from EMs

SSWR Project: 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 2014

Carol L. Silva, PI; Hank C. Jenkins-Smith, Co-PI; Paul Spicer, Co-PI; Peter J. Lamb, Co-PI (all 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.

The project timeline for the period reported (through March 2014):

Initiate 2014 Continuous Collection of Tweets with Weather and Severe Storm Related Key Words

- Twitter data collection continues. However, at this stage most of the focus is on validating and coding the Twitter data.

Presentations

- "The Evolution of Reception, Reliance, and Trust: Public Usage of Information from Social Media about Severe Weather" at the AMS annual meeting.
- "Perspectives on Severe Weather Communication: A Timeline of Products/Services and Decisions/Actions from the Moore Tornado" at the AMS annual meeting.
- "The Evolution of Twitter Messages Before, During, and After Hurricane/Post-Tropical Cyclone Sandy" at the Social Coast Forum.
- "Perspectives on the Oklahoma tornadoes of May 20, 2013" at the National Weather Center in Norman, OK.

Protocol Development

- Developed and validated a protocol for categorizing the users who publish tweets containing the word tornado.
- Developed and validated a protocol for categorizing the approximate location of users who publish tweets containing the word tornado.
- Developed and validated a protocol for categorizing the content of tweets containing the word tornado.
- Developed and validated a protocol for categorizing the photos included in tweets containing the word tornado.

Coding

- Hand coded a random sample of 5,000 tweets containing the word tornado that were published before, during, and after the Moore tornado using the user type, location, and content categorization protocol that we developed and validated.
- Hand coded a random sample of 5,000 pictures that were included in tweets containing the word tornado that were published before, during, and after the Moore tornado using the picture categorization protocol that we developed and validated.

Reporting

- Finalized the outline and analysis to begin writing the final report for this project.

RISA Project: Water Reservoir Data and Visualization Tools for the Southern Great Plains (NA12OAR4310126)

PIs: Mark Shafer (primary – OCS at OU), Kevin Robbins (LSU), and Margret Boone (OCS at OU)

Program Manager: Adam Parris (RISA Program, NOAA Climate Program Office)

Scientific Objectives and Accomplishments:

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 29 October 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 priorities 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 the first figure below. 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 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.

The Reservoir Tool displays reservoir location, historic water levels and an elevation vs. capacity curve for Lake Arrowhead, near Henrietta, Texas.

A dry boat dock at Canton Lake, Canton, Oklahoma.

RISA Project: Climate Training for Native American Tribes (NA13OAR4310208)

Performance Period: 1 September 2013-31 May 2014

Project Team Members: Rachel Riley (PI), Southern Climate Impacts Planning Program and University of Oklahoma; Mark Shafer (Co-PI), Southern Climate Impacts Planning Program and University of Oklahoma; Wayne Kellogg (Co-PI), Chickasaw Nation; Alek Krautmann, Southern Climate Impacts Planning Program and University of Oklahoma; April Taylor, Chickasaw Nation and South Central Climate Science Center

Program Management: RISA – NOAA Climate Program Office

Stakeholder Partners: Chickasaw Nation (April Taylor and Wayne Kellogg). Please note that the proposal for this project was written prior to April Taylor becoming employed by the Chickasaw Nation and SC-CSC. Wayne Kellogg is a project Co-PI, but once April was hired as their Sustainability Scientist she became the point person for the project at the Chickasaw Nation (this exchange was outlined in the proposal). April has played an integral role in planning the workshops. Her expertise on tribal communities in the area has been critical to our success in determining the workshop locations, people that would be suitable for hosting, potential participants, and material relevancy.

Drought/NIDIS Interaction: This project does not focus specifically on drought nor does it involve interaction with NIDIS, although drought will be one of many hazards covered in the workshop materials. Furthermore, drought will be covered as the special

topic on Day 2 at two of the four workshops (see the meeting agenda below).

Accomplishments: The project team has met on a monthly basis since September 2013 to begin planning the workshops. In the fall of 2013, a rough agenda was developed, existing climate science material was reviewed for its relevancy to the project, team members discussed the audience that would be targeted, and workshop locations were selected. In the spring of 2014, workshop dates were determined and logistical planning began with the local hosts, all of whom are tribal employees. Conference calls were held with these individuals in February to determine a locally relevant climate angle for the case study portion of the workshop and confirmed regional interest in the workshops. Work related to the vulnerability assessment portion of the workshop has also occurred;

RISA team program managers were contacted for insight and templates they have used. Further, "save the date" emails were sent to potential participants in Oklahoma and Texas.

Below is a summary of the workshop dates and locations as well as the agenda as it currently stands.

- August 14-15, 2014: Wyandotte, OK
- August 27-28, 2014: Fort Cobb, OK
- September 10-11, 2014: Durant, OK
- September 18-19, 2014: Stroud, OK

Workshop Draft Agenda:

Day 1 (time lengths as listed would run 9am-4:15pm, for example)

15 min *Welcome & Pre-Test*
30 min *Introduction to Climate* (difference between weather and climate)
60 min *The Basics of Climate*: global weather patterns, temperature and precipitation measures of climate, climate - normals and seasonality
15 min Break
60 min *Hazards and Hazard Climatology*
60 min Lunch
30 min *Past Climate Reconstruction, Proxies* (paleo, tree ring, and instrumental record)
60 min *Climate Variability and Change*: including carbon cycle, time scale of how long greenhouse gasses remain in the atmosphere
15 min Break
30 min *Discussion/Roundtable on Climate Change or NCA Tribal Chapter*
60 min *Tool and Data*: exercise and data resource examples, SCIPP tools, Mesonet, ASOS/COOP, CPC Products, Drought Monitor

Day 2 (time lengths as listed would run 9am-2:00pm, for example)

60 min *Special Topic/Case Study* about an extreme event that impacted an area tribe(s)

15 min Break
30 min *Introduce Vulnerability Assessment Concept*
45 min *Discussion about tribe's vulnerability to hazards and climate trends* (include actions to mitigate impact)
60 min Lunch
60 min *Vulnerability Assessment Exercise*
15 min *Post-Test*
15 min *Wrap-Up Discussion*
Adjourn

National Climate Assessment: We have included some time on Day 1 to discuss the 2014 NCA tribal chapter. In the final report for this project we will share how the information was received by workshop participants and any feedback they chose to provide.

Graphics: We do not have any compelling graphics at this time, and do not anticipate having any to share considering the nature of the project (a workshop).

CSTAR Project: A Partnership to Develop, Conduct, and Evaluate Realtime Advanced Data Assimilation and High-Resolution Ensemble and Deterministic Forecasts for Convective-scale Hazardous Weather: Towards the Goals of Weather Ready Nation (NA13NWS4680001)

Ming Xue (CAPS at OU and OU School of Meteorology), and Fanyou Kong, Keith Brewster, and Youngsun Jung (all CAPS at OU)

Objectives
The realtime data assimilation and forecasting performed under this NOAA CSTAR project, together with retrospective analyses using the real time data, aim to address the scientific issues including:

- The value and cost-benefit trade-offs of storm-scale versus coarser-resolution short-range ensembles and even-higher-resolution deterministic forecasts;
- The most suitable perturbation methods for storm-scale ensembles, among breeding, ETKF (ensemble Transform Kalman filter), EnKF, physics perturbations, stochastic physics, and multi-model ensemble;
- Proper handling and use of lateral and lower boundary perturbations;
- The value and impact of assimilating high-resolution data including those from WSR-88D radars;
- The value and impact of using more advanced EnKF data assimilation methods on short (0-12 hours) and intermediate range (12-60 hours) predictions;
- The predictability limits of existing convection within the current diurnal cycle, convection that develop under mesoscale forcing within the second and third day diurnal cycles, and convection whose evolution is affected by earlier convection;
- The performance and impact of more sophisticated double-moment microphysics schemes for severe weather and quantitative precipitation forecasting;

- The accuracy and impacts of planetary boundary layer (PBL) parameterization on the prediction of low-level storm environment and on the location and timing of convective initiation;
- The most useful ensemble forecast products for the storm scales;
- The most effective ensemble post-processing and calibration methods at the convective scale, and
- The impact of unique convective-scale forecast products on realtime forecasting and warning.

Accomplishments

The primary activity in this reporting period is the configuration, code development and test, and the production of a 24-member storm-scale ensemble forecast system (SSEF) for the 2014 Spring season between April and June for the NOAA HWT Spring Prediction Experiment, a 8-member sub-ensemble initiated at 12 UTC running 24-h forecasting, and an experimental EnKF-cycling-based ensemble over the full CONUS domain, experimental 3D/4D visualization of convection-allowing NWP storm forecast, and post-season analysis/verification of the SSEF dataset.

A major push in 2014 is that the experimental EnKF based forecasting is expanded to include a one hour EnKF cycling at 15 min interval from 2300 UTC to 0000 UTC following a 5-h 40-member ensemble forecast initiated at 1800 UTC, and over the same CONUS domain as other regular SSEF. In order to provide an ensemble background for EnKF, a separate 4-km ensemble of 5-h forecasts, starting at 1800 UTC, with 40 WRF-ARW members is produced over the CONUS domain. This ensemble is configured with initial perturbations and mixed physics options to provide input for EnKF analysis. Each member uses WSM6 microphysics with different parameter settings. No radar data is analyzed for this set of runs. All members also include random perturbations with recursive filtering of ~20 km horizontal correlations scales, with relatively small perturbations (0.5K for potential temperature and 5% for relative humidity). EnKF analysis (cycling), with radar data and other conventional data, is performed from 2300 to 0000 UTC every 15 min over the CONUS domain, using as background the 40-member ensemble. A 12-member ensemble forecast (24h) follows using the 0000 UTC EnKF analyses. In addition, two deterministic forecasts, one from the ensemble mean analysis and another from a similarly cycled 3DVAR analysis, are also produced.

ETSs of the probability matched mean (PM) 3-hourly accumulated precipitation for four different thresholds for the 24-hour forecast on 29 May 2014 are presented in Figure 1. Two sets of 12-member ensembles are shown, one from the final EnKF analysis at 0000 UTC (solid) and another from the regular HWT ensemble that is based on 3DVAR analysis (dashed). In general, the forecast started from the EnKF analysis (hereafter EnKF forecast) at 00 UTC shows higher ETSs than the one from the 3DVAR/cloud analysis (hereafter 3DVAR forecast) for higher thresholds such as 0.25" and 0.5".

New for 2014 CAPS endeavored to send a subset of the 3D forecast files from NICS in Tennessee to the HWT in the NWC for use in 3D and 4D visualization. The examination of the ensemble members in the HWT is normally done using pre-

determined variables on one, or just a couple, horizontal levels. The aim of use of complete 3D datasets is to allow more thorough assessment of the structure of storms and mesoscale features that may be severe weather threats. The WDSS-II-3D (Lakshmanan et al. 2007) and VaPOR (Clyne et. al, 2009) visualization programs were chosen as tools. Recent upgrades of networking hardware at the University of Tennessee and within Oklahoma, funded by NSF grants, were expected to help make the file transfers fast enough to deliver the files in time to be useful for forecast preparation in the HWT. Using the 3D visualization allowed study of features such as the 3D development of rotation within storms on some days, and the development and descent of the rear inflow jet was tracked to assess timing of severe weather threat on other days. However, forecaster time to use the 3D visualization program to thoroughly explore the data on top of other experimental forecast duties in the HWT was found to be a limiting factor. The 3D subsetted files transmitted in real-time have been saved and after-the-fact examination of some of the other cases is planned in preparation for greater use of these tools in future HWT forecast experiments.

Figure 2 is an example showing VaPOR visualization of a forecasted supercell storm from the CAPS SSEF ARW control member in Nebraska on 3 June 2014 valid at 2010 UTC. Figure 10 is another example of viewing a model storm in 3D using WDSS-II display software. (a) Plan view of simulated reflectivity on model level 19 valid 2320 UTC for the 00Z SSEF control member. The white box encloses the storm interrogated in 3D in panels (b) and (c). In (b), isosurfaces of vertical velocity > 21 m s-1 (light purple), vertical vorticity > 45 x 10-3 (red), and graupel mixing ratio > 4 g kg-1 (blue) are shown from a perspective from the southwest of the storm. The underlying color fill shows potential temperature (K) on the lowest model level. In (c), isosurfaces of the product of vertical velocity and vertical vorticity (m s-2) > 53 x 10-3 (orange) and simulated reflectivity > 54 dBZ (green) are shown from the same perspective as in (b). The underlying color fill in (c) is the wind speed on model level 3 (about 150 m AGL). The observed composite reflectivity valid at 2110 UTC from the NSSL multi-radar multi-sensor analysis is shown in (d).

CAPS met all deliverable requirements for the reporting period, including two progress reports (November 2013 and July 2014) to NOAA Grants Online website.

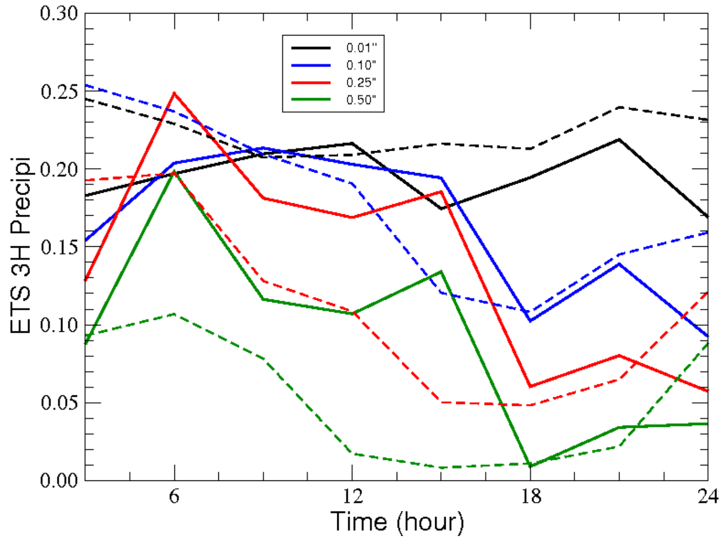


Figure 1. ETSs of probability matched mean 3-h accumulated precipitation >=0.01 (black), 0.10 (blue), 0.25 (red), and 0.5 inches (green) for the 12-member EnKF based forecasts started from the EnKF ensemble analysis (solid) and the regular 12-member HWT SSEF forecast started from 3DVAR analysis (dashed) at 0000 UTC on 29 May 2014.

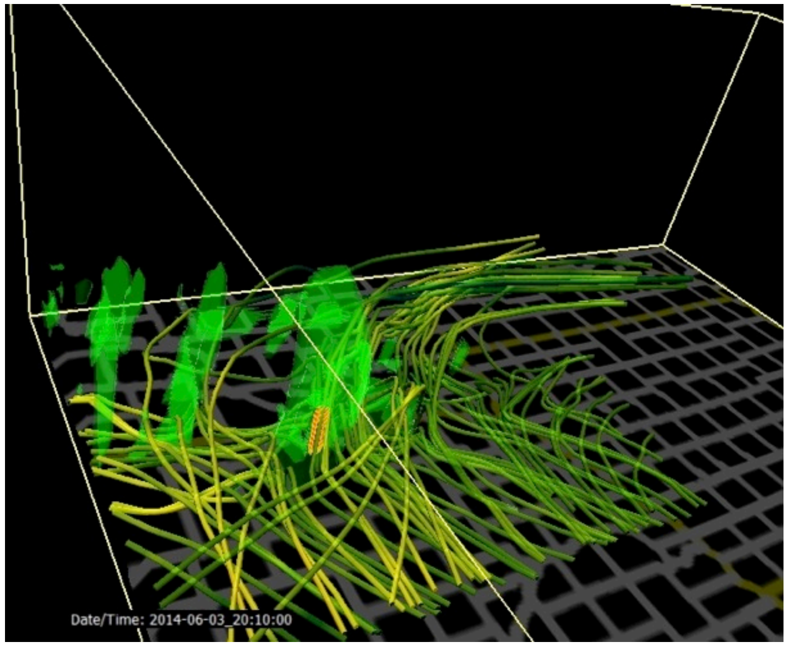


Figure 2. VaPOR visualization of forecasted supercell storm from the CAPS control run in Nebraska on 3 June 2014 at 2010 UTC showing 30 dBZ echo (isosurface), updraft helicity density (shading) and streamlines colored by streamwise vorticity (warm colors are higher streamwise vorticity).

SARP Project: Facilitating Adaptive Management Under Conditions of Rapid Drought Onset Using the GOES-Based Evaporative Stress Index (NA13OAR4310122)

PI: Jason Otkin – University of Wisconsin-Madison; Co-PI: Martha Anderson – USDA/ARS; Co-PI: Jeffrey Basara – University of Oklahoma; Co-I: Mark Shafer – University of Oklahoma; Co-I: Mark Svoboda – University of Nebraska; Co-I: Brian Wardlow – University of Nebraska

TIME PERIOD ADDRESSED BY REPORT: September 2013 – May 2014

I. PRELIMINARY MATERIALS

A. Research project objective

This project will seek to develop and evaluate an innovative drought early warning toolkit based on satellite-derived maps of evapotranspiration (ET) that will be used to support decision-making and risk characterization for the agricultural and natural resources communities. Recent examples of rapid drought intensification across the U.S. have clearly demonstrated the need for a reliable drought early warning system (DEWS) that would be capable of providing stakeholders additional time to prepare for worsening drought conditions. The study will use the Evaporative Stress Index (ESI) dataset generated with the Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance model using GOES thermal infrared imagery. Focus group studies will be convened in two National Integrated Drought Information System (NIDIS) pilot regions to examine how real-time access to the ESI-based drought toolkit could have assisted stakeholders during recent drought events. The end goal is to provide useful remote sensing tools that can be implemented globally to help mitigate crop losses and other drought-related damages – promoting resilience in a changing climate.

B. Stakeholder and decision maker involvement

- Individual farmers and ranchers
- Farm organization representatives
- Federal and state agency representatives
- County and university extension agents
- Natural resources experts and representatives

C. Approach

In this work, statistical and case study analyses will be used to quantitatively assess the ability of the Evaporative Stress Index (ESI) to accurately identify drought onset and development. The ESI is generated using evapotranspiration (ET) estimates from the Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance model using GOES thermal infrared imagery. The ESI represents standardized anomalies in the ratio of the actual-to-potential ET, and has been shown to agree well with standard

precipitation-based drought indices and with classifications in the U.S. Drought Monitor (USDM) archive. Because ALEXI computes ET using remotely sensed land surface temperature, which responds quickly to changes in soil moisture content, the ESI is often able to detect increasing water stress earlier than other drought metrics, sometimes by several weeks, thereby making it a potentially useful drought early warning tool.

A Rapid Change Index (RCI) product derived from rapid temporal changes in the ESI that is designed to identify areas experiencing rapid stress emergence will be refined though comparisons with various drought monitoring and observational datasets. Focus group studies will be convened to examine how real-time access to ESI and RCI products could have assisted stakeholders during recent drought events by facilitating adaptation to changing climate conditions. User feedback will promote improvements in the analysis and visualization tools developed during this project. The project will focus on the NIDIS Southern Plains and Missouri River Basin pilot regions; however, the analysis and visualization tools will be available for the entire contiguous U.S. and will be applicable to multiple end users. The end goal is to develop an innovative suite of drought early warning tools designed to inform the public about rapidly changing drought conditions over regional scales with high spatial resolution.

D. Matching funds

None.

E. Partners

The project team will work with the National Drought Mitigation Center and the USDM authors to examine the potential for integrating the ESI drought early warning toolkit into the operational USDM mapping process. Additional partners in academia, the private sector, federal agencies, and non-governmental organizations will provide input on the drought early warning toolkit through involvement in the focus group meetings.

II. ACCOMPLISHMENTS

A. Summary of accomplishments and findings

During the first nine months of the project, two studies were conducted to improve our understanding of flash drought events through an analysis of in situ observations and to examine the ability of rapid changes in the ESI to provide useful drought early warning signals. Materials are also being prepared for the two focus group meetings that will be held in August 2014. These accomplishments are described in greater detail below.

1) Drought early warning capabilities of the Rapid Change Index

We conducted a study that examined the potential utility of using rapid temporal changes in three drought indices that are sensitive to ET, precipitation, and soil moisture (e.g., the ESI, Standardized Precipitation Index, and soil moisture from the

North American Land Data Assimilation System, respectively) to provide early warning of an elevated risk for drought development over sub-seasonal time scales. RCI datasets were computed for each drought index, and then a simple statistical method was used to convert the RCI values into drought intensification probabilities depicting the likelihood that drought severity would worsen in subsequent weeks. Local and regional case study analyses revealed that elevated drought intensification probabilities often occur several weeks prior to changes in the USDM and in topsoil moisture and crop condition datasets compiled by the National Agricultural Statistics Service (NASS). The results indicate that tools used to identify areas experiencing rapid changes in drought indices may be useful components of future drought early warning systems.

Figure 1 shows the evolution of the drought intensification probabilities, drought indices, and meteorological conditions during a flash drought event across east central Oklahoma in 2011. Flash drought rapidly developed across the region during June, with the USDM drought analysis degrading by one category for three consecutive weeks before stabilizing at extreme drought severity only six weeks after the area was drought-free. The NASS topsoil moisture assessment also transitioned from normal conditions to a severe moisture deficit during this time period. Each of the RCI variables became negative by the second week of June, with elevated drought intensification probabilities occurring thereafter. For this event, rapid changes in the ESI provided the earliest sustained warning of an enhanced risk for drought development.

2) *High resolution analysis of flash drought development at the Marena Oklahoma In Situ Sensor Testbed (MOISST) during 2012*

To provide increased insight into how the physical relationships within the soil-vegetation-atmosphere continuum impact the development and intensity of flash drought development, in situ observations from the Marena Oklahoma In Situ Sensor Testbed (MOISST) were examined during the flash drought of 2012. The results demonstrated that below normal precipitation during May 2012 yielded rapid drying of the soil column as vegetation in the region extracted water from the soil to maintain overall health. Increased rain during June 2012 led to moistening of the topsoil, but observations from the in situ soil moisture sensors demonstrated that the soil column at deeper depths (e.g., 60 cm via the Marena Oklahoma Mesonet station) was not replenished. As such, when precipitation ceased in July and atmospheric demand increased, the soil rapidly dried due to increased evaporation and water extraction by the vegetation. As a result, once the moisture from the topsoil was removed (1) the entire column dried very rapidly, (2) the vegetation quickly reached the wilting point, and (3) the overall ecosystem collapsed by mid-August, which further accentuated the flash drought development. The results demonstrate that the soil and ecosystem played a critical role in flash drought development at the site. Current analyses are examining ESI values at the MOISST site and the in situ soil and vegetation observations to verify the performance of ESI in forecasting flash drought development.

3) Preparation for focus group meetings

In recent months, several telecons were held with members of the research group to discuss plans for the focus group meetings that are a key component of this project. These meetings will be held in Norman, Oklahoma and Lincoln, Nebraska during the second week of August and will be used to better understand how stakeholders could use the ESI and other drought products to mitigate their drought exposure and to prepare for an increased risk for drought development. Presentation slides and hands-on material are currently being prepared for each of these meetings.

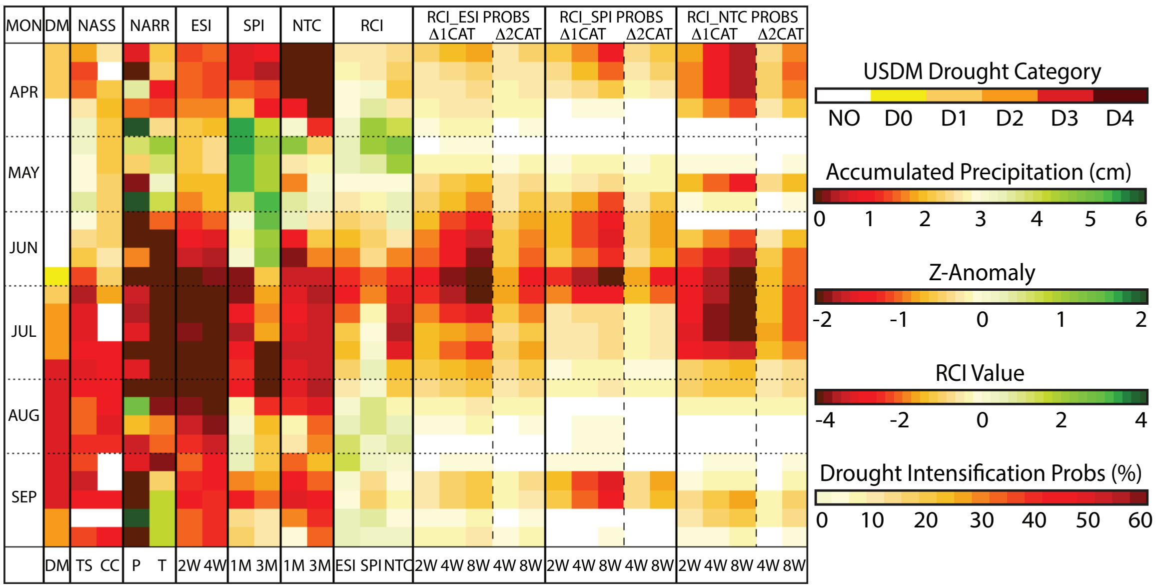


Fig 1. Drought evolution across east-central Oklahoma during 2011. The USDM drought category is shown in column 1, NASS topsoil and crop condition anomalies in columns 2 and 3, and 1-week rainfall (cm) and 2-week temperature anomalies (K) in columns 4 and 5. ESI anomalies for 2- and-4 week composite periods are shown in columns 6-7, with 4- and 8-week SPI and 2- and 4-week NTC anomalies shown in columns 8-9 and 10-11, respectively. RCI_ESI, RCI_SPI, and RCI_NTC values are shown in columns 12-14. 1-category USDM drought intensification probabilities for 2, 4, and 8-week periods, and 2-category probabilities for 4 and 8-week periods computed using RCI_ESI, RCI_SPI, and RCI_NTC data are shown in columns 15-19, 20-24, and 25-29, respectively.

B. Application of your findings to inform decision-making

Results from the first year of the project were shown in two presentations at the 2014 Annual Meeting of the American Meteorological Society (listed below). Additional information and results will be shared with decision makers during the second year of the project through involvement in the focus group meetings and through dissemination of the meeting results.

Otkin, J. A., M. C. Anderson, C. Hain, and M. Svoboda, 2014: Examining the relationship between

drought development and rapid changes in the thermal-based Evaporative Stress Index. *28th Conference on Hydrology*, Atlanta, GA.

Spade, D. M., W. R. Denito, J. B. Basara, and J. A. Otkin, 2014: New insight into the development of flash drought: A case study at the Marena Oklahoma In Situ Sensor Testbed. *28th Conference on Hydrology*, Atlanta, GA.

C. Planned methods to transfer information and lessons learned from this project

Information concerning the drought early warning capabilities of the ESI will be shared with members of the agricultural community via the focus group meetings and through a continued dialogue with the participants after the meetings. In addition, the ESI will be generated and delivered weekly to the USDM authors in a form enabling overlay of the USDM, facilitating real-time assessment and evaluation. The ESI will be exposed to the larger USDM list server group of ~350+ experts for their feedback concerning the accuracy and responsiveness of the indicator. Finally, we will work with the USDM authors to investigate the potential for the ESI to be part of a new suite of gridded objective blend products, particularly the short-term blend, as a means of helping the USDM detect and depict rapid onset drought events.

D. Significant deviations from proposed work plan

None.

E. Completed publications, white papers, or reports

Otkin, J. A., M. C. Anderson, C. Hain, and M. Svoboda, 2014: Examining the relationship between drought development and rapid changes in the Evaporative Stress Index. *Journal of Hydrometeorology*, **15**, 938-956.

III. WEBSITE ADDRESS FOR FURTHER INFORMATION

http://hrsl.arsusda.gov/drought/

NWS HFIP: Improving High-Resolution Tropical Cyclone Prediction Using a Unified GSI- based Hybrid Ensemble-Variational Data Assimilation System for HWRF (Closeout report for NA12NWS4680012)

Dr. Xuguang Wang, PI (OU School of Meteorology and CAPS at OU) and Ming Xue, Co-PI (OU School of Meteorology and CAPS at OU)

Reporting Period: 01/01/2012 - 03/31/2014

Figures referenced not included since they were previously transmitted to the Program Manager.

Objectives

Given the success of the GSI-based hybrid DA system for the Global Forecast System

(GFS, e.g., Wang et al. 2012) and the promises demonstrated by earlier studies in ensemble- based data assimilation for high resolution tropical cyclone (TC) forecasts (e.g., Zhang et al. 2009; Vukicevic 2010, Li et al. 2012), the primary objectives of the proposal are to (a) further extend the capability of the GSI-based hybrid DA system for HWRF and conduct extensive testing and tuning of the system for high resolution TC forecast; (b) investigate and document the ability of the unified GSI-based hybrid DA system in improving TC intensity and track forecasts on nested high resolution grids, as compared to the current operational capabilities based on the GSI DA system. The focus of the proposal was the extension, application and extensive testing of the GSI-based hybrid data assimilation (GHDA) for the HWRF modeling system at high resolutions. The following progresses were achieved during the project period.

Experiments and Results

Extensive data assimilation cycling and forecasts experiments were conducted for the newly developed hybrid DA system for HWRF for cases during 2008-2013 that were observed by the Tail Doppler Radars onboard of NOAA P3 aircrafts. Various verifications and diagnostics were conducted to evaluate and verify the experiment results. Two cases IRENE 2011 and Sandy 2012 were studied in depth together with the overall statistical evaluation of multiple cases. Detailed results are included in the quarterly reports. Below highlights some representative results.

3a. Hurricane Sandy 2012

Figure 1 shows the best track of Sandy 2012 and the flight tracks of the NOAA P3 aircraft. A total of seven P3 missions were fulfilled with the first mission started about 5 days before Sandy made landfall. Our data assimilation and forecast experiments were conducted during these P3 missions. A one-way coupled hybrid DA experiment (denoted as Hybrid) was conducted where a 40 member HWRF EnKF was run to provide flow-dependent ensemble covariance to the GSI. The lateral boundary ensembles were obtained from the GFS ensemble forecasts available from the global hybrid data assimilation system. The airborne tail Doppler radar (TDR) data were assimilated based on flight leg, with an approximately one-hour interval. After assimilating the 4 legs of TDR data, a ~48-hour forecast was launched. To study the impact of assimilating the TDR data, an experiment without assimilating the TDR data, denoted as “NoDA”, was conducted where the forecast was initialized from the GFS analysis. To compare the impact of using the ensemble covariance in assimilating TDR, an experiment using GSI 3DVar with a static covariance denoted as “GSI3DVar” was conducted. To study the impact of using high resolution HWRF ensemble relative to the use of coarse resolution GFS ensemble in HWRF hybrid DA system, additional experiments parallel to the control Hybrid experiment were conducted. In these experiments, the control Hybrid DA system was modified to ingest hourly GFS ensemble instead. These experiments are denoted as “Hybrid-GFSENS”. More details of these experiments and their naming convections are described below and summarized in Table 1.

Verification against HRD radar wind analysis

Both qualitative and quantitative verifications of the analyses from different data assimilation methods were conducted by verifying against the HRD radar wind analysis. Fig. 2 shows an example for Sandy 2012. Without assimilating the TDR data, the simulation showed a large location error. Using the static covariance in GSI3DVar, the location in the analyzed Sandy was largely corrected. However GSI3DVar showed spuriously strong and broad wind maxima. Using the GFS ensemble in the hybrid, the wind pattern in Hybrid-GFSENS looks a lot like the HRD wind composite, which therefore significantly improved upon GSI3DVar. Ingesting HWRF's own EnKF ensemble, the wind pattern in the control "Hybrid" experiment fits the HRD wind analysis the best.

Verification against SFMR wind

Independent observation such as the SFMR wind speed was used to verify the analyses and first guesses during the assimilation. Fig. 3 shows the results after assimilating 4 legs of TDR data. The first guess without assimilating the TDR data was much poorer as compared to the experiments assimilating the TDR data. For both the prior and the posterior, the Hybrid fit the SFMR observation much closer than the GSI 3DVar. While Hybrid-GFSENS improved upon GSI3DVar, it is still inferior to the hybrid ingesting HWRF's EnKF ensemble.

3b. Results for 2012-2013 cases

Systematic evaluations of all TDR cases during 2012-2013 seasons were also conducted.

Verification against HRD radar wind analysis

To perform quantitative evaluation on the analyzed TC vortex structure, we calculated the correlation between HRD radar wind composite and the analyses resultant from different data assimilation methods. To focus only on the spatial pattern in the analysis, these analyses were first relocated so that the TC centers were collocated with that in the HRD wind analysis. It is noted that the higher the correlation the better the TC structure depicted by the analyses. Fig. 4 shows that hybrid using GFS ensemble (Hybrid-GFSENS) produced better estimate of the TC structures than GSI3DVar, hybrid using HWRF's own EnKF ensemble (Hybrid) improved the structure analysis further compared to Hybrid-GFSENS.

Verification against SFMR and flight level wind

We also conduct verification of the analysis and the background forecast against independent SFMR wind and flight level observations for all cases. Consistently, as shown in Fig. 5, using GFS ensemble in the hybrid (Hybrid-GFSENS) significantly outperformed the GSI3DVar and hybrid using HWRF's own EnKF (Hybrid) fit these observations the better than Hybrid-GFSENS.

Track and Intensity forecast verifications

Fig. 6 shows the root mean square errors of track, MSLP, and max wind forecasts for all cases surveyed by TDR during 2012-2013 seasons for all data assimilation systems considered. Hybrid using HWRF's own EnKF ensemble and assimilating TDR (control Hybrid experiment) performs the best especially for track forecasts. Hybrid-GFSENS performed better than GSI3DVar. Hybrid (using HWRF ensemble instead of GFS ensemble) showed further improvement relative to Hybrid-GFSENS especially for track forecasts. Without assimilating the TDR data, the forecasts were significantly degraded, suggesting the benefits of assimilating the TDR data. The control Hybrid experiments also performed better than the operational HWRF forecast system.

3c. Results for dual resolution hybrid DA with moving nests

As part of the effort of using convection allowing 3km domain in the HWRF hybrid DA system, a two-way dual-resolution hybrid DA system is further established for HWRF. Different from a one-way hybrid system, in the two-way configuration, the EnKF analyses are re-centered around the control analysis from the hybrid. In the dual-resolution configuration, the control hybrid analysis and forecast were conducted at a higher resolution than the EnKF analyses and forecasts. In our experiments, the control hybrid analysis and forecast were at 3km resolution and the EnKF were run at 9km resolution. During the data assimilation cycling, the 3km domain is movable following the TC center. The description and naming conventions of the experiments are summarized in Table 2.

This dual-resolution two-way hybrid system has a few promising features. Running the EnKF at a reduced resolution compared to the control analysis can significantly save computational costs. Different from HWRF-GFSENS, in this system the HWRF EnKF ensemble was cycled through the data assimilation and therefore better represent the HWRF forecast errors. Compared to the hybrid DA system run at a single 9km resolution, this dual resolution hybrid DA system can benefit from the use of the high-resolution control analysis and forecast during the data assimilation and during the free forecasts. To test these hypotheses, we first conduct experiments using the two-way dual-resolution hybrid for IRENE 2011.

Fig. 7 shows the experiment domains and the 4 TDR missions for IRENE 2011. Hourly continuous data assimilation cycling was conducted for each TDR mission. The root mean square forecast errors for MSLP and track were calculated for all 4 missions and summarized in Fig. 8. It is found that the two-way dual-3/9km-resolution hybrid system improved both the track and MSLP forecasts as compared to the one-way single-9km-resolution hybrid system. Built on the work supported by this grant, a total of 35 cases during 2008-2011 were experimented, and series of specifically designed experiments were conducted to isolate the impact of the differences of the DA systems on the forecasts under a different support. In summary, the new dual-resolution two-way hybrid data assimilation system performed better than the baseline 9km single-resolution

hybrid DA system. It was also found (not shown) for Vmax and CSLP forecasts, such improvements were due to both (1) running the 3/9km moving nest during free forecasts and (2) dual-resolution analysis during the DA cycles. For track forecasts, such improvements are due mostly to running the 3/9km moving nest during free forecasts. In addition, we are currently diagnosing the experiments by categorizing the TCs based on their intensity. We are also developing a single-resolution two-way hybrid data assimilation with moving nest capabilities. The goal is to let 3km movable control analysis ingests 3km EnKF ensemble rather than the 9km ensemble. In order to achieve this goal, we have implemented a new method to direct the moving of the 3km nest. This new method allows all ensemble members of 3km nests move to the same location, making the single-resolution moving-nest hybrid DA straightforward. Experiments are being conducted with this new functionality.

Transition to Operations

The extended high resolution HWRF hybrid DA system developed and tested under the support of this award is based upon NCEP operational DA system GSI, operational HWRF model and observational data sets passed through and/or to be included to NCEP NCO. Lateral boundary conditions for our regional TC DA and forecasting are provided by the operational global hybrid DA. Therefore, the new data assimilation system and new capabilities established represent the fastest possible path to operations.

In fact, a few new developments have already been transitioned to operations. The development of the extended control variable component in GSI hybrid for HWRF is already transitioned to operational HWRF since 2013 hurricane season where the operational HWRF system uses this capability to ingest the GFS ensemble in real time, operational forecasts. The enhancement of the TDR assimilation described in 2a) is also already transitioned to operational HWRF since 2013 hurricane season.

All the developments under the support of this award are targeted for operational implementation in addition to its scientific findings. This new system is being tested in near real time (stream 2.0) during the 2014 hurricane season. Through collaboration with EMC, ESRL and HRD, we plan to transition the full systems including the EnKF component and the newly developed moving nests hybrid DA capabilites to operations after the real time runs during the 2014 season concludes.

Appendix F

NOAA SUPERSTORM SANDY COMPETITIVE AWARD RECIPIENT REPORTS

Figures and tables not included since they were previously submitted to NOAA

Project: Advancements in Weather Radar

Award Number: **NA13NWS4830030**
NOAA Sponsor: **Mike Istok**
NOAA Sponsoring Organization: **NWS Office of Science and Technology**
Reporting Period: **April 1 – June 30, 2014**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Accomplishments

1. HCA Improvement: Winter-Weather and Hail Size Discrimination

a. Development of the "background classifier" based on explicit microphysical modeling of the processes of melting and refreezing in cold season storms

The "background classifier" of winter surface precipitation based on explicit microphysical modeling of melting, ice nucleation, and freezing of atmospheric particles has been coded as an operational algorithm and its testing on a national scale using the output of the HRRR model begins. The output of the spectral (bin) model has been converted into vertical profiles of polarimetric radar variables using a forward observational radar operator by Ryzhkov et al. (2011). It is important that the model adequately reproduces the "refreezing" signature associated with transition from freezing rain to ice pellets near the surface. This signature is marked by a sharp increase of differential reflectivity Z_{DR} and specific differential phase K_{DP} at the level where massive refreezing of supercooled raindrops starts in the subfreezing surface layer beneath the melting layer aloft (Fig. 1). The model correctly reproduces the refreezing signature in the case of ice pellets (Fig. 2) and demonstrates its absence in the case of freezing rain (Fig. 3).

A functional description of the "background classification" algorithm is available upon request along with the "research" IDL and operational C++ versions of the code. A detailed description of the algorithm can also be found in the extended abstract submitted to the 8th European Conference on Radar Meteorology and Hydrology (Ryzhkov et al. 2014).

b. Develop a methodology to integrate the background classifier and "hybrid melting layer" algorithm into a new classification product "Surface Hydrometeor Classification Algorithm (SHCA)". Develop and test preliminary prototype SHC algorithm.

The principles of integration have been determined and a special report “Principles of integration and preliminary testing of the new Surface Hydrometeor Classification Algorithm” is available upon request (Schuur 2014). Two extended abstracts on the subject have been submitted to the 8th European Conference on Radar Meteorology and Hydrology (Schuur et al. 2014a,b).

The performance of the modified SHCA is illustrated for two cases of transitional winter weather in Figs. 4 – 6. One of the cases is a historic winter storm that occurred in the Northeastern U.S on 8 February 2013. Fig. 4 shows Z, Z_{DR}, and ρ_{hv} measured by the KOKX (New York City National Weather Service Office, located on Long Island at Upton, NY) WSR-88D radar at 1504 UTC on 8 February 2013. From an examination of the Z_{DR} and ρ_{hv} fields, it is clear that a widespread region layer of warm air to the north shore of Long Island (with a few pockets of radar-indicated ML extending over Long Island Sound) at this time. Precipitation type reports overlaid on top of the Z, Z_{DR}, ρ_{hv} and surface-based HCA fields at this time show good overall agreement, with rain over much of Long Island and snow to the north. An analysis of this same event at a later time by Schuur et al. (2014b) demonstrated that the transition region slowly progressed to the south over the next several hours, eventually resulting in snow and ice pellet observations over much of Long Island.

The classification output of the existing HCA currently implemented on WSR-88D at this time is shown in Fig. 5 (left panel) and compared with the modified surface based HCA results (right panel in Fig. 5). The NEXRAD HCA identified a melting layer (ML) for this event. However, since the algorithm then assumes that the ML detected in regions close to the radar can be geometrically projected outward along each azimuth, the resultant fuzzy-logic HCA (mapped to the conical surface) showed a broad “bull’s eye” of rain that was centered on the radar site and extended well into Connecticut to the north. It is clear that the surface HCA provides much better agreement with both the radar and mPING surface observations (Fig. 5, right panel).

Another transitional winter weather event over a major metropolitan area is illustrated in Fig. 6 which shows the fields of Z, Z_{DR}, ρ_{hv}, and results of classification from the KLWX (Washington, DC National Weather Service Office, located in Sterling, VA) WSR-88D radar at 1205 UTC on 13 February 2014. Again, SHCA exhibits quite good skills as the comparison with mPING data shows although further improvement is anticipated if the most recent version of the background classifier is implemented.

c. Modify and test the prototype of the Hail Size Discrimination Algorithm (HSDA) that distinguishes between small, large, and giant hail.

The initial prototype of HSDA has been modified based on the results of SHAVE validation. Several parameters of the membership functions have been changed and the procedures for taking into account anomalous differential attenuation and checking consistency of hail size designation with the height of the 50 dBZ echo have been formulated. A latest version of the functional description of the modified HSDA is available upon request.

The analysis of the SHAVE validation experiment for HSDA has been finalized. Fig. 7 shows probability density distributions of Z, Z_{DR}, and ρ_{hv} for small, large, and giant hail at different height levels above the ground obtained from about 1800 hail reports obtained during the SHAVE campaign. It is obvious that Z steadily increases with hail size, whereas Z_{DR} and ρ_{hv} decrease with

hail size. However, the value of Z_{DR} and ρ_{hv} diminishes at the heights approaching the freezing level. The radar reflectivity factor is a primary discriminator for hail size above the freezing level, although such additional signatures as bounded weak echo regions (BWER), Z_{DR} columns, and ρ_{hv} "holes" can also be very informative at higher levels.

An example of the HSDA product for the case of giant hail recorded on May 15 – 16, 2013 in the Fort Worth, TX area is shown in Fig. 8.

2. Improvements of Polarimetric QPE

a. Improve estimation of K_{DP} using the consistency with specific attenuation A.

Numerous investigations of the performance of the rainfall estimation algorithm based on K_{DP} indicate that the $R(K_{DP})$ relation performs better than $R(Z,Z_{DR})$ in moderate and heavy rain at C and X bands and in heavy rain at S band. Disadvantages of $R(K_{DP})$ include the noisiness of the K_{DP}-based rainfall estimate in lighter rain, degraded radial resolution, and vulnerability to the effects of nonuniform beam filling which result in negative values of K_{DP}. There is an apparent need to replace the corrupted values of K_{DP} (and $R(K_{DP})$) with something meaningful. We suggest replacing corrupted values of K_{DP} by the estimates of K_{DP} from specific attenuation A (K_{DP}' hereafter). The value of K_{DP}' can be obtained as a ratio A/α where $\alpha = A / K_{DP}$ after the factor α is optimized using the Z_{DR} slope.

A new technique for K_{DP} estimation was tested for a number of cases. As an example, we select the storm on 2013/05/22 which was observed by the KTYX WSR-88D radar. The composite PPI of Z, ρ_{hv}, K_{DP}, and K_{DP}' at elevation 0.5° is presented in Fig. 9 at the time 2138 UTC. The field of K_{DP}' is much smoother, has better radial resolution similar to the one of Z, and does not exhibit negative values as opposed to the field of K_{DP} which was processed in a routine way. The field of K_{DP}' is much more consistent with the reflectivity field than the original K_{DP} map.

b. Modification and integration of the R(A) methodology into existing DP QPE algorithm.

The R(A) methodology has been modified via optimization of the net ratio of specific attenuation and specific differential phase along the propagation path using the estimate of Z_{DR} slope. An automatic routine for robust estimation of the Z_{DR} slope has been developed and tested for several WSR-88D radars and large number of rain events which allowed to get an idea about the climatology of the Z_{DR} slope which

characterizes rain type (more continental vs more tropical). It was confirmed that on average the Z_{DR} slope is lower for the East Coast WSR-88D radars compared to the Great Plains radars as expected but within-the-storm variability greatly exceeds average climatological dependence.

Our study shows that the R(A) algorithm performs very well in terms of overall bias (R/G or radar / gauge ratio) with default value of the factor $\alpha = A/K_{DP}$ equal to 0.015 dB/deg in central part of the continent but tends to underestimate rain in the eastern part where rain regime is more tropical. Using adaptive factor α obtained from the Z_{DR} slope dZ_{DR}/dZ in rain dramatically improves the performance in the eastern US. Table 1 summarizes the results of the R(A) performance for nine notable flash flood events in the US using fixed and adaptable parameter α (number of R/G in parenthesis).

c. Validate the results of correcting rainfall estimated in the presence of bright band contamination.

We continue exploring different techniques for rainfall estimation in the presence of bright band contamination. A typical situation with bright band contamination is illustrated in Fig. 10, where the area affected by bright band is recognized by the depression of the cross-correlation coefficient ρ_{hv} below 0.95 (pink area in the middle panel of Fig. 10). It is well known that the radar-retrieved rain rate is grossly overestimated under the melting layer if a standard R(Z) relation is utilized across the whole area of radar coverage (left panel) and certain reduction of artificially enhanced rain rate is needed under the melting layer (right panel in Fig. 10).

Utilization of the R(Z) relation with the "fudge factor " 0.2 in the area of bright band contamination (i.e., R = 0.2 R(Z)) yields the best correspondence with gauges in the area for a cold season event with low bright band observed with the KICT WSR-88D radar on 12/19/2011 (Fig. 11). The "fudge factor" in the existing WSR-88D QPE algorithm is 0.6 and this example indicates the need for dynamically updated fudge factor that requires further scrutiny.

References

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*, **52**, 2549-2566.

Project: Implementation of Multi-Radar Multi-Sensor (MRMS) Software into National Weather Service Operations at the National Centers for Environmental Prediction

Award Number: **NA13OAR4830236**
NOAA Sponsor: **Mark Miller**
NOAA Sponsoring Organization: **National Weather Service Office of Science and Technology NextGen Program**
Reporting Period: **April 1 – June 30, 2014**

Related NOAA Strategic Goal: **Weather-Ready Nation**

Accomplishments

The Multi-Radar Multi-Sensor (MRMS) system is in the final stages of implementation into operations at the National Centers for Environmental Prediction (NCEP) Central Operations (NCO) as part of the Integrated Dissemination Program (IDP). Several important milestones were achieved during this quarter. These milestones are summarized in this report along with other aspects of the project.

1. MRMS input data was tested and finalized

The following input data sets are required for MRMS initial operating capability (IOC): Level II NEXRAD data; Canadian radar data; Rapid Refresh (RAP) model data; Hydrometeorological Automated Data System (HADS) precipitation gauges; GOES East and West satellite imagery; National Weather Service watches and warnings; and lightning data.

All of the listed feeds required testing and validation. Custom scripts were developed to address the unique configuration for the RAP, HADS and satellite data feeds at NCO. The acquisition and decoding of lightning data proved difficult due to changes made by the provider (Vaisala). In the end, it was decided that NSSL would temporarily provide lightning data to NCO until an official solution was in place. Note the requirement for Terminal Doppler Weather Radar (TDWR) data was removed due to the delay in acquiring the appropriate feeds.

2. MRMS development ("DEV") system implementation and code drop

In mid-April a set of virtual machines (VMs) were created by NCO staff for the installation, configuration and testing of a DEV system by CIMMS staff. In total, 47 VMs were built based on MRMS requirements provided to NCO. The resulting system demonstrated MRMS processing and system configuration from raw input to final products in GRIB2 format. While this system continues to be updated as needed with algorithm enhancements, configuration changes and bug fixes, the initial setup was completed in mid-May. At that time the first full code drop was provided to NCO along with configuration files for the entire DEV system.

3. MRMS operational ("OPS") system was implementation

A second MRMS system was created for OPS after the DEV system proved stable. It is NCO's policy to create a DEV system for staging and testing (accessible to NCO and the development group staff) and an OPS system (only accessible to NCO). The OPS system is updated to include only changes successfully tested on the DEV system.

The OPS system was created from scratch since automated duplication of the DEV system was not permitted. CIMMS staff provided support to NCO for the creation of the OPS system via conference calls, email, documentation created in Google Drive, and an on-site visit.

4. On-site visit to NCO

In mid-June, CIMMS staff visited NCO in College Park, MD. For three days, CIMMS staff participated in several planning and review meetings and assisted NCO staff in configuring the MRMS OPS system, which doubled as hands-on training for MRMS system management. At the end of the three days, the OPS system was 95% configured and CIMMS staff received good productive feedback on the MRMS onboarding documentation.

5. Initial version of MRMS "onboarding" documentation completed

At the end of May an initial version of the MRMS onboarding documentation was completed and provided to NCO. It should be noted that NCO staff had access to the working drafts of these documents beforehand and have access to revisions made since May.

The following is a listing and brief summary of all the documents provided to NCO:

- Software Design -- Detailed definition of the MRMS data flow and processing modules
- Build Instructions -- Steps for compiling the various software components of MRMS
- Implementation Instructions -- Steps for installing and configuring MRMS on a server or virtual machine
- Execution Instructions -- Steps for starting, stopping and generally managing MRMS processes on a server or virtual machine.
- Testing and Troubleshooting -- Instructions for testing all the individual components of MRMS along with suggestions for troubleshooting common problems.
- Stress Test Instructions -- Detailed instructions for stressing the MRMS system to determine if enough computing resources have been allocated.

In total, the MRMS onboarding documentation consists of approximately 200 pages and 3 companion spreadsheets. A copy of the documentation can be made available if requested.

Weekly MRMS status meetings began with NCO in mid-March and have continued throughout the onboarding process. These meetings are used to review the project management schedule, track progress, and identify problems. These meetings are attended by NCO's deputy director, several NCO group managers, the acting NWS Program Management Branch Chief, the MRMS project manager, NSSL management, and technical staff from both NCO and MRMS/NSSL.

Use of the National Weather Service's "Virtual Lab" (VLab) continues to grow. It will be the central location for submitting and tracking issues related to product performance.

Both NSSL and NCO will move their MRMS code repositories to VLab. A timetable has not been set. CIMMS staff continues to attend monthly VLab Focal Point conference calls, which are meant to engage major users of VLab, demonstrate new services and best practices, and provide a method for general community feedback.

The previous report mentioned that NSSL was in the process of procuring additional Dell Blades and VMware licenses to begin the setup of a new local system meant to mimic the infrastructure at NCO. The idea being that identical hardware and software will help facilitate more rapid research to operations. The procurement is now complete. The hardware is currently being installed and configured in NSSL machine room for initial testing.

In addition to these activities, CIMMS staff worked on the following improvements of the MRMS software:

- MRMS vertical reflectivity profiles have been matched to high-resolution hail reports from the Severe Hazards Analysis and Verification Experiment. These profiles are being combined with near-storm environment data, like the melting layer height for example, to refine hail size estimates for the MRMS system.
- Work on source code for reading native WDSSII (MRMS) products directly for including within future AWIPS2 visual or data plugins.
- Developing/evaluating cases and writing AWIPS-2 configuration code for the MRMS Software Best Practices Experiment. The experiment itself ran from April 7-18.
- Attending and provided support during the MRMS SBPE 2 week period.
- MRMS ingest and display capabilities for the PHI (FACETs) experiment, which ran alongside the EWP experiment in both May and June.

Project: Develop Improved Predictions of Inland Flooding

Award Number: **NA14OAR4830100**
NOAA Sponsor: **John Cortinas**
NOAA Sponsoring Organization: **OAR Office of Air and Water Quality**
Reporting Period: **April 1-June 30, 2014**
Related NOAA Strategic Goals: **Weather Ready Nation**

Objectives

Guide the development of a new distributed hydrologic modeling framework and deliver a state-of-the-science flood prediction system for operational use by the US National Weather Service.

Accomplishments

During this quarter, we have hired a post-doctoral level researcher and two new graduate students to work on this project. Since at its beginning stage, our efforts have been mainly focusing on the following tasks (1) forcing data preparation/quality control, (2) the model framework development, (3) initial field experiment during this summer

flood season, and (4) early work on coupling of hydrological and landslide models. Accomplishments of the four tasks are detailed as below:

(1) A total of 14 out of 15 years of Multi-Radar Multi-Sensor precipitation estimates has been reanalyzed from the NEXRAD archive. After the final year is completed, efforts will focus on quality control of this dataset before the hydrologic and landslide models are run for the reanalysis period. Quantitative precipitation forecasts from the High Resolution Rapid Refresh (HRRR) model, which is being transitioned to operations at the National Center for Environment Prediction, are now being used to force the Flooded Locations and Simulated Hydrographs (FLASH) distributed hydrologic model in real-time.

(2) Progress has been made in the development of the EF5 modeling system through the estimation of a-priori parameters for the kinematic wave-based routing scheme. These routing parameters have led to improved timing of peakflow simulation on a test sample of 12 basins. If the parameter estimates lead to improved prediction on a much larger sample of basins, then the new estimates will be transitioned from the research code set to the operational version of code.

(3) In preparation for the inaugural HWT-hydro experiment, all initial products that have resulted from the Inland Flooding project have been formatted so that they are all displayable in AWIPS2 in real time. This task also includes the development of menus and color tables, which are still being refined through forecaster feedback in HWT-hydro. The team has also developed documentation for each product following the protocols for uploading materials on the NWS Vlab website.

(4) Early work has been completed to couple the soil states from the CREST model (one of the model cores in FLASH) to the SLIDE landslide prediction model. A case study in North Carolina has indicated good capabilities in simulating the landslides, but the coupled system is computationally expensive and the results appear insensitive to the coupling vs. using the SLIDE system alone. More research is required in the mechanics of the model coupling.

Project: Develop and Deliver a MRMS Course for WFO and CWSU Forecasters

Award Number: **NA14NWS4830006**
NOAA Sponsor: ***Mark Miller***
NOAA Sponsoring Organization: **NWS Office of Science and Technology (OST), NextGen Program**
Reporting Period: **April 1-June 30, 2014**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Objectives
Increase forecaster situational awareness of short-fused hazardous weather events for three service sectors including public severe weather warnings, aviation forecasts, and flash flood warnings; help the National Weather Service (NWS) achieve Government Performance Requirements Act (GPRA) Goals 1-5.

Accomplishments
As stipulated in the Statement of Work for this project, the WDTB will create four tracks of Multi-Radar/Multi-Sensor (MRMS) training content to prepare forecasters to use MRMS products in an operational environment. These tracks include: an introduction to the MRMS system and its products, a Severe Track, an Aviation Track, and a Hydro Track. While some MRMS products overlap between tracks, many of the products are track-specific.

The first of these tracks, the introduction, has been the main focus of work during this reporting period. MRMS product technical documentation has been provided by subject matter experts from NSSL. For each product, the documentation generally contains information about:

- the purpose of the product
- its resolution
- the methodology used to create it
- its inputs
- its applications
- potential user groups
- known limitations
- references

This documentation has been the basis of the WDTB's MRMS Product Job Aids, or reference guides, which are meant to consolidate and adapt the technical information into a form that is suitable for forecasters. This includes, but is not limited to, adding information about the product strengths, providing example images of products, creating short descriptions for quick and easy reference, and creating longer descriptions for a more thorough understanding. The content for the severe Job Aids was drafted during this reporting period and CIMMS personnel have been and will continue drafting the hydro and data quality product descriptions. Once all Job Aids are completed and formatted, they will become available on the WDTB's website. The web template for presenting the Job Aid is also being developed by CIMMS personnel (in conjunction with WDTB instructors).

For two separate weeks in April, CIMMS personnel helped conduct the MRMS-Severe Best Practices Experiment in the Hazardous Weather Testbed. Each week, four NWS forecasters worked with MRMS products in an operationally representative warning environment to better understand the utility of the products and provide feedback to researchers. This experiment was a vital link in the Research-to-Operations/Operations-to-Research (R2O/O2R) process for MRMS severe products. Results from this

experiment have helped guide the Severe Track module content creation and will be presented at the 2014 National Weather Association Annual Meeting (CIMMS personnel are co-author).

In May, CIMMS personnel accompanied WDTB staff to the NWS Forecast Office in Fort Worth, TX to observe the use of MRMS products during warning operations. They documented warning methodology and best practices related to the MRMS severe products suite that was available. This information provided valuable insight on how to best deliver content that is pertinent to forecasters using MRMS severe products. On that trip, they also visited the West Gulf River Forecast Center and discussed the utility and best practices of the National Mosaic & Multi-Sensor QPE (NMQ)/Quantitative Precipitation Estimation (Q3) products within their office. A blog about this trip is available on the NOAA Virtual Lab in the MRMS Community.

Future CIMMS work related to this project includes: finalizing all MRMS Job Aids for dissemination on the WDTB website, continuing to develop content for the four MRMS tracks, working with NSSL to ingest all MRMS IOC products into the AWIPS II real-time system, creating cases in AWIPS II to use in training, and developing Weather Event Simulator 2 (WES2)-bridge simulations for interactive training reinforcement.

Project: Warning Decision Making and Training

Award Number: **NA13OAR4830230**
NOAA Sponsor: **Mark A. Tew**
NOAA Sponsoring Organization: **Marine and Coastal Weather Services Branch**
Reporting Period: **April-June 2014**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Objectives

Improve understanding of warning related issues for Tropical Cyclone Tornadoes, helping the NWS achieve GPRA Goals 1-5.

Accomplishments

A National Weather Service (NWS) service assessment on Hurricane Sandy provided a series of findings and recommendations related to NWS performance and training needs regarding NWS tropical cyclone operations. A team of researchers, forecasters, and instructors gathered at the National Hurricane Center (NHC) in June 2013 to create a Tropical Forecast and Warning Professional Development Series (PDS). CIMMS staff participated in that initial meeting and are involved with the current development of this PDS. The framework of this PDS focuses on the skills and expertise NWS personnel should have by combining both scientific and technical understanding with professional skills and techniques for a variety of job responsibilities and competencies. The development of the Tropical Forecast Warning PDS and previous NWS service assessment finding aided in the identification of NWS training gaps and performance needs for tropical cyclone operations.

One of the training needs identified focused on warning operations for tornadic convection during tropical cyclone events.

CIMMS scientists in collaboration with WDTB instructors and subject matter experts completed development of a Tropical Cyclone Tornadoes Course. This course consists of four online modules, an optional case study, and a Weather Event Simulator (WES) application designed to illustrate the learning objectives provided in the online modules. Topics covered in the online course modules include the following:

- Environmental threat assessment for regions of favorable tornadic development,
- Radar interrogation guidance regarding convective tornadic potential aimed to preserve a high probability of detection (POD) while reducing tornado warning false alarm rates (FAR),
- Warning decision making and storm-based warning principles related to tropical cyclone tornadoes
- Effective communication of the tornadic threat with tropical cyclones

The WES application that follows the online components of the course allows NWS forecasters to apply the learning objectives into performance elements regarding radar interrogation, warning decision making, and storm-based warning strategies. The WES application utilizes a displaced real-time complex convective and warning situation during Tropical Storm Andrea from 2013. Simulation material includes feedback on convective tornadic potential, various warning strategies, and effective communication in conveying the tornadic threat. Development of an optional case review was also completed. This optional case review allows NWS forecasters to practice applying environmental threat assessment learning objectives using Tropical Storm Debby from 2012.

During the past couple of months CIMMS scientists have tracked course progress of NWS personnel and awarded course certificates of completion to those that have completed the course.

Future work that CIMMS scientists plan to address is the continued monitoring and tracking of course progress as well as the presentation of course certificates to those that complete the course.

Project: Improving High-Resolution Tropical Cyclone Prediction Using a Unified GSI-based Hybrid Ensemble-Variational Data Assimilation System for HWRF

Award Number: **NA14NWS4830008**
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Objectives
The overall goal of the project is to continue the research and development of the GSI based hybrid ensemble-variational data assimilation system for HWRF with a focus on the high- resolution inner domains at the 9km and 3km resolutions. The specific accomplishments during this report period are documented below.

Accomplishments

Further experiments and studies of two-way dual-resolution hybrid data assimilation system with moving nests

During last report period, as part of the effort of using convection allowing 3km domain in the HWRF hybrid DA system, a two-way dual-resolution hybrid DA system was established for HWRF. As shown in Fig. 1, different from a one-way hybrid system, in the two-way configuration, the EnKF analyses are re-centered around the control analysis from the hybrid. In the dual-resolution configuration, the control hybrid analysis and forecast were conducted at a higher resolution than the EnKF analyses and forecasts. In our experiments, the control hybrid analysis and forecast were at 3km resolution and the EnKF were run at 9km resolution. During the data assimilation cycling, the 3km domain is movable following the TC center. During the free forecast, movable 3km nests inside 9km domain were run. This dual-resolution two-way hybrid system has a few promising features. Running the EnKF at a reduced resolution compared to the control analysis can significantly save computational costs. Different from the operational HWRF hybrid which ingests low resolution GFS ensemble, in this system the HWRF EnKF ensemble was cycled through the data assimilation and therefore better represent the HWRF forecast errors. Compared to the hybrid DA system run at a single 9km resolution (the baseline single resolution experiment as shown in Fig. 1a. In this experiment, all components involved were run at 9km resolution), this dual resolution hybrid DA system can benefit from the use of the high-resolution control analysis and forecast during the data assimilation and during the free forecasts. To test these hypotheses, during the last report period, we conduct experiments using the two-way dual-resolution hybrid for IRENE 2011 assimilating observations from tail Doppler radar (TDR) onboard the NOAA P3 aircraft.

During this report period, extensive experiments were conducted with the two-way dual-resolution hybrid DA system for hurricanes during 2008-2011 seasons. Data assimilation and forecast experiments were carried out only when TDR observations were available. For the cases selected, the maximum winds in NHC best track were at or stronger than category 1 during the data assimilation (DA) cycles, and were at or stronger than tropical storm category during the free forecast.

Table 1 lists a total of 35 such cases. The geographical distribution of the observed positions for these cases, as obtained from the National Hurricane Center’s (NHC’s) hurricane database (HURDAT), also known as the “best track database,” is shown in Fig. 1.

In addition to extending the experiments to more cases, five experiments were also

designed to understand the impact of using the two-way dual-resolution (3km and 9km) hybrid as compared to the baseline 9km single resolution hybrid DA experiments. Table 2 lists these experiments including the description, motivation and naming conventions. These experiments were designed to address the following questions by isolating the differences between the two- way dual-resolution hybrid and the baseline 9km single-resolution hybrid:

- What is the impact of just running a free forecast at 3km as compared to a free forecast at 9km both initialized from the same 9km hybrid analysis?
- What is the value of including a 3km resolution control analysis and forecast during the data assimilation cycles?
- What is the impact of recentering the 9km EnKF ensemble around the 3/9km control analysis, i.e., what is the difference between a two-way dual-resolution hybrid and a one- way dual-resolution hybrid DA?
- What is the impact of the ensemble from two-way dual-resolution hybrid?

In other words, would replacing the ensemble in the 9km single resolution hybrid with the ensemble from two-way dual-resolution hybrid improve the forecast? Fig. 3-7 show the RMSEs and biases of maximum wind (Vmax), central sea level pressure (CSLP) and track forecasts. These results are based on 35 cases during 2008-2011 seasons listed in Table 1. For the RMSEs of Vmax forecasts (Fig. 3), dualHYB2way93 has the smallest RMSEs, suggesting the overall superior performance of the dual-resolution two-way hybrid system than other configurations. Comparing sinHYBe1w9 and sinHYBe1w93 reveals that the improvement of dualHYB2way93 relative to the baseline single resolution hybrid is partly from the use of 3km-9km moving nest run during the free forecasts. Comparing sinHYBe1w93 with dualHYB2way93 suggests that additionally the improvement of dual- resolution two-way hybrid is also attributed to the better analysis produced by using the two-way dual resolution hybrid DA mode. Re-centering of the 9km EnKF analyses around the control 3/9km dual-resolution two-way hybrid analysis shows positive impact (dualHYB1way93 vs. dualHYB2way93). Using the ensemble from dual-resolution two-way hybrid in single resolution hybrid did not improve the performance (sinHYB2w93 vs. sinHYBe1w93). For the bias of Vmax forecasts (Fig. 4), baseline single resolution experiment sinHYBe1w9 showed “spin down” issue at the beginning of the forecast and the bias was near zero during day 2 forecast. All experiments involving 3km grid did not show spin down issue early in the forecast and had positive bias during day 2 forecast. 3/9km dual resolution analysis including both one-way and two-way hybrid during the DA cycles again showed reduced biases compared to using 9km single-resolution analysis during the DA cycles (dualHYB2way93 and dualHYB1way93 vs. sinHYBe1w93).

For the RMSEs of CSLP forecasts (Fig. 5), the results are in general similar to Vmax forecasts. The peak of CSLP RMSEs around hour 12 for sinHYBe1w9 is associated with the peak of CSLP forecast bias (Fig. 6) and the “spin down” of Vmax forecast (Fig. 4). For the biases of CSLP forecast (Fig. 6), experiments using dual-resolution hybrid analysis during the DA cycles including both one-way and two-way hybrid (dualHYB1way93 and dualHYB2way93) showed an overall better performance than all experiments where the analysis were produced using the 9km single resolution hybrid

(sinHYBe1w9, sinHYBe1w93 and sinHYBe2w93). Among these experiments where the analysis were produced using the 9km single resolution hybrid, sinHYBe1w9 showed an overall positive bias, and sinHYBe1w93 and sinHYBe2w93 showed an overall negative bias.

For the RMSEs of track forecasts (Fig. 7), the baseline single resolution DA experiment (sinHYBe1w9) has the largest errors. All experiment involving the use of 3km grid shows similar performances. Comparing sinHYBe1w9, sinHYBe1w93 and dualHYB2way93 reveals that the improvement of the dual-resolution two-way hybrid DA experiment (dualHYB2way93) relative to the baseline is mostly attributed to running 3/9km-nested grid during free forecasts rather than attributed to the dual resolution analysis.

In summary, the new dual-resolution two-way hybrid data assimilation system performed better than the baseline 9km single-resolution hybrid DA system. Series of specifically designed experiments were conducted to isolate the impact of the differences of the DA systems on the forecasts. It was found for Vmax and CSLP forecasts, such improvements were due to both (1) running the 3/9km-moving nest during free forecasts and (2) dual-resolution analysis during the DA cycles. For track forecasts, such improvements are due mostly to running the 3/9km-moving nest during free forecasts.

We are currently diagnosing the experiments by categorizing the TCs based on their intensity. In addition, we are developing single-resolution two-way hybrid data assimilation with moving nest capabilities. The goal is to let 3km movable control analysis ingests 3km EnKF ensemble rather than the 9km ensemble. In order to achieve this goal, we have implemented a new method to direct the moving of the 3km nest. This new method allows all ensemble members of 3km nests move to the same location, making the single-resolution moving-nest hybrid DA straightforward. Experiments are being conducted with this new functionality and results will be reported in the next report.