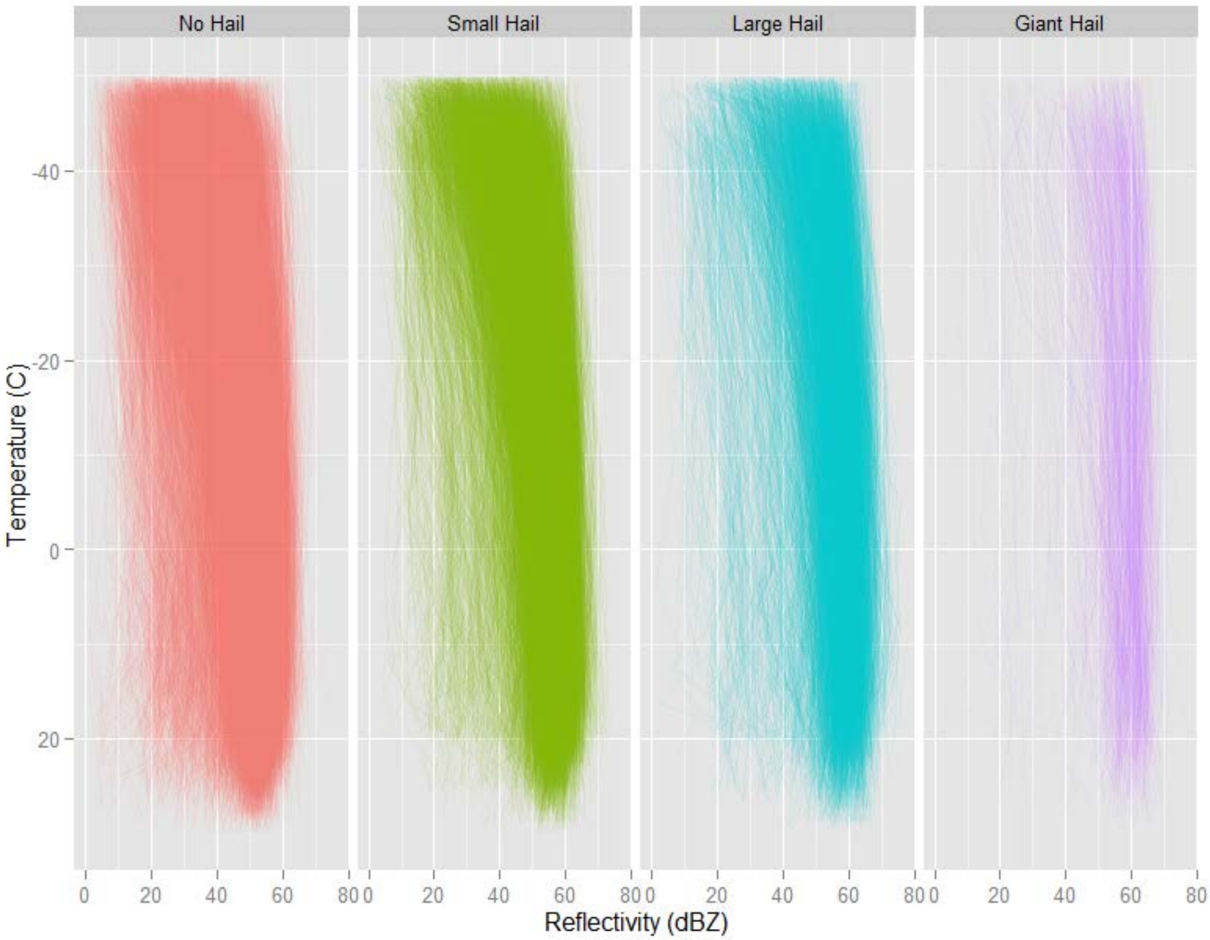

Cooperative Institute for Mesoscale Meteorological Studies

Annual Report

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

Cooperative Agreement NA11OAR4320072

Fiscal Year – 2015

Cover figure – *Vertical reflectivity profiles from the Multi-Radar Multi-Sensor (MRMS) system for hail reports from the Severe Hazards Analysis and Verification Experiment (SHAVE). There are 486 giant (diameter greater than 2 inches), 3,648 large (diameter between 1 and 2 inches), 9,896 small (diameter less than 1 inch), and 7,130 “no” hail reports. The data illustrate the large amount of overlap between the hail size classes, and thus, difficulty in hail size estimation.* *For more on this project, see pages 187-188.*

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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 2015 Fiscal Year

Randy A. Peppler, Interim Director
Tracy L. Reinke, Executive Director of Finance and Operations
Sebastian Torres, Assistant Director for NOAA Relations

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 Division (WDTD), 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 improvements in 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 Division (WDTD)
- 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 2014 through 30 June 2015. 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 Council 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 Council 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 among University and NOAA scientists on problems of mutual interest to improve basic understanding and to help produce better forecasts and warnings that save lives and property*

Vision *– A center of research excellence in mesoscale meteorology and related topics, fostering vibrant University-NOAA collaborations*

The organizational structure of CIMMS in FY15 was lean and included: Interim Director (Randy Peppler), Executive Director of Finance and Operations Director (Tracy Reinke), Assistant Director for NOAA Relations (Sebastian Torres), Administrative Assistant (Luwanda Byrd), and Account and Budget Specialist (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.

Executive Summary Listing of Activities during FY2015

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
  - Dual-Polarization Signal-Processing Improvements
  - Correlation Coefficient Estimation
  - Spectrum Width Estimation
  - Less-Tapered Windows to Improve Dual-Polarization WSR-88D Data
  - Real-Time Weather Signal Processing
  - Hardware Development and Maintenance for KOUN and Mobile Radars
  - WSR-88D Data Management
  - Improving the Quality of Polarimetric WSR-88D

- Dual-Polarization
  - Optimization of the QPE Algorithms based on Specific Attenuation and Specific Differential Phase
  - Validation of the Hail Size Discrimination Algorithm (HSDA) and Exploring its Further Refinements
  - Improving Melting Layer Detection for a New Surface-based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network
  - The Creation of a Background Surface Hydrometeor Classification Algorithm for Use with Dual-Pol Observations
  - Automated Detection of the Polarimetric Tornadic Debris Signature (TDS)
  - Development of a Z_{DR} Column Detection Algorithm

- Examining the Polarimetric Structure of Tornadic Supercells Using High-Resolution Radar Data
    - Develop Climatology of Tornadic Events Scanned by the Polarimetric WSR-88D for New Algorithm Development, Existing Algorithm Correction, and Signature Studies
    - Using Quasi-Vertical Profiles (QVP) Methodology for Investigation of Microphysical Processes in Mixed-Phase Clouds
    - Airborne Microphysics Data Collection During the Plains Elevated Convection at Night (PECAN) PROJECT: Understanding Polarimetric Radar Signatures in MCS Stratiform Regions
    - Studying Polarimetric Radar Signatures with an Advanced Forward Operator
    - Microphysical and Thermodynamic Retrievals Using Polarimetric Radar data for Assimilation Into Numerical Weather Prediction Models
    - Computational Electromagnetics Applied to the Scattering Observed by the Polarimetric Weather Radar
    - Investigation of Size Distributions and Radar Characteristics of Snow Using 2D-video Disdrometer Data and Polarimetric Radar Measurements

- Phased Array Radar
    - MPAR Advanced Technology Demonstrator
    - MPAR Dual-Polarization Demonstrator
    - MPAR Program Support
    - PAR Dual Polarization
    - PAR Adaptive Beamforming
    - PAR Pulse Compression
    - Forecaster Use of Phased Array Radar Data
    - Rapid-Update Radar Observations of Downbursts
    - Rapid-Scan Dual-Polarization Observations of Tornadic Supercells
    - Assimilation of PAR Data for Analysis of Storm Mergers
    - NWRT PAR Software Upgrades

- Research-to-Operations Transition
    - Develop AWIPS-2 and WDSS-II Visualization Networks for the MRMS Transition to NWS Operations

NSSL Project 2 – Hydrometeorology Research

- Operational Implementation of the Multi-Radar Multi-Sensor System
- WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities
- Radar Vertical Profile of Reflectivity Correction with Satellite Observations Using a Neural Network Approach
- Development of a Novel Radar QPE Approach Using Specific Attenuation for Two C-Band Dual-Polarization Radars
- Quality Control and Data Filling in Areas Impacted by Wind Farms, Terrain, and the Zero Isodop

- Multiple Year Reanalysis of Remotely Sensed Storms – Precipitation (MYRORSS – P)
- Evaluating MRMS Quantitative Precipitation Estimates Versus Single Source Radar QPE Products and NCEP Stage IV Estimates
- Conducting O2R Site Visits to NWS River Forecast Centers
- Quality Control Advancements of Hourly Rain Gauge Observations
- Combining Multiple Precipitation Products to Generated a Merged QPE
- 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
  - Maintenance Updates
  - QPE Verification System (QVS) for NSSL Mirror of MRMS Products at NCEP Central Operations
  - Next Generation QVS
  - Hydromet Viewer for Salt River Project
- meteorological Phenomena Identification near the Ground (mPING)
- mPING Random Forest Research

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
  - Scalable and Reconfigurable Polarimetric Array Modeling and Measurement
  - Scalable Real-time Backend System for MPAR
  - Characterization of and Edge Diffractions on a High Performance S-Band Dual-Polarized Finite Phased Array Antenna
  - MPAR Resource Management and Adaptive Weather Sensing
  - Multi-Channel Interference Mitigation Techniques & Real-Time Studies
  - Simulation of Weather Observations With Polarimetric Phased Array Radars
  - Cylindrical Array Design through Phase Mode Analysis and Careful Pattern Synthesis
  - Risk Mitigation for Large-Scale, Low-Cost, Highly Digital Phased Array Systems
  - CPPAR Demonstrator Calibration, Pattern Enhancements, and Planning for Larger-Scale Array Calibration
- Polarimetric Phased Array Radar Research in Support of MPAR Strategy

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

- Establishing Model Resolution Requirements for Warn-on-Forecast
- Evaluating the Competitiveness of the LETKF for Warn-on-Forecast
- Impact of Phased Array Radar Data Assimilation on Warn-on-Forecast
- Ensemble Verification of Proxy Severe Storm Reports
- NSSL WRF Ensemble Severe Storm Environments Evaluating the NSSL WRF Using the Multi-Year Reanalysis Of Remotely Sensed Storms (MYRORRS)
- Evaluation of Rapid Post-Processing and Information Extraction from Large Convection-Allowing Ensembles Applied to 0-3 Hour Tornado Outlooks
- Expanding High Performance Computing Resources for Storm-Scale Modeling and Data Assimilation
- Development of the NSSL Weather Research and Forecasting (WRF) Model
- Implementation and Development of the NSSL NMMB
- Development of the NSSL SREF Ensemble
- Implementation of Lightning Data Assimilation Code in the NSSL WRF
- Complete a Real Time Evaluation of Total Lightning Data Assimilation Algorithm within the WRF framework
- The Assimilation of Hyperspectral Sounder Observations into Mesoscale Models
- Advancing a Sophisticated Polarimetric Radar Forward Operator
- Simulating Polarimetric Signatures Using High-resolution Numerical Simulations
- Storm-Scale Data Assimilation and Ensemble Forecasting for Warn-on-Forecast
- Application of the Warn-on-Forecast Concept to Severe Mesoscale Convective Systems
- Short-term Probabilistic Forecasts of the 31 May 2013 Oklahoma Tornado and Flash Flood Event Using Continuous Update Cycle Storm-scale Ensemble System

- Comparison of the Analyses and Forecasts of a Tornadic Supercell Storm from Assimilating Phased Array Radar and WSR-88D Observations
- Analyses and Forecasts of the 24 May 2011 Oklahoma Tornadic Supercell Storms using Ensemble of 3DVAR System
- Using Spatiotemporal Relational Data Mining Techniques to Improve Understanding of Tornadogenesis
- Development of a Community Variational Dual-Doppler Wind retrieval Code
- Investigating Forcing Mechanisms of Internal Rear-Flank Downdraft Momentum Surges in a 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)

NSSL Project 4 – Hydrologic Modeling Research

- Demonstrate Real-Time Flash Flood Predictions Across the Conterminous U.S
- Compare Skill of FLASH Model Outputs to Operational Flash Flood Guidance System

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

- Improve and Optimize E-WRF for Sub-Kilometer Resolution Simulations of Tropical Cyclones
- Physical Process Studies
- Forecast and Model Evaluation during the 2015 HWT Spring Forecast Experiment (SFE)
- Sensitivity of Lake-Effect Snow Forecasts to the Choice of Boundary Layer Parameterization

CIMMS Task III Projects

- Storm Tracking and Lightning Cell Clustering using Geostationary Lightning Mapping Data for Assimilation and Forecast Applications
- Lightning Mapper Array Operations in Oklahoma and the Texas Gulf Coast Region to Aid Preparation for the GOES-R GLM
- Using Total Lightning Data from GLM/GOES-R to Improve Real-Time Tropical Cyclone Genesis and Intensity Forecasts
- 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
- Hybrid Data Assimilation for Convective-Scale “Warn-on Forecast”
- Objective Probabilistic Guidance for Severe Weather Outbreaks

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
- Experimental Warning Program
  - Probabilistic Hazard Information (PHI) Experiment
  - GOES-R Convective Applications
  - Earth Networks Total Lightning Network
  - Lightning Jump Algorithm
  - Evaluation of Experimental Forecast Program Probabilistic Severe Weather Outlooks

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

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

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

- Dual-Polarization Precipitation Identification
- Quantitative Precipitation Estimation Analyses using MRMS and WDSS-II Tools
- 3D Modeling of Clouds to Aid in Development of a Cloud Detection Algorithm
- ROC Applications and Engineering Branches Undergraduate Student Projects

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

- Hazardous Weather Testbed Experimental Forecasting Program
- Verification of SPC Winter Weather Mesoscale Discussions
- Lightning Characteristics and Relationship to Preliminary Local Storm Reports

- Definition of Dry Thunderstorms for Use in Verifying SPC Fire Weather Products
- Social Science Collaborations
  - Test and Evaluation of Rapid Post-Processing and Information Extraction from Large Convection-Allowing Ensembles Applied to 0-3 Hour Tornado Outlooks
  - Collaboration for Applying Social Science Within the SPC
  - Continued Work on the May Tornadoes of 2013 and 2015
- GOES-R Proving Ground Activities

WDTD Project 12 – Warning Decision-Making Research and Training

- The Advanced Warning Operations Course (AWOC) – Core, Flash Flood, and Severe Tracks
- Advanced Weather Interactive Processing System (AWIPS) – II Training
- Distance Learning Operations Course (DLOC)/Radar and Applications Course (RAC)
- Experimental Warning Program/NOAA Hazardous Weather Testbed Support: Tales from the Testbed Webinars
- Geostationary Operational Environmental Satellites – R Series (GOES-R) Science Infusion into WDTD Training
- Multiple-Radar/Multiple-Sensor (MRMS) Training
- Science and Operations Officer (SOO)/Development Operations Hydrologists (DOH) Facilitation Workshop
- Weather Event Simulator – I (WES)
- Weather Event Simulator – II (WES-2) Bridge
- 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 System Optimization
  - AWIPS II Distance Learning
  - Community Hydrologic Prediction System Distance Learning
  - Deliver Broadcast Message Handler Training
  - Assist Instructors with Distance Learning Updates and Maintenance
  - Datzilla User Training
  - Cooperative Observer Course and Station Information System Support
  - Hazard Services Training

- NWS Proving Ground Operational Service Delivery Simulations
- Impact Based Decision Support Services (IDSS) Research and Development
  - IDSS Deployment Boot Camp
  - Create and Deliver a Traveling IDSS Boot Camp Course
  - Conduct Training Sessions to Compliment Online Media Training
  - Create and Deliver Training Sessions on Communication
- Advanced Training Development
  - Sub-Matter Expertise in Learning Technology and Techniques
  - Conduct Internal Training at the NWSTC
  - Create and Perform Outreach within the Agency

CIMMS Task III Projects

- The Lightning Jump Algorithm: A National Field Test for Operational Readiness
- Development and Testing of Probabilistic Hazard Information Weather Tools for Forecasting a Continuum of Environmental Threats (FACETs)
  - Probability Hazard Information (PHI) Objects
  - Regional PHI
  - Guidance PHI
  - End-User PHI
  - HWT Spring Experiment PHI Activities
- Development of Short-Range Real-time Analysis and Forecasting System Based on the ARPS for Taiwan Region
- 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 Activities
- Prototyping and Evaluating Key Network-of-Networks Technologies

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

- 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

- Creation of Numerical Weather Guidance
- Warning Decision-Making
- Production of Valuable Warnings for Users

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

- Eye-Tracking Pilot Study
- The 2015 Phased Array Radar Innovative Sensing Experiment (PARISE)

CIMMS Task III Projects

- Southern Climate Impacts Planning Program (SCIPP)
    - Absence of Long-Term Trends in Hurricane Winds or Storm Surge Flooding Events along the U.S. Gulf Coast
    - Temperature Threshold for Mangrove Mortality Reached Several Times Over Past 130 years along the US Gulf Coast
    - Drought Indices May be Effective in Explaining Variability in Waterfowl Habitat
    - Water Utilities in Oklahoma Possessing Dynamic Capabilities Better Suited for Innovation
    - Lake Pontchartrain-Maurepas Storm Surge Consortium
    - Field Photos Weekend
    - Climate Training for Native American Tribes
- Rio Grande/Bravo River Basin Climate Outlook
- Drought Risk Management for the United States
- Life and Death Decisions: An Integrative Approach to Extreme Weather (The *Living With Extreme Weather Workshop*)

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
- WDTD Outreach

Awards and Honors

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

- **CIMMS Scientists** were key contributors to the NOAA 2015 Silver Medal for the "successful transition of the Multi-Radar, Multi-Sensor system into operations to provide critical radar-based products to forecast weather hazards." Contributors (present and recent past) include (alphabetical order): Ami Arthur, Alyssa Bates, Jeff Brogden, Kristin Calhoun, Steven Cocks, Karen Cooper, Matthew Elliott, Heather Grams, Jill Hardy, Eric Jacobsen, Brian Kaney, Darrel Kingfield, Valliappa Lakshmanan, Carrie Langston, Kevin Manross, Steven Martinaitis, Tiffany Meyer, Dale Morris, Kiel Ortega, Youcun Qi, Heather Reeves, Travis Smith, Chris Spannagle, Gregory Stumpf, Lin Tang, Matt Taraldsen, Robert Toomey, Yadong Wang, and Andy Wood

- **Andrew Wood** (CIMMS at WDTD) was recognized for the 2015 Dean's Award for Outstanding Service for "his exceptional support of severe weather education and outreach to the National Weather Service (NWS), NOAA, and key partners of the Weather-Ready Nation initiative"

- **Corey Potvin** (CIMMS at NSSL) was nominated for 2015 Presidential Early Career Award for Scientists and Engineers (PECASE)

- **Zachary Flamig** (CIMMS at NSSL and OU School of Meteorology) was selected as the 3rd Place Winner – Poster Presentation Category – in the AMS *Joint EIPT-R2O Conferences* Student Competition at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "HWT-Hydro: Evaluation of Experimental Forecast and Nowcast Tools"

- **Robert "Race" Clark** (CIMMS at NSSL and OU School of Meteorology) was as the 3rd Place Winner – Oral Presentation Category – in the AMS *Joint EIPT-R2O Conferences* Student Competition at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "The Inaugural Hazardous Weather Testbed – Hydrology (HWT-Hydro) Experiment"

- **Elizabeth Mintmire Argyle** (CIMMS at NSSL and OU School of Industrial and Systems Engineering) was a Student Presentation Award Winner (oral presentation) in the AMS *10th Symposium on Societal Applications* at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "Forecaster 'Best Practices' During Operations in the Hazardous Weather Testbed Hydrology Experiment 2014."

- **Burkely Twiest** (CIMMS at NSSL and OU School of Meteorology) was a Student Presentation First Place Award Winner (oral presentation) in AMS *27th Conference on Weather Analysis and Forecasting* in Chicago, IL (29 June–3 July 2015) for "Using the High-Resolution NSSL-WRF Ensemble to Provide Hazard Guidance"

- **Eswar Iyer** (CIMMS at NSSL and OU School of Meteorology) was a Student Presentation Second Place Award Winner (oral presentation) in the AMS 23rd Conference on Numerical Weather Prediction in Chicago, IL (29 June–3 July 2015) for “Comparison of 36-60 Hour Precipitation Forecasts from Convection-Allowing and Convection-Parameterizing Ensembles”

- **James Kurdzo** (ARRC at OU and OU School of Meteorology) won the Tommy C. Craighead Award for Best Paper in Radar Meteorology – *School of Meteorology (2014-2015)*, 2nd Place Oral Presentation – *AMS Severe Local Storms Conference (2014)* – 2nd Place Oral Presentation – *AMS Conference on Environmental Information Processing Technologies (2015),* 2nd Place Oral Presentation – *AMS Conference on Research to Operations (2015)*

- **Nicholas Gasperoni** (OU School of Meteorology) won the 2015 Douglas Lilly Best Ph.D. Publication Award from the OU School of Meteorology, and won Best Student Oral Presentation at the IOAS-AOLS Conference at the AMS Annual Meeting, January 2015.

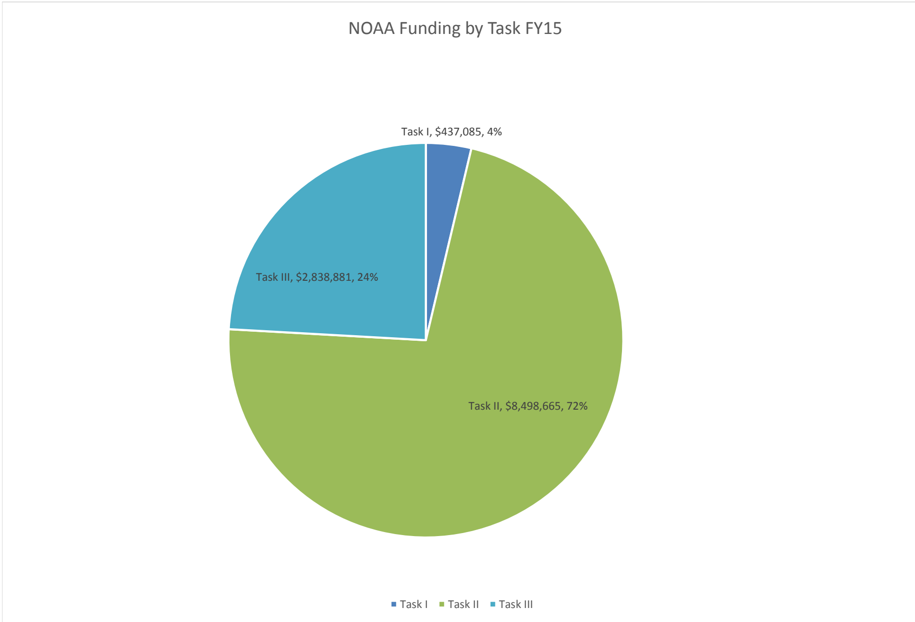
- Two papers with CIMMS authors were designated “Significant Papers” by NSSL – these include, (1) Sudesh Boodoo, David Hudak, **Alexander Ryzhkov**, **Pengfei Zhang**, Norman Donaldson, David Sills, and Janti Reid, “Quantitative Precipitation Estimation from a C-Band Dual-Polarized Radar for the 8 July 2013 Flood in Toronto, Canada”, *Journal of Hydrometeorology* and (2) **Dustan Wheatley, Kent Knopfmeier, Thomas Jones, and Gerald Creager**, “Storm-Scale Data Assimilation and Ensemble Forecasting with the NSSL Experimental Warn-on-Forecast System, Part 1: Radar Data Experiments”, *Weather and Forecasting*

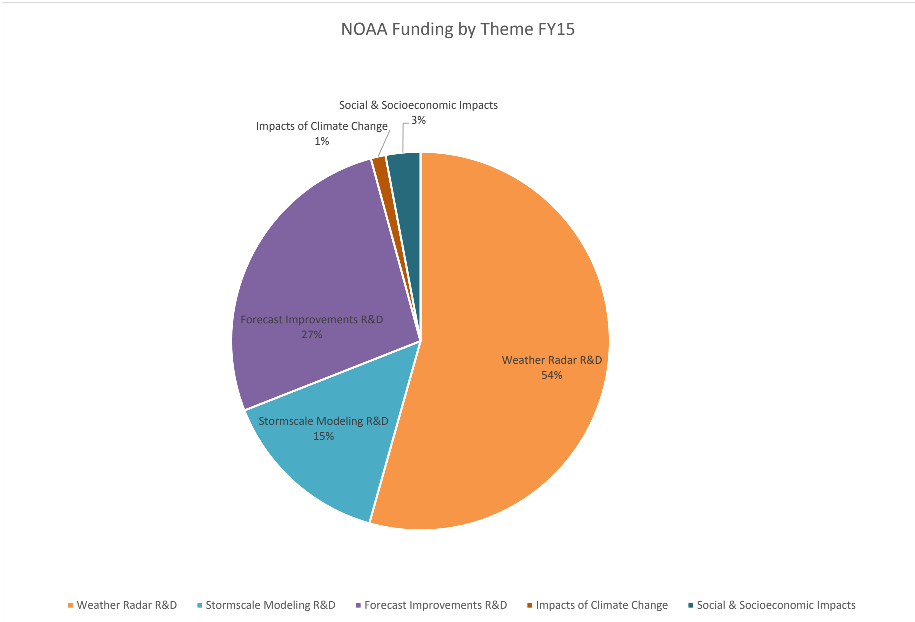
- **Caleb Fulton** (ARRC and ECE at OU) was presented a DARPA Young Faculty Award to support further research into “Risk Mitigation for Large-Scale, Low-Cost, Highly Digital Phased Array Systems” for general digital beamforming systems, the proposal for which benefited substantially from work done under the support of the NSSL for this grant

- **Guifu Zhang and Robert Palmer** (ARRC at OU) **and Richard Doviak and Dusan Zrnic** (NSSL): A Patent #8988274 of “Cylindrical Polarimetric Phased Array Radar” awarded by U.S. Patent Office, 24 March 2015

- **Guifu Zhang** (ARRC at OU), **Dusan Zrnic** (NSSL), and **Lesya Borowska** (ARRC at OU): “Joint Signal Processing for High Efficiency in MPAR Design and Development”, OU Intellectual Property Disclosure (#15NOR003), 14 July 2014

Distribution of NOAA Funding by CIMMS Task and Research Theme





CIMMS Executive Board and Council of Fellows Meeting Dates and Membership

No Executive Board or Council of Fellows meetings took place in FY15.

Executive Board membership for 2015 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, Executive Director, ARRC, and Professor and Tommy C. Craighead Chair, School of Meteorology, OU (Provost designated)
- Dr. Carol Silva, Director, CRCM, Associate Director, CASR, and Associate Professor of Political Science, OU (Provost designated)
- Dr. Kirsten de Beurs, Chair and Associate Professor, Department of Geography and Environmental Sustainability, OU (Provost designated)
- Mr. Lans Rothfusz, 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. Boon Leng Cheong, Research Scientist, ARRC (Elected from Assembly of Fellows)
- Dr. David Turner, Research Meteorologist, NSSL (Elected from 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, WDTD (*ex-officio* member)
- Dr. Russell Schneider, Director, SPC (*ex-officio* member)
- Mr. Terry Clark, Director, ROC (*ex-officio* member)
- Dr. David Parsons, Chair, OU School of Meteorology, Associate Director, CAPS, and Mark and Kandi McCasland Professor of Meteorology (ex-officio member)

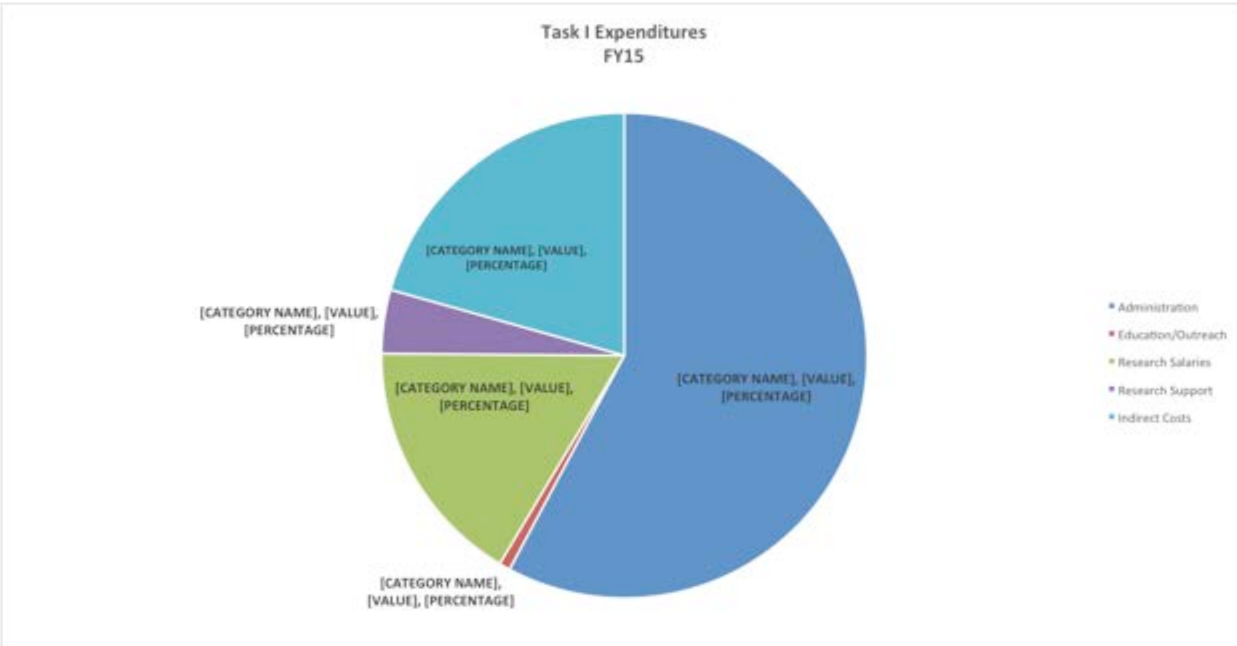
Council of Fellows membership for 2015-2017 is as follows:

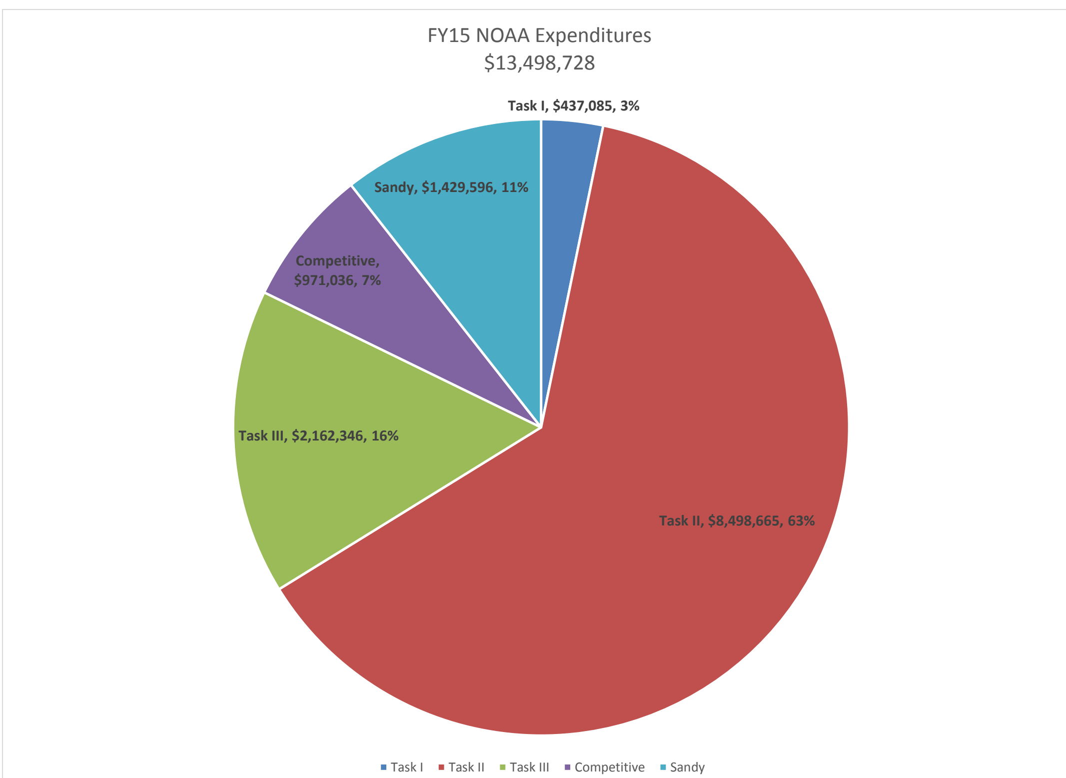
- Dr. Jeffrey B. Basara, Director of Research, OCS, and Associate Professor of Meteorology, OU
- Dr. William H. Beasley, Professor of Meteorology, OU
- Dr. Michael I. Biggerstaff, Professor of Meteorology, OU
- Dr. Howard B. Bluestein, George Lynn Cross Research Professor of Meteorology, OU
- Dr. Keith 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. Frederick H. Carr, Professor of Meteorology OU
- Dr. Steven Cavallo, Assistant Professor of Meteorology, OU
- Dr. Boon Leng Cheong, Research Scientist, ARRC, OU
- Dr. Phillip Chilson, Professor of Meteorology, OU
- Dr. Adam J. Clark, Research Meteorologist, NSSL
- Mr. Terrence Clark, Director, ROC
- Dr. Michael Coniglio, Research Scientist, NSSL
- Dr. Kirsten de Beurs, Chair and Associate Professor of Geography and Environmental Sustainability, OU
- Dr. Michael W. Douglas, Retired Research Scientist, 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. Evegeni Fedorovich, Professor of Meteorology, OU
- Dr. Chris Fiebrich, Associate Director, OCS
- Dr. Jack Friedman, Research Scientist, CASR, OU
- 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, Associate Director, CASR, and Professor of Political Science, OU
- Dr. Israel Jirak, Science and Operations Officer, SPC
- 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
- Dr. James F. Kimpel, Director, Emeritus NSSL, and Emeritus Professor of Meteorology, OU
- Dr. Kevin Kloesel, Director, OCS, and Associate Professor of Meteorology, OU
- Dr. Steven Koch, Director, NSSL
- Dr. Fanyou Kong, Research Scientist, CAPS, OU
- Dr. Daphne LaDue, Research Scientist, CAPS, OU
- Dr. Valliappa Lakshmanan, Director of Meteorology, The Climate Corporation
- 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, WDTD
- Dr. Edward Mansell, Research Scientist, NSSL
- Dr. Patrick Marsh, Techniques Development Meteorologist, SPC
- Dr. Elinor Martin, Assistant Professor of Meteorology, OU
- Dr. Amy McGovern, Associate Professor of Computer Science, OU
- Dr. Renee McPherson, Director of Research, South Central Climate Science Center, and Associate Professor of Geography and Environmental Sustainability, OU
- 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
- Mr. Richard Murnan, Radar Meteorologist, ROC
- Mr. John Ogren, Acting Chief Learning Officer, NWS
- Dr. Robert D. Palmer, Associate Vice President for Research, Executive Director, ARRC, and Tommy Craighead Chair and Professor of Meteorology, and OU
- Dr. David Parsons, Director, School of Meteorology, Mark and Kandi McCasland Professor of Meteorology, OU
- Dr. Robert Rabin, Research Scientist, NSSL
- Dr. Michael B. Richman, E. K. Gaylord Presidential Professor of Meteorology, OU
- Mr. Lans Rothfusz, Deputy Director, NSSL
- Dr. Jessica Ruyle, Assistant Professor of Electrical and Computer Engineering, OU
- Dr. Jorge Salazar-Cerreno, 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, Director, CRCM, Associate Director, CASR, and Professor of Political Science, OU
- Dr. Paul Spicer, Professor of Anthropology, OU
- Dr. David J. Stensrud, Chair, Department of Meteorology, Pennsylvania State University
- Dr. Jerry M. Straka, Professor of Meteorology, OU
- Dr. Aondover A. Tarhule, Associate Dean, College of Atmospheric and Geographic Sciences, and Associate Professor, Department of Geography and Environmental Sustainability, OU
- Dr. David Turner, Research Scientist, NSSL

- Dr. Xuguang Wang, Associate Professor of Meteorology, and Presidential Research Professor, OU
- 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, Professor of Electrical and Computer Engineering, OU
- Dr. Tian-You Yu, Director of Operations, ARRC, and Professor of Electrical and Computer Engineering, OU
- Mr. Allen Zahrai, Team Leader, Radar Engineering and Development, NSSL
- Dr. Guifu Zhang, Professor of Meteorology, OU
- Dr. Jian Zhang, Research Hydrometeorologist, NSSL
- Dr. Yan Zhang, Associate 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 (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

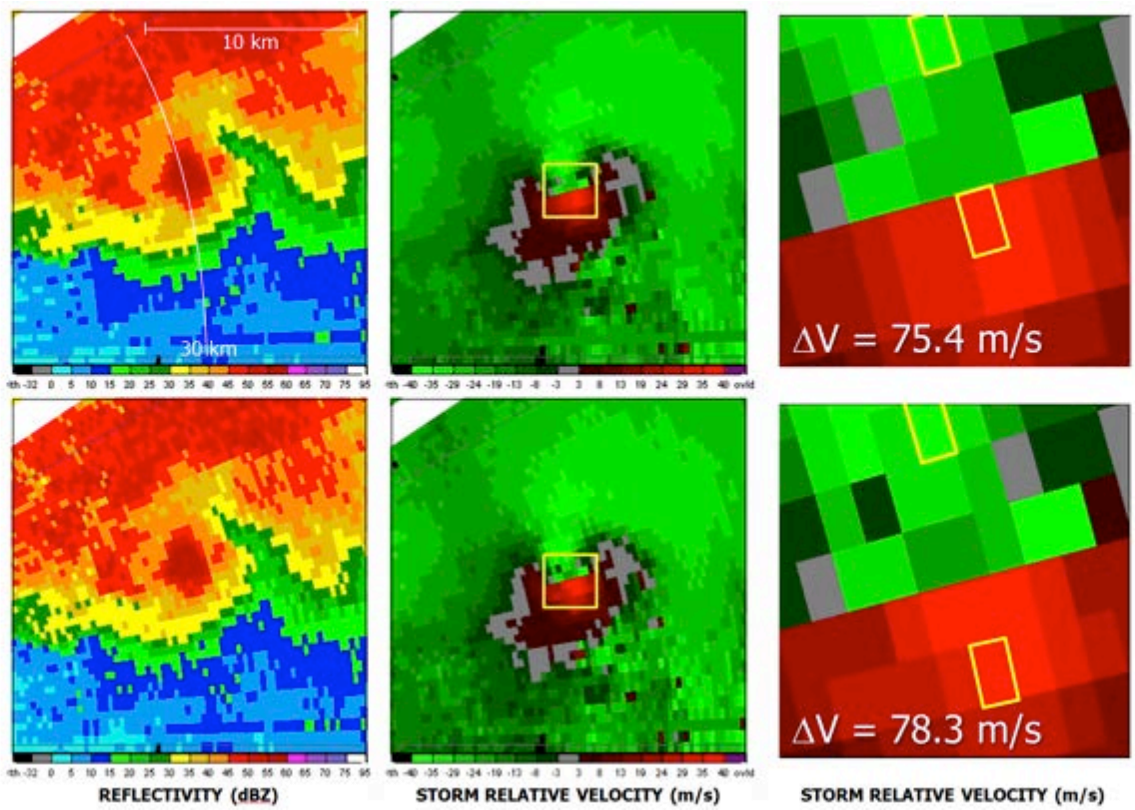
Christopher Curtis and Sebastian Torres (CIMMS at NSSL)

Obtaining radar data at faster rates can provide an important capability for the observation of rapidly evolving weather phenomena. When increasing data rates, the conventional trade-off involves sacrificing either spatial coverage or data precision. With range oversampling, it is possible to add a new dimension to this trade-off: signal processing. Range oversampling allows us to either obtain data twice as fast with variances similar to conventional processing or improve data quality without sacrificing update time or spatial coverage. This type of processing has been used to significantly reduce update times on the National Weather Radar Testbed Phased Array Radar (NWRT PAR) and to improve polarimetric data quality on NEXRAD research radar KOUN. In FY15, we focused our efforts on two research areas: the effects of range oversampling processing on WSR-88D tornado velocity signatures and a novel way of using adaptive pseudowhitening on non-traditional estimators.

Range oversampling processing can significantly improve radar data quality, but it also affects the range resolution of the data. Using an innovative simulation technique, we captured the effects of antenna rotation, data windowing, and range oversampling processing on the difference between the maximum and minimum radial velocities. Although the simulation shows a slight degradation of the tornado velocity signatures, the improved data quality from range oversampling should outweigh this minor negative

impact. The results were captured in a paper that was accepted for publication during the review period (Torres and Curtis 2015).

The second research area examined a novel way of using adaptive pseudowhitening on non-traditional estimators. In the original implementation of adaptive pseudowhitening, we used explicit variance expressions for each estimator to choose a transformation that was appropriate for the weather signal characteristics. This worked well for traditional radar-variable estimators, but some of the new non-traditional estimators either do not have an explicit variance expression or have a difficult-to-derive expression. We formulated a lookup-table technique that uses Monte Carlo simulations to find the proper transformation without utilizing a variance expression.



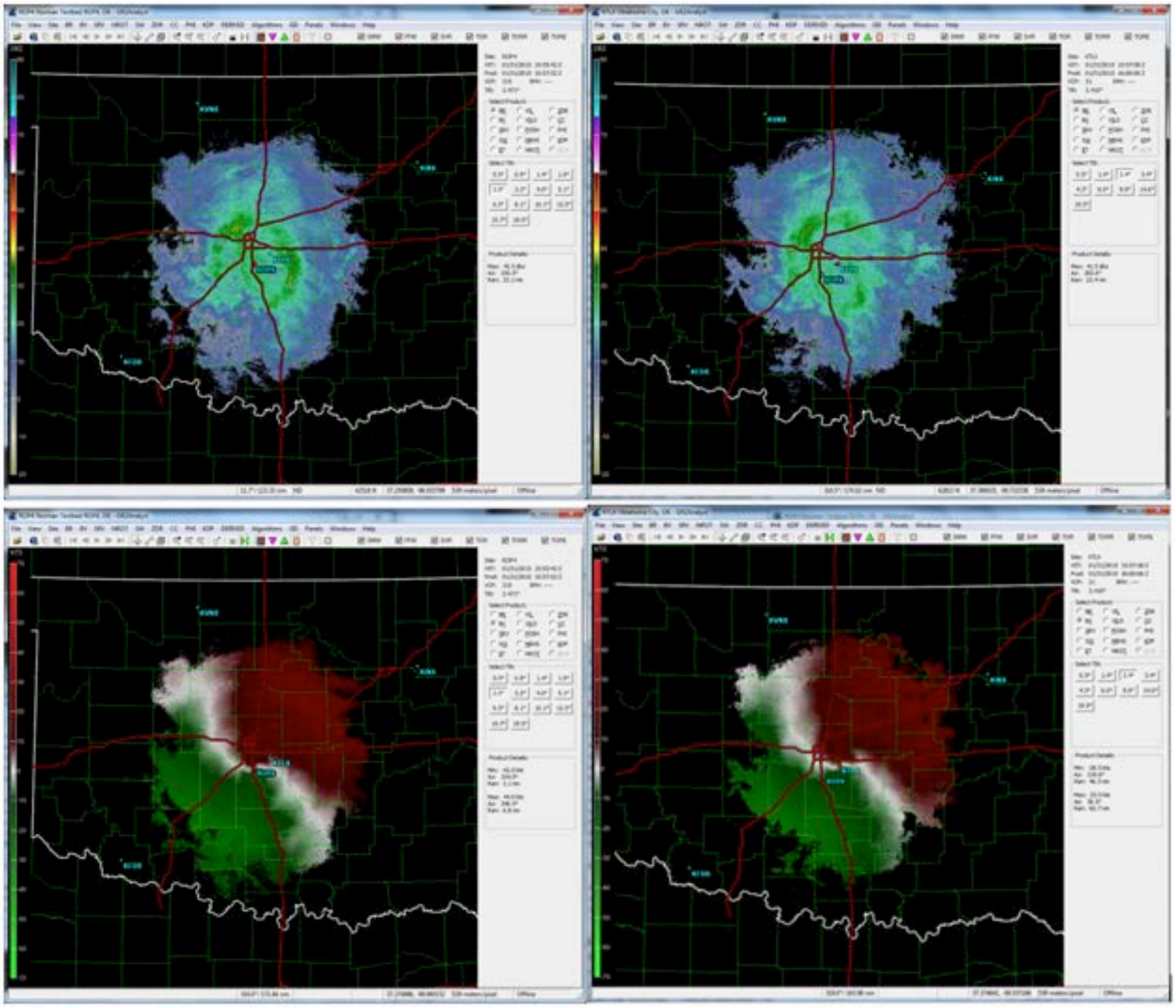
Reflectivity (left) and storm-relative Doppler velocity (middle and right) corresponding to tornado data collected with the NWRT PAR on 20 May 2013 at ~23:20 UTC at an elevation of 0.5°. The top row corresponds to super-resolution data processed with an adaptive pseudowhitening transformation. The bottom row corresponds to super-resolution data processed with a standard matched filter. In the zoomed-in panels (right), corresponding to the yellow boxes in the middle panels, the gates with maximum and minimum velocities are highlighted in yellow, and the measured values of ΔV are shown for each case. Note that the adaptive pseudowhitening data looks smoother and has better data quality compared to the matched-filter data, but the magnitude of ΔV is only slightly smaller.

b. Range-and-Velocity Ambiguity Mitigation

David Warde and Sebastian Torres (CIMMS at NSSL)

In pulsed Doppler weather radars, the range and Doppler velocity ambiguity problems are coupled so that trying to alleviate one of them worsens the other. Special techniques are necessary to resolve both range and velocity 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. The first stage of upgrades that implemented SZ-2 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 SPRT.

In past years, we developed a novel spectral processing SPRT algorithm that incorporates the mature Clutter Environment Analysis using Adaptive Processing (CLEAN-AP) filter, range-overlaid recovery, dual polarization and a generalized PRT ratio. The generalized autocorrelation spectral density (ASD) was formulated for SPRT waveforms to assist with ground clutter mitigation. This was an extension of the autocorrelation spectral density work that was captured in Torres and Warde (2014). In FY15, we supported preliminary testing of the SPRT algorithm on the ROC testbed (see the figure below). Research coupled with an operational need to improve spectrum width estimation (additional information in subsection f) drove an update to the SPRT algorithm description. With the recommended changes, we have provided a robust SPRT solution with enhanced ground clutter mitigation technology capable of meeting NEXRAD operational needs in the dual-polarization era.



31January 2015 testing of SPRT on the NEXRAD testbed in Norman, OK is compared to the batch mode collected on the NEXRAD operational radar (KTLX). PPI reflectivity and velocity images of staggered PRT (top left and bottom left, respectfully) and PPI reflectivity and velocity images of batch mode (top right and bottom right, respectfully) are shown for the 2.4-degree elevation for each radar. Clutter suppression for SPRT is provided by CLEAN-AP.

c. Ground Clutter Mitigation

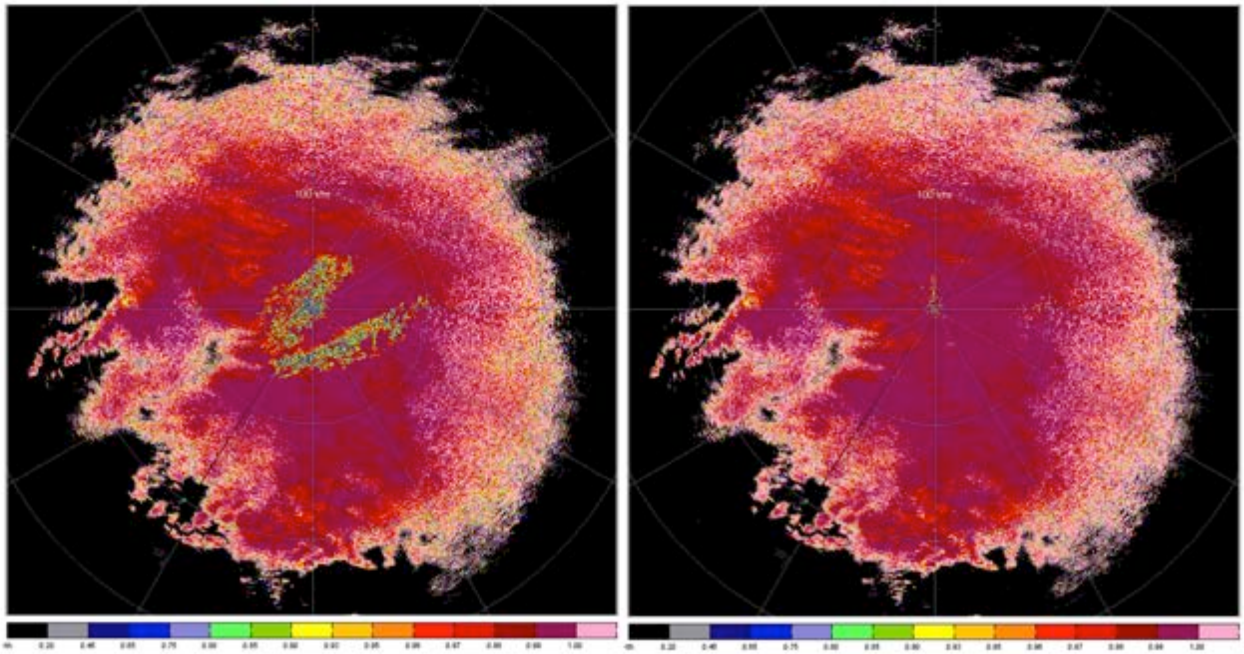
David Warde and Sebastian Torres (CIMMS at NSSL)

A common dilemma in obtaining good-quality radar-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 because of the dynamic atmospheric effects on radar beam propagation. The goal of this project is to develop efficient techniques that provide both automated detection and application of ground clutter filtering. The CLEAN-AP filter is a spectral technique for automatic detection and mitigation of ground clutter contamination. We had previously shown the clutter detection and mitigation performance of the CLEAN-AP filter using time-series data from the national network of weather surveillance radars (WSR-88D), the dual-polarized (DP) KOUN and OU Prime radars, and the NWRT PAR.

A challenge when trying to mitigate ground clutter is the loss of weather signals with low radial velocity, especially when these weather signals have radar-observed characteristics that are similar to ground clutter (as is typical in stratiform rain and snow events). Polarization diverse weather radars such as the newly upgraded NEXRAD WSR-88D provide additional discriminating signatures that can assist in identification of low radial velocity weather signals. In FY15, we examined the use of dual-polarimetry estimates to assist with ground clutter mitigation. We developed the Weather Environment Thresholding (WET) algorithm to accurately identify weather signals, which reduces the ambiguity between low velocity weather signals and ground clutter. The WET algorithm, when combined with CLEAN-AP, was shown to enhance the ground clutter mitigation capability for a snow event where current NEXRAD WSR-88D ground clutter mitigation techniques had failed.

Compared to current technologies used for ground clutter mitigation, the WET/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.

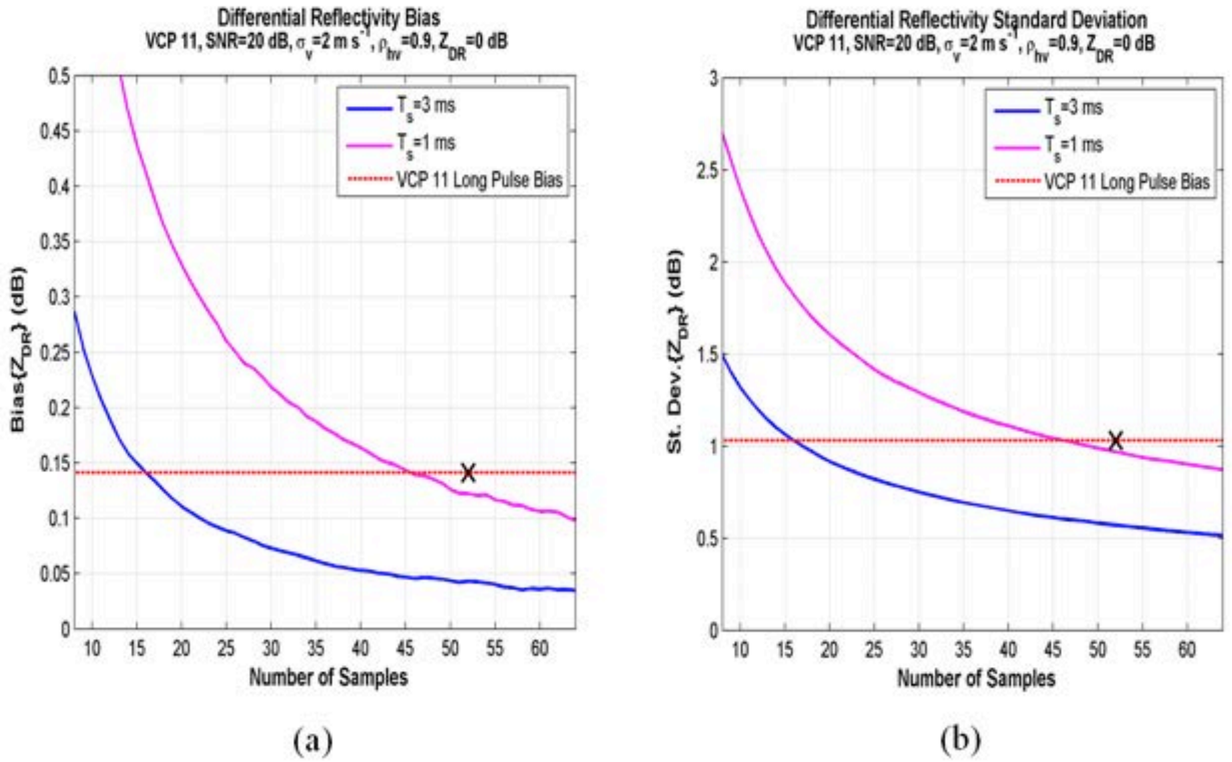


PPI display of unfiltered cross-correlation coefficients (left) shows ground-clutter contamination as reduced cross-correlation coefficients (orange to blues and grays as compared to the surrounding red field); whereas, the PPI display of WET/CLEAN-AP filtered cross-correlation coefficients (right) are homogenously red in the same regions indicating the mitigation of ground clutter in these regions. The data was collected from operational WSR-88D radar during a snow event.

d. Dual-Polarization Signal-Processing Improvements

David Warde, Brad Isom, and Sebastian Torres (CIMMS at NSSL)

The NWS has recently 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 FY15, we analyzed the statistical properties of the polarimetric estimates from both the long- and short-PRT cuts at the same elevation (i.e., split cuts) in typical NEXRAD volumetric coverage patterns. Through simulations, we quantified the performance improvements of polarimetric estimates for overlaid conditions when the short PRT estimate is uncontaminated and can replace the long PRT estimate. We continue to support the real-time implementation and update the signal processing.



The bias (a) and standard deviation (b) of differential reflectivity for a non-overlaid situation is shown for both the long PRT (3 ms – blue) and short PRT (1 ms – Magenta) for a typical NEXRAD VCP 11. The red dotted line shows the estimate bias and standard deviation for the long PRT with 17 samples. When compared to the short PRT with 52 samples (i.e., magenta line below x mark), it is seen that the short PRT estimate has less bias and a lower standard deviation than the long PRT estimate and would provide a better differential reflectivity estimate.

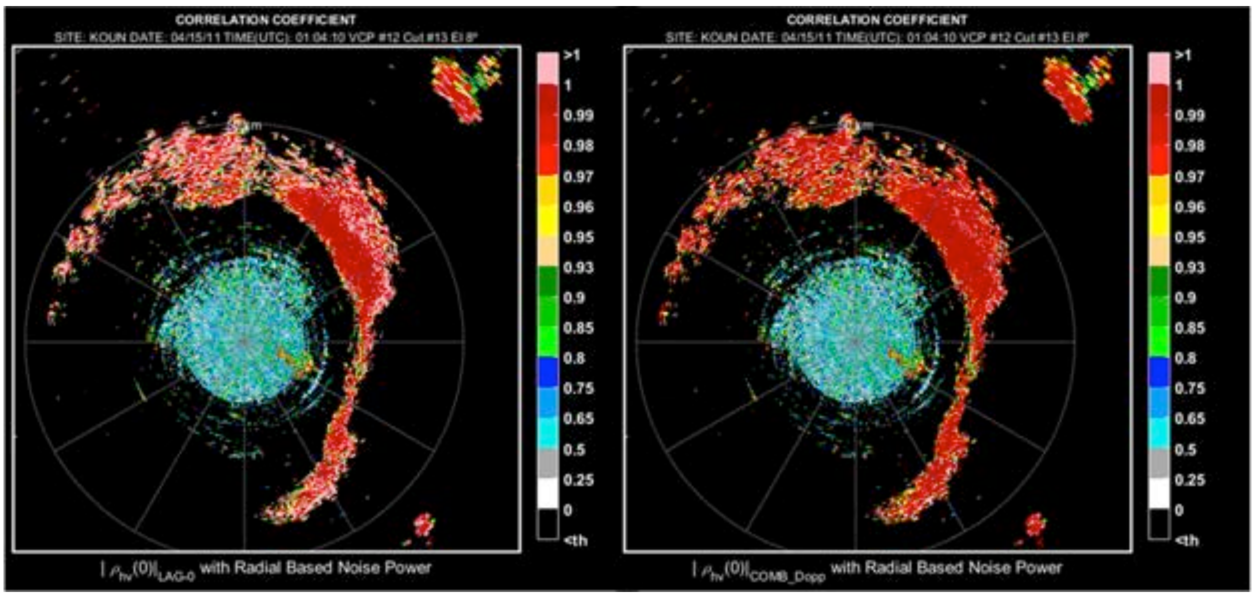
e. Correlation Coefficient Estimation

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 different types of radar echoes and in the 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 estimation technique was developed that has the potential of producing less biased estimates. Mitigating the CC bias will result in more accurate estimates, which will improve polarimetric recognition of echoes. It will also reduce the number of estimates that cannot be used for classification (i.e., invalid estimates). The

improved CC estimator will provide improved accuracy while being computationally viable for easier operational implementation on the WSR-88D.

During FY15, the algorithm was modified to work in cases when the unambiguous velocity and the number of available pulses are larger (e.g., Doppler and higher elevation scans). This modification resulted in a similar but simpler algorithm than the one tailored for scans in which the unambiguous velocity and the number of available pulses are small (i.e., surveillance scans). The results were presented to the NEXRAD Technical Advisory Committee. The CC estimation technique was also presented at the 8th European Conference on Radar in Meteorology and Hydrology held in September 2014 at Garmisch-Partenkirchen, Germany.



Comparison between CC fields produced using the legacy estimator (left) and the improved CC estimation technique (right) at 8° elevation. The field on the right exhibits visibly reduced number of invalid estimates (shown in pink).

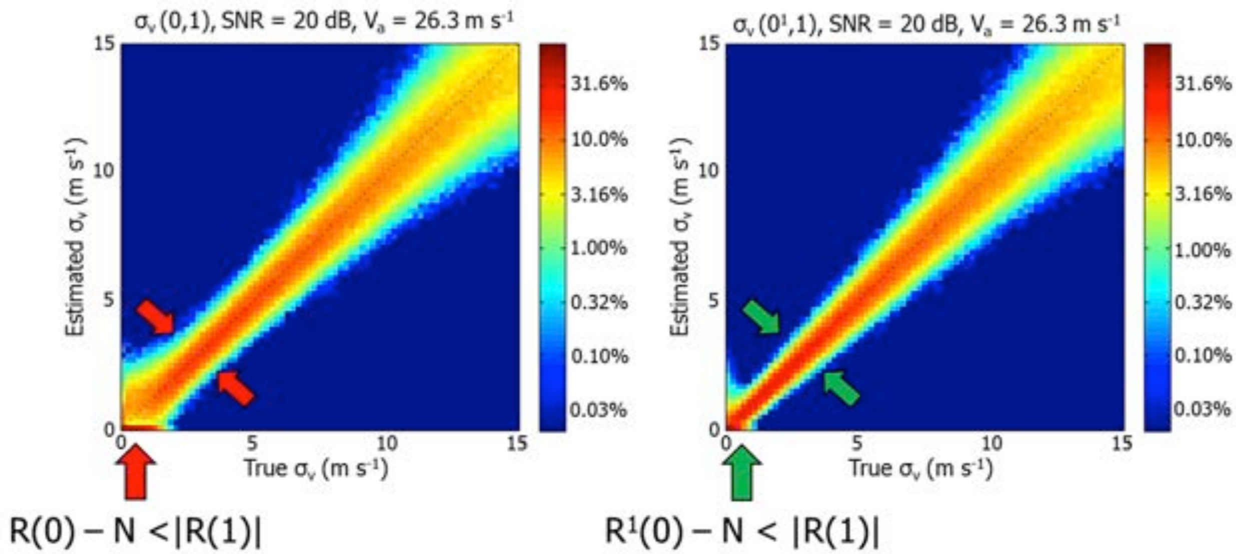
f. Spectrum Width Estimation

David Warde and Sebastian Torres (CIMMS at NSSL)

Improving the quality of spectrum width estimates would enhance data assimilation (Warn-on-Forecast), storm feature identification (rear flank downdrafts, boundaries, tornado genesis, and hail spikes), and downstream algorithms (NEXRAD Turbulence Detection Algorithm, range oversampling, non-uniform beam filling, 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 depends on accurate noise measurements. The R1/R2 estimator, 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.

In FY15, we implemented the improved spectrum width estimators in the staggered PRT algorithm and provided the updated algorithmic description to ROC for implementation on the NEXRAD WSR-88D. Additionally, we provided scientific and technical support to assist NCAR and ROC with incorporation of the improved estimators into the NEXRAD hybrid spectrum width estimator.



2-D histograms of true (x-axis) to estimated [y-axis, $\hat{\sigma}_v(0, 1)$ (left) to $\hat{\sigma}_v(0^1, 1)$ (right)] spectrum width for 5,000 realizations of a 20 dB SNR simulated weather signal. The logarithmic color scale displays the percentage of the total realizations (5,000) from 0% (blue) to 100% (maroon). The large arrows (bottom of figures) indicate a breakdown in the estimator where meaningless values are assigned 0 ms^{-1}. The smaller arrows indicate the spread (variance) of the output estimates. Improvements are seen as reduced variance and less bias for the new ($R0^1/R1$) estimator on the right as compared to the classic (R0/R1) estimator on the left.

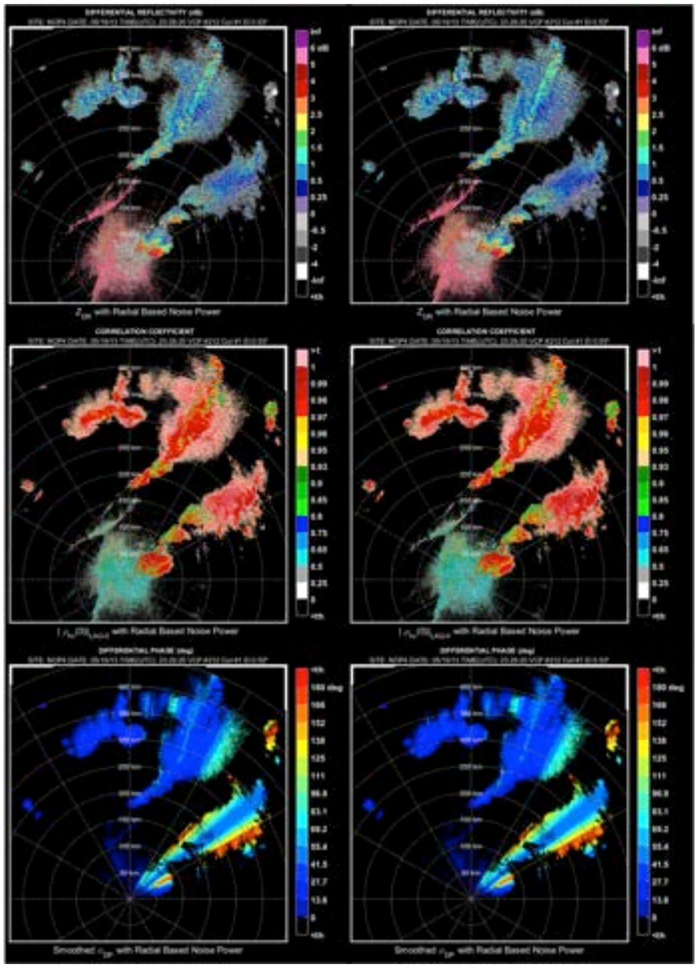
g. Less-Tapered Windows to Improve Dual-Polarization WSR-88D Data

Igor Ivić (CIMMS at NSSL)

To achieve better detection of mesocyclone and tornado signatures, super-resolution base data with finer resolution on a 250 m-by-0.5° grid is produced. To achieve the finer

azimuthal resolution, the von Hann window is applied to data at every range position. Fine azimuthal resolution is warranted for the velocity product because the mesocyclone and tornado signature detection algorithms use it. However, in case of other products, the azimuthal resolution is less important. Application of a tapered window reduces the amount of information from which estimates are extracted resulting in increased variances and, in some cases, biases of base data. Degradation in the data quality is most visible for polarimetric variable estimates when the von Hann window is applied. This prompted the proposal to replace the von Hann window with a less-tapered one for dual-polarization products. To address this, a less-tapered window was developed, which allows for adjustment of azimuthal resolution so that the balance between the data quality degradation and resolution can be achieved.

During FY15, a presentation demonstrating the polarimetric data quality improvement resulting from the less tapered window application was presented to the NEXRAD Technical Advisory Committee. A subsequent presentation was also given to the ROC team, where two options for the less-tapered window were proposed. The first option was the rectangular window, which resulted in the most data quality improvement but the largest increase in effective beamwidth. The second option proposed was the modified von Hann window, which produced a level of data quality improvement between the current von Hann and rectangular window but also yielded smaller effective beamwidth compared to the rectangular window. At the same meeting, it was concluded that the application of rectangular window produced too large of an effective beamwidth increase. The team found the modified von Hann window to be more acceptable and made the decision to proceed with efforts to implement this (or a similar) window for polarimetric products. Due to the implementation aspect, it was decided that the less-tapered window would also be applied to reflectivity data.



Comparison between fields produced using the von Hann window (left) and the modified von Hann window (right) at 0.5 ° elevation. The fields on the right are visibly less noisy.

h. Real-Time Weather Signal Processing

Eddie Forren and John Thompson (CIMMS at NSSL)

Prior to this reporting period, NSSL's radar-independent real-time digital signal processing software was significantly rewritten, and the rewrite was capable of processing non-oversampled NWRT data, traditional NEXRAD data, or Sigmet sector scan data. Real-time or playback processing was available for NWRT data, and playback processing was available for NEXRAD/Sigmet sector data. However, Sigmet sector data had to be processed with different command line flags from NEXRAD scans, and testing on sector scan processing was limited. Functions implemented from the MATLAB/offline version included basic dual polarization processing with CLEAN-AP clutter filtering, calculations based on the R0/R1 Autocorrelation Spectral Density function, and some other functionality from the previous NWRT versions adapted to handle dual polarization data. To support real-time processing, an initial version of a

tool to capture real-time KOUN data from the UDP broadcast and feed it to the DSP was developed.

During this reporting period, Sigmet sector and NEXRAD scan processing was significantly enhanced and tested to work better and more seamlessly to support switching between streams. Range oversampling processing and several other DSP functions were implemented, tested, and validated using KOUN and NWRT data. For offline testing, tools to record and playback the broadcast data stream were developed; data was collected several times to test and refine the software. While many problems were solved and we are fairly close to real-time testing, the real-time processing stream was not fully functional at the end of this reporting period because of significant 64-bit porting work required for the Advanced Technology Demonstrator (ATD) project. Since 32-bit operating systems will be phasing out over the next couple of years, the 64-bit port will eventually be used for both KOUN and ATD processing.

Most of the effort for this work involved testing, finding problems, and iteratively enhancing the software. Problems with idiosyncrasies in the playback and real-time data streams, buffer sizing, calibration values in the data stream, radial offloading, bad radials, speed, data drops in the broadcast stream, setup of the real-time processing environment, and a few carryover problems from previous development were resolved.

As of the end of this reporting period, the software is in relatively good shape, and testing of a fully functional real-time thread is expected soon. Following shortly thereafter will be work to collect and process oversampled data in real-time.

i. Hardware Development and Maintenance for KOUN and Mobile Radars

Danny Wasielewski and Mike Schmidt (CIMMS at NSSL), and Mike Shattuck (NSSL)

NSSL maintains several radar assets used by researchers, including both mobile radars and NSSL's research and development WSR-88D, KOUN. In addition to their use as meteorological and hydrological research instruments, these radar assets also serve as testbeds for technological research. Technologies prototyped on KOUN in particular are directly applicable to the WSR-88D network. Maintenance and continual improvement of these assets is essential to providing high quality instruments for new research and for supporting NSSL's commitment to Research-to-Operations.

<u>KOUN</u>. The ROC performed a major hardware and software upgrade on KOUN in December 2014 as a risk reduction activity for the planned tech refresh of the entire WSR-88D network. This upgrade caused several compatibility issues addressed by CIMMS staff. NSSL's custom data acquisition software was modified for compatibility with the new signal processor software. The changes also rendered obsolete several of the processors NSSL maintained on the KOUN network. A development machine configured identically to the old (replaced) KOUN signal processor was removed. Another machine was repurposed as a development machine for the new signal processor. NSSL also maintains two passive digital signal processors (DSPs) for

prototyping new signal processing techniques without impacting the operational system. The software on these DSPs was modified for compatibility with the data format of the new KOUN signal processor. Additionally, these DSPs were configured for multi-node processing, and a RAID was configured on one for data storage. A faulty power distribution unit was identified and replaced.

Mobile Radars. The signal processor for NOXP was upgraded to the Sigmet RVP900 in September-October 2014 in order to support the needs of the PECAN field experiment in June 2015. This effort also involved moving and reconfiguring large parts of the server rack and transmitter cabinet. The uninterruptible power supply batteries were found to be weak and were replaced. A new antenna controller was selected to replace the current, unreliable antenna controller. A list was generated of upgrades and improvements to perform between NOXP's return in July 2015 and redeployment in March 2015. Various repairs were performed on the C-band SR-2 mobile radar. An issue with antenna azimuth alignment was resolved by replacing a photointerrupter on the rotary joint. The slip rings were cleaned and several worn brushes replaced. The Radar Control Workstation motherboard was replaced to resolve an intermittent boot-up problem.

j. WSR-88D Data Management

Richard Adams (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 FY15, data from KOUN, several operational WSR-88D radars, and the NWRT PAR were archived. We actively coordinated with IT staff for the maintenance and development of the RAID systems. This work is ongoing.

k. Improving the Quality of Polarimetric WSR-88D

Valery Melnikov (CIMMS at NSSL)

Various methods for calibration of differential reflectivity Z_{DR} have been investigated. The method based on the use of ground clutter was explored in a particular detail. Increasing sensitivity of the WSR-88D radars was another focus of research, which resulted in development of the algorithm for detection of non-precipitating clouds. The reports summarizing latest findings will be available upon request and presented on the NSSL website in October 2015.

Publications

Torres, S. M. and C. D. Curtis, 2015: The impact of range oversampling processing on tornado velocity signatures obtained from WSR-88D super-resolution data. *Journal of Atmospheric and Oceanic Technology*, **32**, 1581-1592.

Torres, S. and D. Warde, 2014: Ground clutter mitigation for weather radars using the autocorrelation spectral density. *Journal of Atmospheric and Oceanic Technology*, **31**, 2049-2066.

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. Optimization of the QPE Algorithms based on Specific Attenuation and Specific Differential Phase

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

The Quantitative Precipitation Estimation (QPE) algorithms based on the use of specific attenuation A and specific differential phase K_{DP} have been further refined and tested using operational WSR-88D radars and the Multi-Radar Multi-Sensor (MRMS) platform for systematic comparisons of radar rainfall estimates with rain gauge measurements. Some of the work has been done as part of international collaboration with researchers from Canada, Germany, Korea, and Taiwan with results summarized in four journal publications.

The algorithms' optimization was implemented via (a) automatic determination of the key parameters of the R(A) and R(K_{DP}) algorithms based on the real-time estimation of the Z_{DR} slope, (b) developing robust routine for estimation of the total span of differential phase $\Delta\Phi_{DP}$ in rain, and (c) substituting currently calculated values of K_{DP} with the ones obtained from $\Delta\Phi_{DP}$ and the radial profiles of Z in the areas where the quality of routinely estimated K_{DP} is compromised.

b. Validation of the Hail Size Discrimination Algorithm (HSDA) and Exploring its Further Refinements

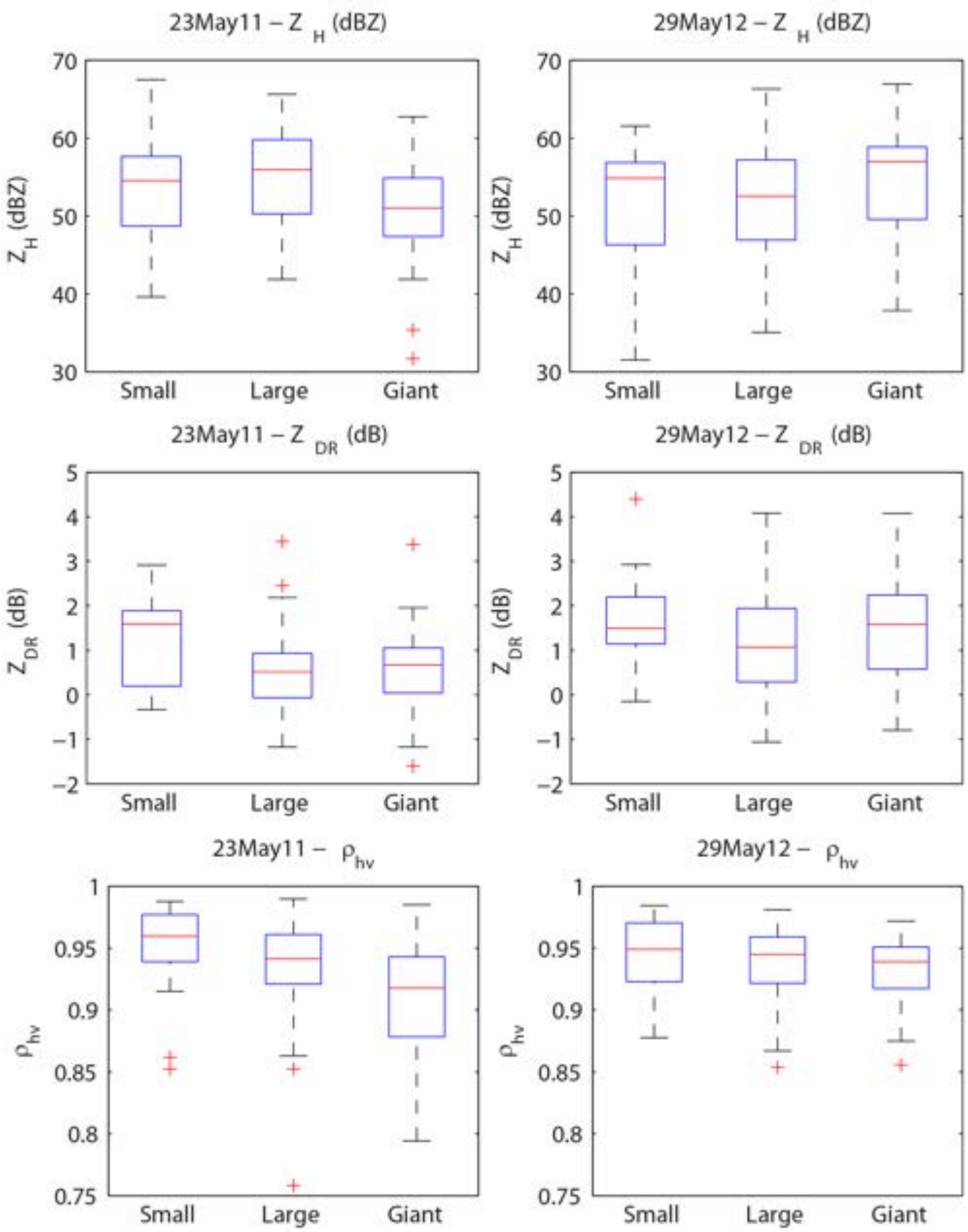
Kiel Ortega, Alexander Ryzhkov, Jeff Snyder, and John Krause (CIMMS at NSSL)

The Hail Size Discrimination Algorithm (HSDA) which distinguishes between small ($D < 2.5$ cm), large ($2.5 \text{ cm} < D < 5.0$ cm), and giant ($D > 5.0$ cm) hail has been optimized and tested using new validation methodology. The HSDA validation is performed using radar data collected by numerous WSR-88D radars and more than 3000 surface hail reports obtained from the Severe Hazards Analysis and Verification Experiment (SHAVE).

The original HSDA version was modified in the process of validation and the modified algorithm demonstrates probability of detection (POD) of 0.594, false alarm rate (FAR) of 0.136, and resulting critical success index equal to 0.543. The HSDA algorithm outperformed the current operational single-polarization Hail Detection Algorithm (HDA), which only provides a single hail size estimate per storm and is characterized by CSI equal to 0.324. It is shown that HSDA is particularly sensitive to the quality of Z_{DR}

measurements that might be affected by possible radar miscalibration and anomalously high differential attenuation.

A special study of polarimetric characteristics of giant hail exceeding 12 cm in diameter has been performed for two supercell storms occurred in central Oklahoma on 23 May 2011 and 29 May 2012. These events were sampled by polarimetric S-band radar (KOUN) and polarimetric X-band mobile radar (RaXPol) and the corresponding high-resolution in situ hail observations at the surface were available from the HailSTONE field project. Results of the HSDA validation and giant hail investigations are presented in a journal article and a conference paper.



The HailSTONE observations from the two supercells examined for this project were matched to KOUN radar data in time and space. The distribution of Z_H, Z_{DR}, and ρ_{hv} for small (diameter < 2.54 cm), large (diameter between 2.54 cm and 7.62 cm), and giant (diameter exceeding 7.62 cm) are plotted for each quantity. The blue boxes represent the 25th and 75th percentiles; the whiskers extend to approximately the 1st and 99th percentiles, and the red line marks the median value. Unfortunately, at least for these two datasets, there is an inconsistent trend in the quantities, particularly those characterizing large vs. giant hail. It is likely that additional information regarding updraft intensity (e.g., Z_{DR} column height, magnitude of ρ_{hv} reduction aloft, etc.) will be necessary to better discriminate between large hail and giant hail.

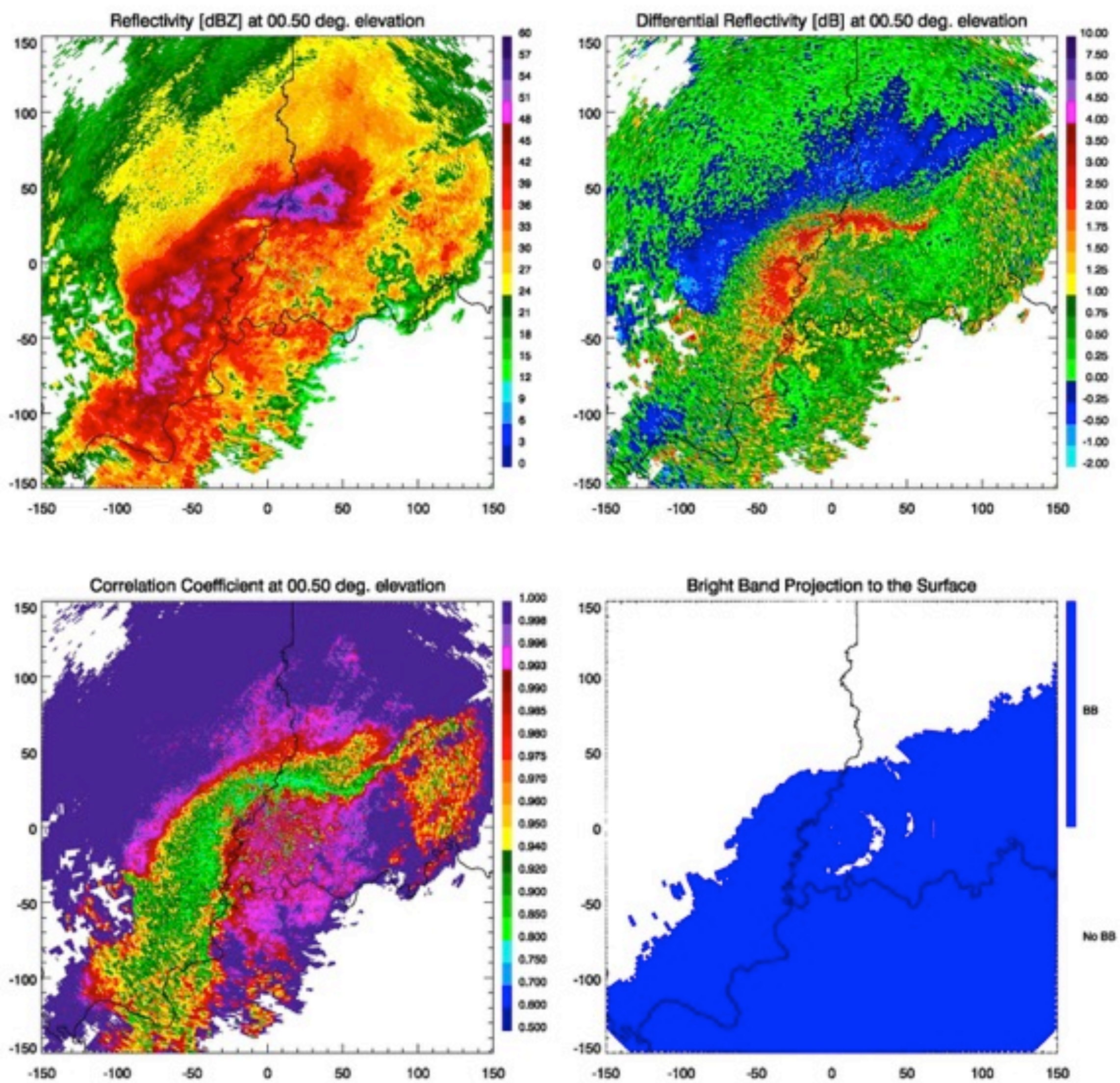
c. Improving Melting Layer Detection for a New Surface-based Polarimetric Hydrometeor Classification Algorithm for the WSR-88D Network

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

The failure of the currently-deployed fuzzy-logic-based Hydrometeor Classification Algorithm (HCA) to provide accurate precipitation type designations in transitional winter weather events is largely due to 1) the HCA providing classifications on conical surfaces, which are often not representative of the precipitation type observed at ground level, and 2) a Melting Layer Detection Algorithm (MLDA) that only uses high elevation scans and then projects the results out to more distant ranges, which often leads to erroneous melting layer detections at more distant ranges from the radar. This has led to the development of a new surface-based HCA that uses thermodynamic information from the High Resolution Rapid Refresh (HRRR) model to provide a background classification that can then be modified later if warranted by polarimetric radar observations. The radar-based modification, in turn, relies heavily on the accurate detection of the melting layer, thereby stressing the importance of improving upon the existing melting layer detection technique.

As part of a surface-based HCA project, a new "hybrid" MLDA that uses both data from polarimetric radars and thermodynamic output from the HRRR model is currently under development. The advantages of polarimetric radar observations include their typically high (5-10 minute) temporal resolution, as well as their ability to provide excellent melting layer detections at near to moderate distances from the radar. On the other hand, the disadvantage of polarimetric radar observations is their inability to provide information at more distant ranges from the radar where the radar's beam, even at the lowest elevation angles, may be well above the melting level. These advantages and disadvantages, in contrast, are complemented well by numerical model output which, though not actual observations and of somewhat poorer (60 minute) temporal resolution, provides information that is of increasing importance to the melting layer detection process at more distant ranges from the radar. With the new "hybrid" MLDA, polarimetric radar data and numerical model output from the HRRR are both used to provide melting layer designations at all ranges from the radar. To take advantage of these strengths and weaknesses of each of their respective contributions, however, a combination of range-based and Gaussian weighting functions are used to increase

(decrease) the importance of the radar (model) contribution at close ranges to the radar, increase (decrease) the importance model (radar) contribution at more distant ranges from the radar, and to decrease the overall importance of the model contribution as the Dt from the radar volume time and model analyses time increases. An example of the "hybrid" MLDA results for a winter weather event observed by the KVWX (Evansville, Indiana) radar at 170140 UTC on 5 January 2014 is shown in the figure below.

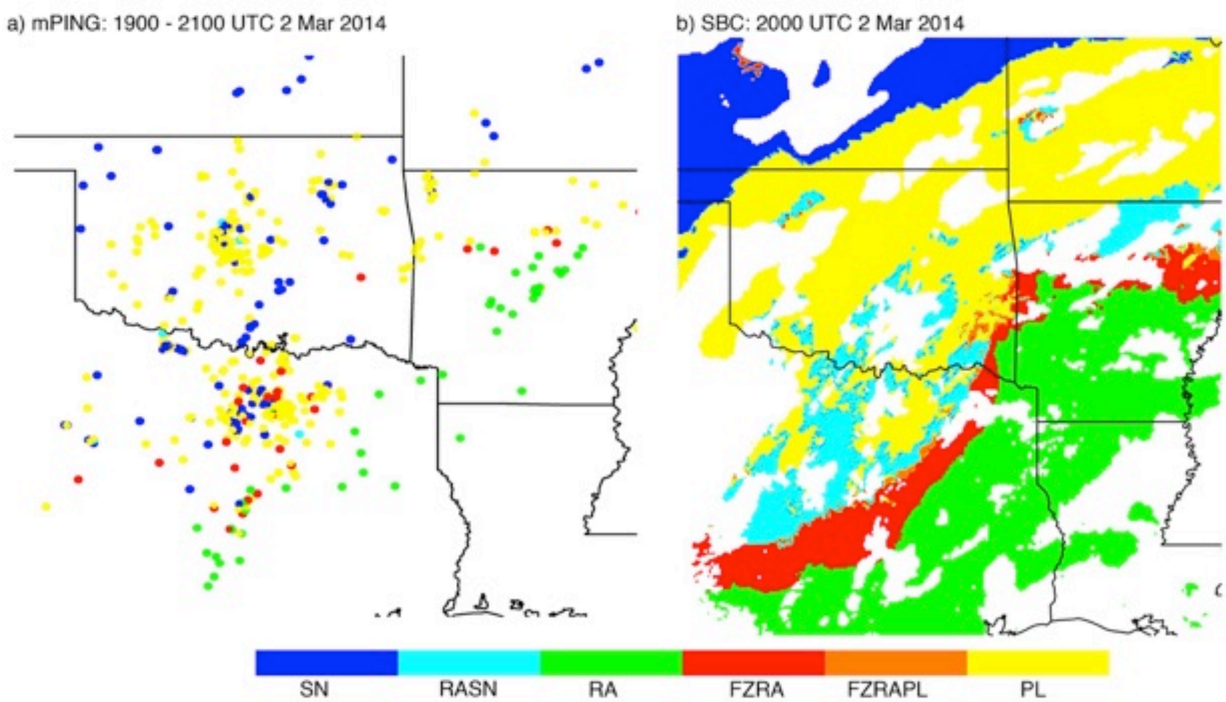


Radar reflectivity (upper left), differential reflectivity (upper right), correlation coefficient (lower left), and hybrid MLDA results (lower right) for a winter weather event observed by the KVWX (Evansville, Indiana) radar at 170140 UTC on 5 January. In the lower right panel, blue depicts the locations where the hybrid MLDA determined the presence of a melting layer.

d. The Creation of a Background Surface Hydrometeor Classification Algorithm for Use with Dual-Pol Observations

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

The aim of this project is to create a background or first-guess of the surface precipitation type using numerical model data. This background class will then be modified using dual-polarized observations. A classifier was created that explicitly calculates the liquid-water fraction (LWF) of falling hydrometeors and uses the summed LWF at the surface in concert with wet bulb temperature data to assign a class. This classifier is referred to as the Spectral Bin Classifier (SBC). The SBC distinguishes between six classes: rain, snow, wet snow, freezing rain, ice pellets and a freezing rain/ice pellet mix. Comparisons of the SBC to previously developed ones shows superior performance. It also has the added advantage of allowing one to identify regions of super-cooled liquid water aloft and to provide the LWF at the surface, which is useful for hydrological and transportation applications.



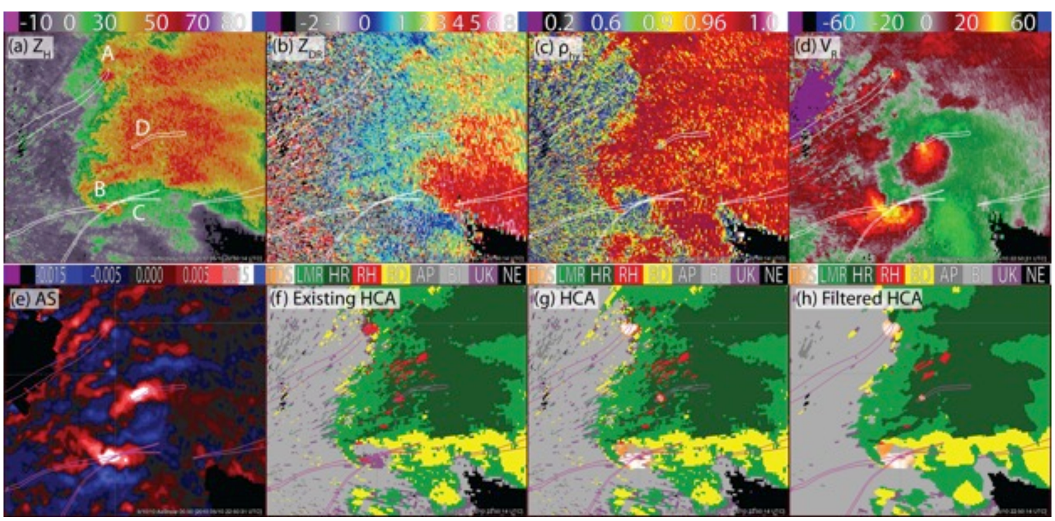
Observed surface precipitation type according to the meteorological Phenomena Identification Near the Ground (mPING) data (panel a) and the surface precipitation type according to the Spectral Bin Classifier (SBC) (panel b).

e. Automated Detection of the Polarimetric Tornadic Debris Signature

Jeff Snyder, Alexander Ryzhkov, and John Krause (CIMMS at NSSL)

Owing to the distinctly different scattering characteristics of debris lofted in a tornado relative to those of hydrometeors, polarimetric weather radar can be an effective tool for detecting tornado debris. Whereas the spatiotemporal resolution of the WSR-88D is often insufficient to resolve tornadoes well (or at all), debris produced by a tornado occupies a relatively unique part of the parameter space of polarimetric quantities; specifically, a tornado debris signature (TDS) is characterized by moderate to high Z_H, relatively low Z_{DR}, and reduced ρ_{hv} co-located with a strong rotational couplet in V_R. When visual confirmation is difficult (e.g., in locations where visibility is restricted or at night), the presence of a TDS can provide operational meteorologists with critical confirmation that a destructive tornado is occurring.

A hydrometeor classification algorithm (HCA) is used within the WSR-88D network to provide an estimate of the dominant hydrometeor in a radar resolution volume. We have modified the existing HCA to add a new TDS output class; the addition of a TDS category required the addition of azimuthal shear (currently, as estimated through the local least squares derivative method) as an input. We described the algorithm and showed results from several tornadic events observed by WSR-88D radars in a manuscript that was accepted for publication in June 2015.



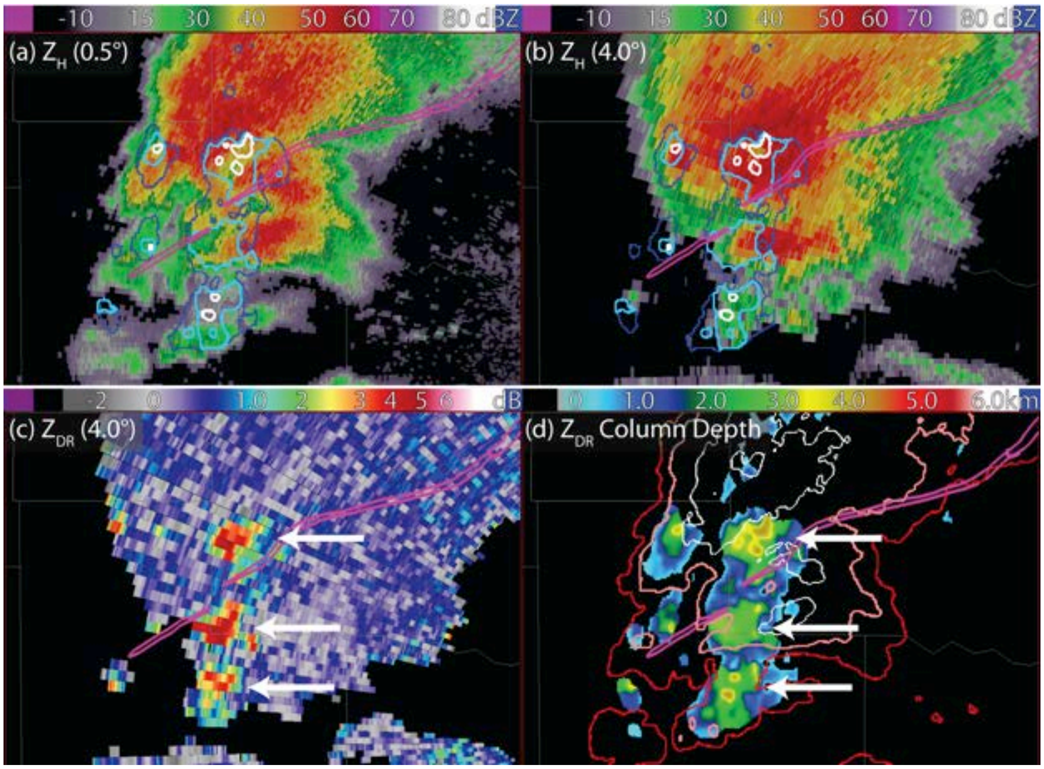
Z_H (dBZ), (b) Z_{DR} (dB), (c) ρ_{hv}, (d) V_R (m s^{-1}), (e) AS (s^{-1}), and results from the (f) existing HCA and the (g) new HCA valid near 2250 UTC on 10 May 2010 from the KOUN WSR-88D radar in Norman, Oklahoma. New HCA results filtered using a 5x5 mode filter to reduce speckling can be seen in (h). Tornado paths as determined by the Norman NWS Forecast Office are shown as (a-d) white or (e-h) magenta polygons. Letters A, B, C, and D denote the paths of four tornadoes that were ongoing at this time. HCA output classes are labeled as TDS, LMR (light/moderate rain), HR (heavy rain), RH (rain/hail mixture), BD (big drops), AP (anomalous propagation), BI (biological), UK (unknown), and NE (no echo).

f. Development of a Z_{DR} Column Detection Algorithm

Jeff Snyder and Alexander Ryzhkov (CIMMS at NSSL)

Characterizing the intensity and structure of convective storm updrafts can provide valuable information about the threats posed by such storms. Unfortunately, using only Z_H available from conventional weather radars can limit how much an operational meteorologist can infer about storm intensity. Polarimetric weather radars, however, provide much more information about hydrometeor type, shape, and composition. In particular, Z_{DR} can be used to infer the location of rain or mixed-phased hydrometeors (e.g., wet hail). Numerical modeling and previous observational studies have noted a strong association between the location of convective storm updrafts and columns of enhanced Z_{DR} above the ambient freezing level (appropriately called Z_{DR} columns). During the current reporting period, we showed results of simulated Z_{DR} columns in a high-resolution numerical model with spectral bin microphysics.

To illustrate the potential operational application of Z_{DR} columns, we have developed a Z_{DR} column algorithm that provides the depth of the Z_{DR} column above the local environmental 0 ºC level. The estimates of Z_{DR} column depth were compared with storm-top divergence and echo top height – two other measures that have been used operationally to assess updraft intensity – for two strong supercells observed in central Oklahoma, and the retrieved output was also compared with updraft velocity data obtained by other researchers using different radar data and different methods. In general, Z_{DR} column depth as estimated by the algorithm corroborates other measures of and methods for obtaining updraft intensity. The sampling strategies used by operational WSR-88Ds tend to yield quite limited vertical data coverage and resolution in the middle troposphere; these suboptimal strategies can degrade (and inhibit) the ability to sample Z_{DR} columns in their full vertical extent. As such, the algorithm performs poorly at longer distances from the radar (e.g., >150 km) and for shallow Z_{DR} columns and/or weak convective storm updrafts. A discussion of the algorithm and some results has been included in a recently submitted manuscript.



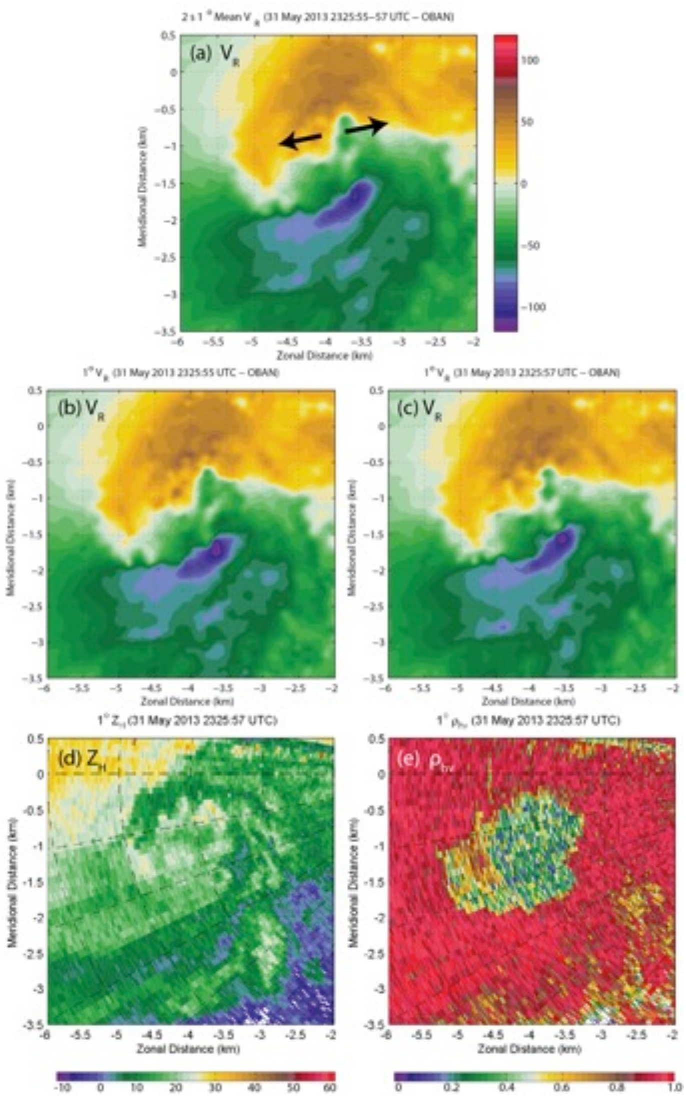
Data from a supercell near El Reno, OK, near 2055 UTC near the genesis of a violent tornado -- (a) Z_H at 0.5º elevation angle (dBZ), (b) Z_H at 4.0º elevation angle (dBZ), (c) filtered Z_{DR} at 4.0º elevation angle (dB), and (d) Z_{DR} column depth provided by the Z_{DR} column algorithm (km above the environmental 0 ºC level). Three primary Z_{DR} columns are identified by the algorithm and noted by white arrows in (c) and (d). Z_{DR} column depth contours at 1 km, 2.3 km, and 3.7 km are marked in dark blue, light blue, and white contours in (a) and (b). Contours of Z_H at 10 dBZ, 30 dBZ, and 50 dBZ are marked in red, pink, and white in (d). The purple swaths in all panels are tornado tracks from the Norman, OK NWS Forecast Office.

g. Examining the Polarimetric Structure of Tornadic Supercells Using High-Resolution Radar Data

Jeff Snyder (CIMMS at NSSL)

In order to examine the evolution of tornadoes, it is often useful, if not required, to use a rapid-scan radar owing to the very short characteristic/advection time scale of tornadoes [i.e., O(10 s)]. Since 2011, faculty and students at OU have used mobile, rapid-scan, polarimetric weather radar to study tornadic supercells. The annual spring field campaigns have produced some very unique data. In Houser et al. (2015), we discussed the evolution of an intense, tornadic supercell that occurred on 24 May 2011; in particular, we examined a ~20 minute period during which a strong tornado dissipated and an extremely intense tornado developed. Rapid-scan polarimetric radar data of an exceptionally intense tornado collected on 31 May 2013 have been used in several publications written and/or published in the reporting period (i.e., Snyder and Bluestein

(2014); Bluestein et al. 2015; Wakimoto et al. 2015). In Snyder and Bluestein (2014), some considerations are highlighted regarding the comparison of radar data estimates of radial velocity with damage-based wind speed estimates obtained through the Enhanced Fujita Scale. Several other datasets are being analyzed, with the goal of examining the spatiotemporal evolution of the observed tornadic supercells. For example, Z_{DR} column estimates from KTLX are being compared with dual-Doppler-retrieved updraft estimates using data collected in a violent-tornado-producing supercell in central Oklahoma on 19 May 2013.



RaXPol data from 2325:55–2325:57 UTC on 31 May 2013 valid at a truck-relative elevation angle of 0.0º objectively-analyzed using a two-pass Barnes scheme with horizontal grid spacing of 15 m, $\kappa = 0.0097$ km^2, and $\gamma = 0.3$: (a) an average V_R using two consecutive scans separated by 2 s, (b) analyzed V_R at 2325:55 UTC, (c) analyzed V_R at 2325:57 UTC, (d) Z_H, and (e) ρ_{hv}. In (a)–(c), gates with NCP < 0.2 have been removed, and the analysis linearly interpolated V_R for such gates. Accounting for non-zero platform pitch and roll, the antenna boresight-aligned estimated beam height

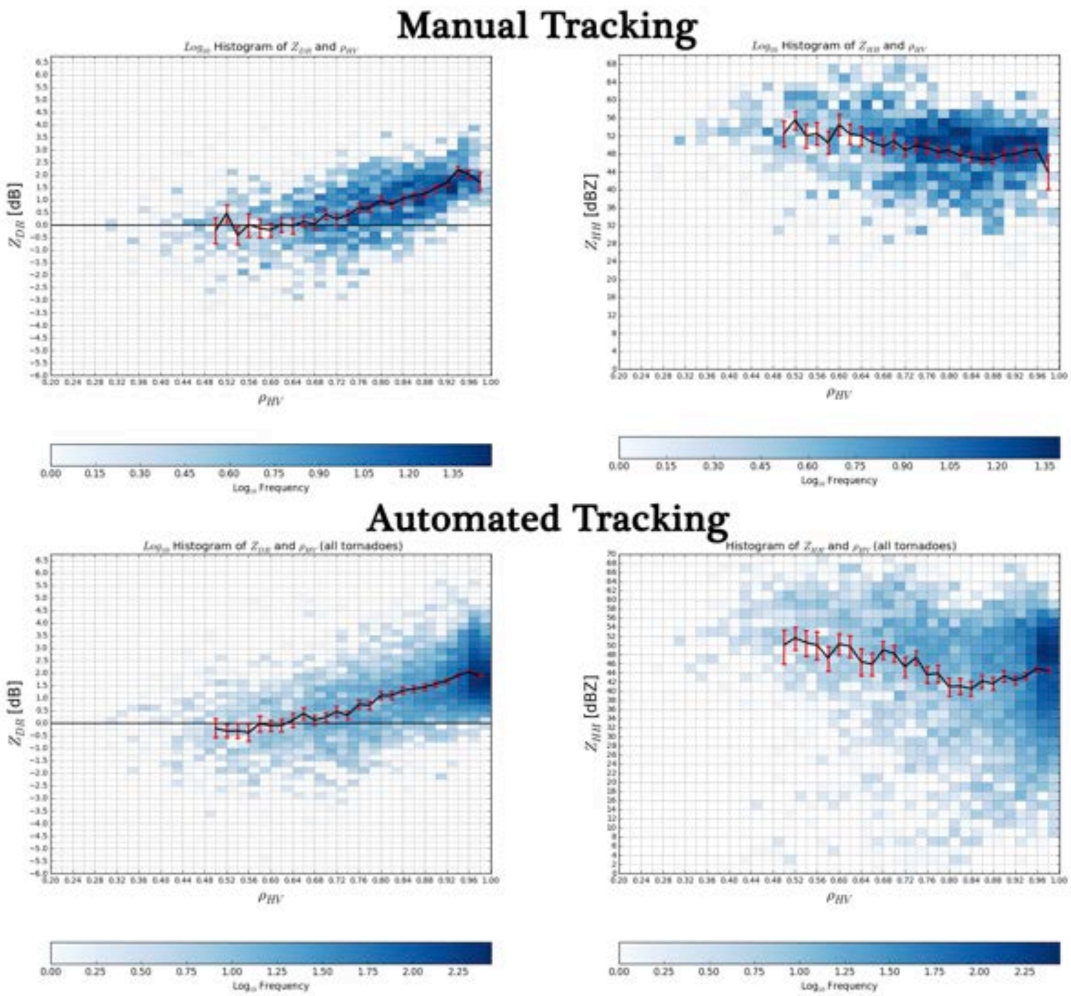
through the tornado center is approximately -50 m ARL; partial beam blockage from nearby trees and other structures, as well as significant ground interception as an increasingly amount of the radar beam interaction with the ground, essentially left only the top part of the antenna pattern illuminated. Range rings are plotted every 1 km. Maximum inbound averaged V_R in (a) is 109.3 m s^{-1}; the maximum V_R in (b) and (c) is 119.5 m s^{-1} and 116.4 m s^{-1}, respectively. Strong radial divergence is observed near the center of the tornado [denoted by black arrows in (a)], potentially indicating that the tornado has primarily a two-cell structure. Axes labels in all panels are relative to the radar location. (From Snyder and Bluestein 2014).

h. Develop Climatology of Tornadic Events Scanned by the Polarimetric WSR-88D for New Algorithm Development, Existing Algorithm Correction, and Signature Studies

Darrel Kingfield, Kiel Ortega, and Samuel Degelia (CIMMS at NSSL)

Tornadic debris contains a diverse range of non-meteorological scatterers with respect to size, shape, and orientation. When scanned with polarimetric radar, a tornadic debris signature is usually identified by a decrease in co-polar cross correlation coefficient (ρ_{HV}), a decrease in differential reflectivity (Z_{DR}) to around zero, and an increase in horizontal reflectivity (Z_{HH}). With the national rollout of polarimetric capabilities to the WSR-88D completed in 2013, a geographically and climatologically diverse dataset of polarimetric signatures of tornadoes can be assembled.

Utilizing relative positions of tornado genesis and dissipation from the *Storm Data* publications, all WSR-88D data within 140km of either point are processed within a +/-30 min time window around the event. The reflectivity field was further quality controlled using a neural network to remove spurious artifacts while the velocity field was dealiased using a two-dimensional dealiasing scheme with a model-derived near-storm velocity profile. Azimuthal shear was derived from the velocity field using a local linear least squares derivatives technique to generate velocity products that are less susceptible to noise and other issued affecting radar quality. Currently, 2103 candidate paths have been processed through this system. Further development of this dataset and subsequent applications is ongoing.



Two-dimensional histograms of ρ_{HV} vs. Z_{DR} (left column) and ρ_{HV} vs. Z_{HH} (right column) using a 3x3 window around a (top) human-identified tornado central point and (bottom) an automated technique that identifies the highest azimuthal shear within a 5-7.5km variable spatial buffer around an estimated tornado position. Both techniques show similar directionality between variables but the human technique is far cleaner with tighter distributions at each sampling interval.

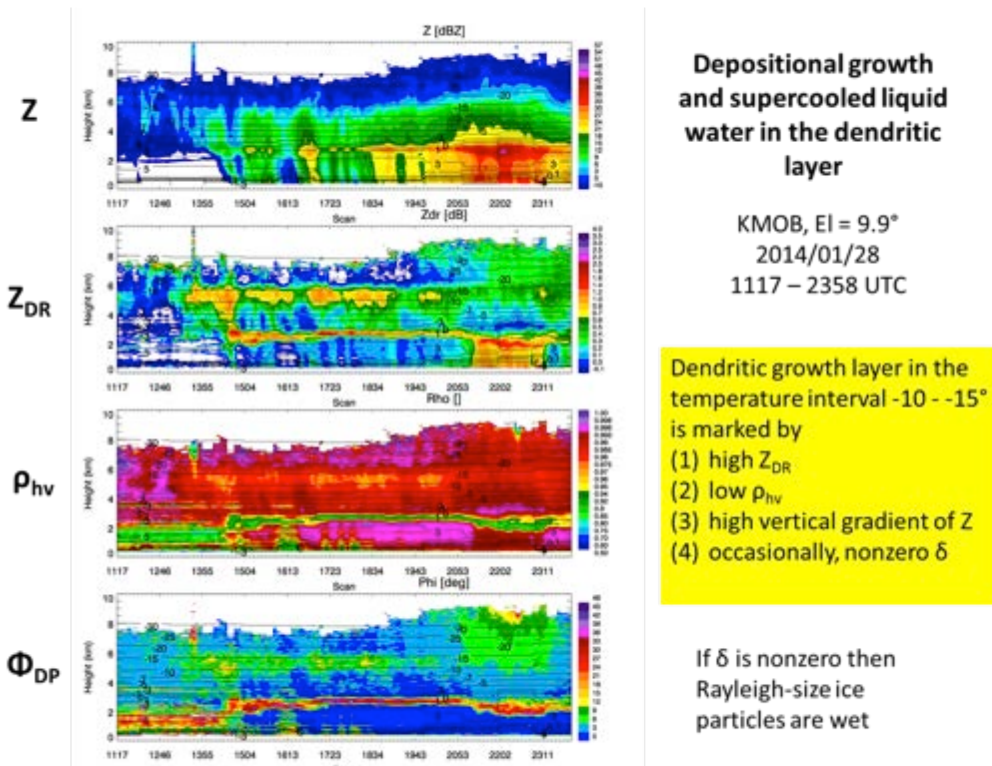
i. Using Quasi-Vertical Profiles (QVP) Methodology for Investigation of Microphysical Processes in Mixed-Phase Clouds

Alexander Ryzhkov, Pengfei Zhang, John Krause, and Heather Reeves (CIMMS at NSSL)

A novel methodology has been recently introduced at CIMMS for processing and representing polarimetric data collected by weather surveillance radars. It involves azimuthal averaging of radar reflectivity Z, differential reflectivity Z_{DR}, cross-correlation coefficient ρ_{hv}, and differential phase Φ_{DP} at high antenna elevation and presenting resulting "quasi-vertical profiles (QVPs)" in a height vs. time format. Multiple examples

of QVPs retrieved from the data collected by S-, C-, and X-band dual-polarization radars at elevations ranging from 6.4° to 28° illustrate advantages of the QVP technique. The benefits include an ability to examine temporal evolution of microphysical processes governing precipitation production and compare polarimetric data obtained from the scanning surveillance weather radars with observations made by vertically looking remote sensors, such as wind profilers, lidar, radiometers, cloud radars, and radars operating on spaceborne and airborne platforms. Continuous monitoring of the melting layer and the layer of dendritic growth with high vertical resolution as well as possible opportunity to discriminate between the processes of snow aggregation and riming constitute other potential benefits of the suggested methodology.

QVPs of polarimetric radar variables combined with in situ aircraft measurements and other complementary radar measurements in two stratiform precipitation events during the Midlatitude Continental Convective Clouds Experiment (MC3E) have been examined in great detail and provide insight into microphysics of snow genesis and formation above the freezing level. The results of such analysis combined with various examples of QVPs at different radar wavelengths in different types of clouds are summarized in three journal papers.



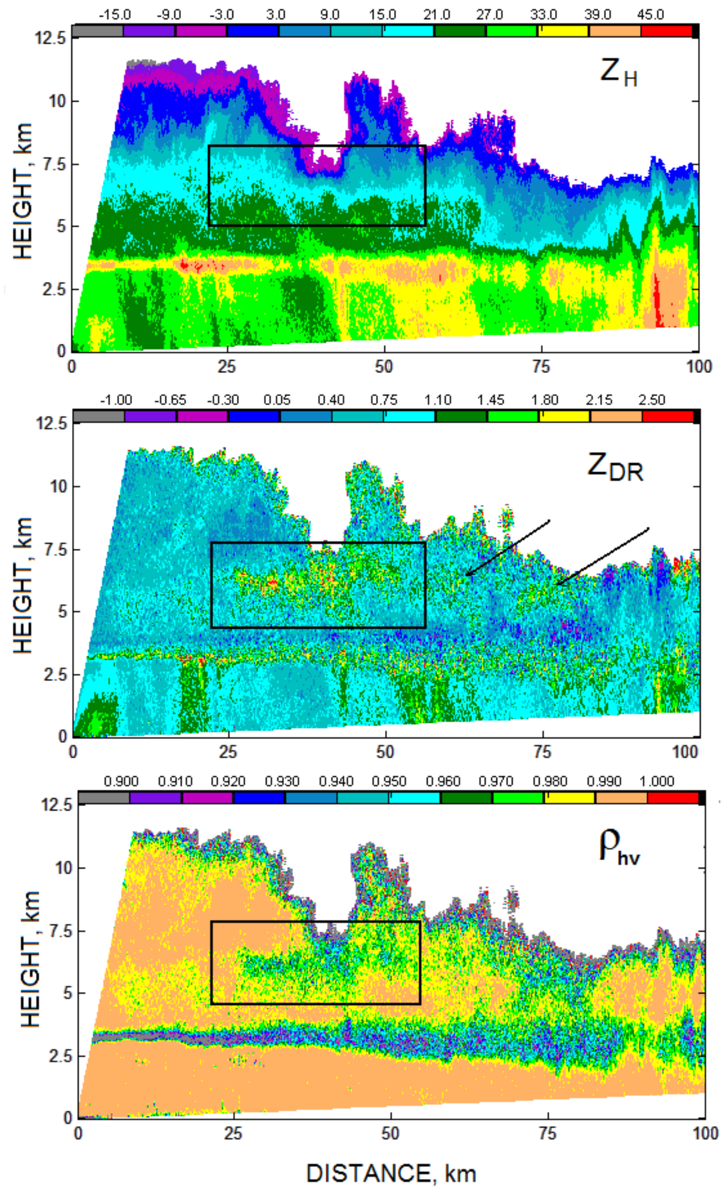
The height vs. time representation of the quasi-vertical profiles of polarimetric radar variables retrieved from the KMOB WSR-88D observations on 28 January 2014. The melting layer at the height of about 2 km and dendritic growth layer between 5 and 6 km are clearly identified in the plot.

j. Airborne Microphysics Data Collection During the Plains Elevated Convection at Night (PECAN) PROJECT: Understanding Polarimetric Radar Signatures in MCS Stratiform Regions

Terry Schuur (CIMMS at NSSL)

With the deployment of radar polarimetry across the WSR-88D network, an opportunity exists to study the relationship between polarimetric signatures, and the thermodynamic and microphysical processes that they represent, at spatial and temporal scales never before possible. In the past several years, several new, repeatable polarimetric signatures have been observed, yet their microphysical interpretation has relied almost exclusively on conventional wisdom, assumed particle types and concentrations, and electrostatic model simulations; very few datasets that document simultaneous in-situ kinematic, thermodynamic, and microphysical structure have been collected. An example of such a signature is an elevated region of enhanced specific differential phase (K_{DP}) and differential reflectivity (Z_{DR}) and reduced correlation coefficient (ρ_{hv}) that is typically found to be located at temperatures between -10 and -15°C and in a zone of a large radar reflectivity gradient, with Z increasing toward the ground often referred to as the dendritic growth signature/layer. Since this is a layer within which considerable water mass is added, a better understanding of its origins and strength has the potential to provide valuable information to operational forecasters that might be used to produce improved short-term forecasts for increases in rainfall or, in the case of winter storms, snow accumulation. Other recently discovered polarimetric signatures are equally intriguing and, in many cases, poorly understood.

During the Plains Elevated Convection at Night (PECAN) project, which was conducted over the central U.S. plains states in June-July 2015, the NOAA P-3 aircraft was deployed with a complete suite of microphysical instrumentation. As part of NSF-funded research, NOAA P-3 data were collected in nine Mesoscale Convective Systems (MCS) during the PECAN project. The NOAA P-3 data will be used to investigate the in-situ thermodynamic conditions, vertical motions, and precipitation particle types and concentrations, under the umbrella of the polarimetric radar coverage provided by WSR-88D network, mobile X-band NOXP radar, and mobile C-band SMART-R radars, therefore presenting a unique opportunity to not only advance our understanding of these signatures, but also of the thermodynamic and microphysical processes that they represent and the potential impact of those processes on the MCSs kinematic evolution.



RHI of radar reflectivity, differential reflectivity, and correlation coefficient measured by the polarimetric KOUN WSR-88D radar on 18 August 2008 (from Andrić, 2011). The box in each panel provides an example of an elevated "depositional growth" signature that will be investigated using the recently collected PECAN NOAA-P3 microphysics data set.

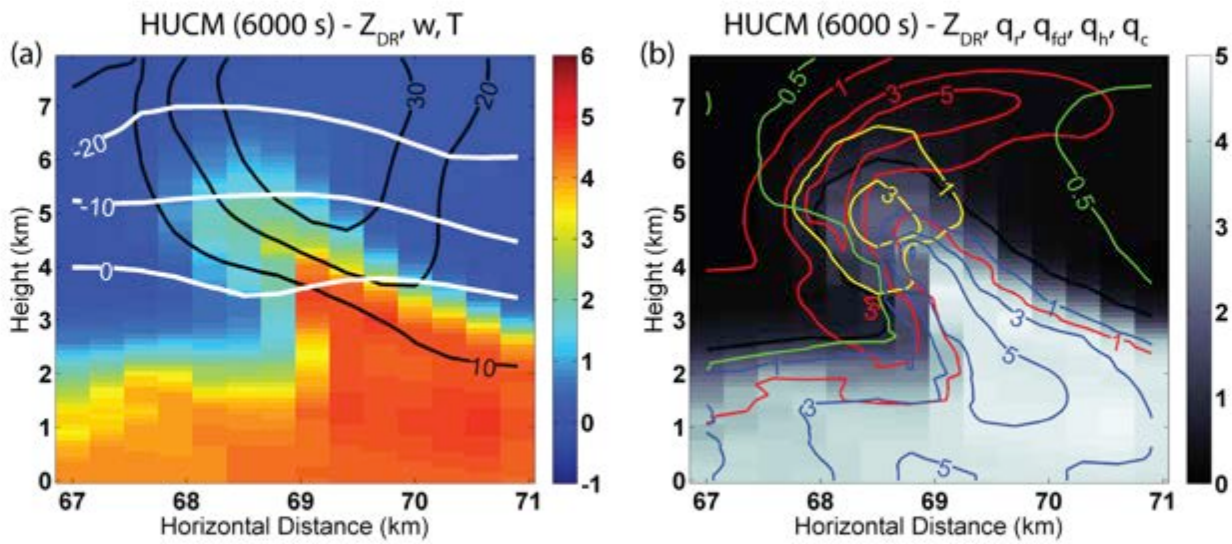
k. Studying Polarimetric Radar Signatures with an Advanced Forward Operator

Jeff Snyder and Alexander Ryzhkov (CIMMS at NSSL)

Convective storms have been simulated using numerical models for several decades. It can be quite difficult, however, to verify the accuracy of the model owing to the difficulty in obtaining verifying observations on the temporal and spatial scales used in the model.

Similarly, while we have an ever-expanding number of polarimetric radar datasets of convective storms, it can be difficult to know what the hydrometeor types and distributions being sampled by the radar. As numerical models and microphysics schemes have become more sophisticated, the opportunity to couple radar data with numerical model output has become quite clear.

During the reporting period, we have made some significant modifications to a forward operator currently embedded within the Hebrew University Cloud Model (HUCM). The forward operator calculates Z_H, Z_{DR}, ρ_{hv}, specific differential phase (K_{DP}), specific attenuation (A_H), specific differential attenuation (A_{DP}), and circular depolarization ratio (CDR) for the eight hydrometeor species handled by HUCM. Several bugs have been identified and fixed, and we began to update the forward operator to use a two-layer T-matrix scattering routine that should better represent the complex scattering behavior that can accompany melting hail and freezing raindrops.



(a) Z_{DR} (colored; dB), w (contoured in black every 10 m s^{-1} starting at 10 m s^{-1}), and air temperature (contoured in white at 0 ºC, -10 ºC, and -20 ºC) shows the general relationship between the Z_{DR} column and the updraft. (b) The general microphysical mass composition of the Z_{DR} column (grayscale color; dB) for rain (blue contours), freezing drops (yellow contours), and hail (red contours) every 2 g cm^{-3} starting at 1 g cm^{-3}. The 0.5 g cm^{-3} cloud water contour is shown in green.

I. Microphysical and Thermodynamic Retrievals Using Polarimetric Radar data for Assimilation Into Numerical Weather Prediction Models

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

Radar data is the only source of hydrometeor information available for assimilation on the scale of convective-resolving models, which have seen a surge in development in

the past two decades and will play a crucial role in the Warn-on-Forecast paradigm. This has necessitated the use of hydrometeor retrieval equations in many assimilation systems, which are widely used and have remained essentially unchanged since their inception decades ago.

Novel methods for retrievals of the mixing ratios of rain and hail 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. Basic principles for thermodynamic retrieval of vertical profiles of diabatic cooling/heating using polarimetric radar data are also outlined.

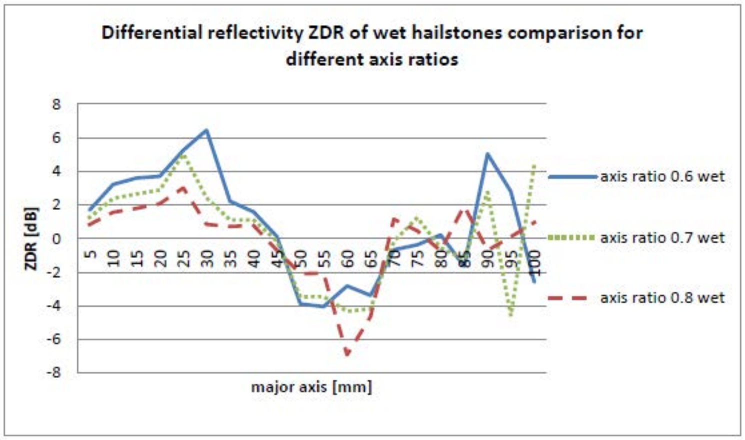
Another important aspect of this research is investigation of a life cycle of convective storms with a focus on the aerosol impact on the initial stage of convective development and radar characteristics of the first echo as revealed from radar observations and theoretical simulations based on the Hebrew University Cloud Model with spectral microphysics. Some of the aspects of this study are discussed in the paper by Jacob Carlin in *Physics Today*.

m. Computational Electromagnetics Applied to the Scattering Observed by the Polarimetric Weather Radar

Djordje Mirkovic (CIMMS at NSSL)

Most of routine computations of the scattering characteristics of atmospheric scatterers such as hydrometeors and biota are made either in Rayleigh approximation or using the T-matrix code that are valid for the objects of spherical or spheroidal shape. Such radar scatterers as snowflakes, hailstones, insects, birds, and bats may have very complex shape that affects their radar characteristics.

A commercially available computational electromagnetic software WIPL-D has been used to calculate the scattering matrices of irregular, rough shape atmospheric scatterers for the first time. The model explains negative values of differential reflectivity Z_{DR} of rough giant hailstones with diameters larger than 5 cm (see attached figure) and substantial reduction of the cross-correlation coefficient ρ_{hv} unaccounted for by the conventional models for scattering computations. Additionally, the ability of the WIPL-D software to realistically reproduce scattering characteristics of biota (e.g., Brazilian free-tailed bat) has been proven and tested via comparison with direct measurements in an anechoic chamber. The results of this study are summarized in the PhD dissertation of D. Mirkovic.



Z_{DR} of rough hailstones vs their size computed using the WIPL-D software for different aspect ratios and roughness of 2%.

n. Investigation of Size Distributions and Radar Characteristics of Snow Using 2D-video Disdrometer Data and Polarimetric Radar Measurements

Petar Bukovcic and Alexander Ryzhkov (CIMMS at NSSL)

Radar quantification of snow remains a difficult challenge due to high variability of snowflake size distributions, shapes, and density. For rain the Z–S relations are even more variable than the corresponding Z–R relations. Differential reflectivity Z_{DR} combined with Z has a potential to improve both snow classification and its quantification. Its possible role in improvement of snow QPE has been investigated using extensive datasets of snow disdrometer measurements in Oklahoma and Colorado combined with polarimetric WSR-88D radar observations performed in central Oklahoma from 2009 to 2015 winter season and west Colorado during the winter of 2013 / 2014. It was also found that the relation $S = aZ^b$ can be effectively parameterized by the intercept parameter of the exponential snow size distribution.

A new algorithm for 2D video disdrometer particle (snow) matching was introduced which mitigates the mismatching problems inherent to the existing algorithms for processing of disdrometer data.

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3. Phased Array Radar

Overall Objectives

Continue research and development in collaboration with NSSL and other government, industry, and university partners to determine the usefulness of phased array radars for meteorological observations in a multifunction environment. The NWRT PAR 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 multiple functions (i.e., aircraft and weather surveillance). Other areas of research and development include design of algorithms for fast scan radars, new display techniques, data analysis to study structure and dynamics of weather phenomena, novel fast and adaptive scanning techniques, adaptive beamforming techniques, and advanced digital signal processing techniques.

Accomplishments

a. MPAR Advanced Technology Demonstrator

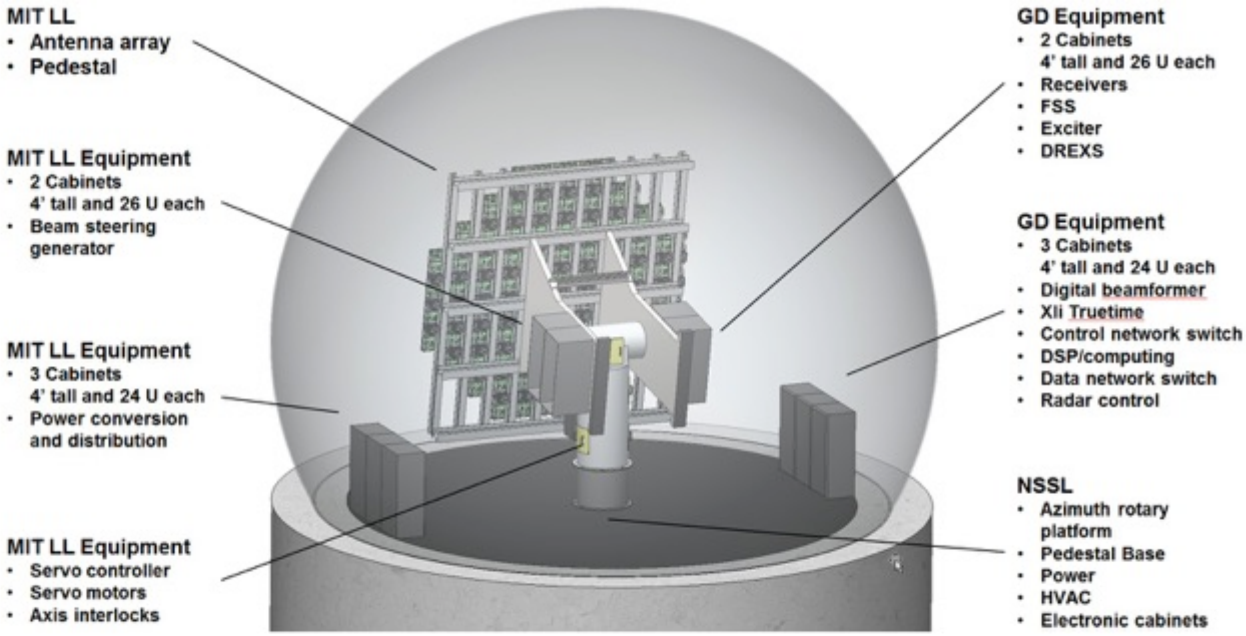
Hoyt Burcham, Christopher Curtis, Eddie Forren, Doug Forsyth, Brad Isom, Rick Rhoton, Bob Staples, and Sebastian Torres (CIMMS at NSSL), Kurt Hondl, Allen Zahrai, and Mark Benner (NSSL), and other government, industry, and university collaborators

The Advanced Technology Demonstrator (ATD) is being developed to demonstrate Multifunction Phased-Array Radar (MPAR) risk reduction. It will replace the current SPY-1A antenna at the National Weather Radar Testbed with an S-Band, 4-m diameter, dual-polarization, active phased array. The system's initial operating capabilities are intended to support the FAA investment decisions pertaining to the next generation of aircraft surveillance and weather sensing radar as well as to serve as a basis for ongoing meteorological research at NSSL. The ATD leverages several prior investments in order to provide a flexible, useful system while striving to keep cost and risk low. The antenna system is based around tile-able array panels developed under the MPAR Government Proof-of-Concept Technology Risk Reduction Program carried out by MIT/Lincoln Laboratory. The receiver and exciter electronics leverage work done by General Dynamics Advanced Information Systems (GDAIS) for the United States Navy in support of the Air and Missile Defense Radar development. The radar control system leverages the work done by GDAIS for the Office of Naval Research under the Digital Array Radar and Affordable Common Radar Architecture (ACRA) programs. Finally, the weather signal processor (including the inter-process-communication infrastructure, system control and monitoring, techniques, and algorithms) leverages the work done by CIMMS and NSSL for the original SPY-1A-based NWRT/PAR. Accomplishments by CIMMS staff in three main areas are described next: programmatic, application software, and facilities.

CIMMS staff supported programmatic ATD efforts by actively participating in several planning and design meetings, by providing input to scheduling and budget decisions, outlining and reviewing system requirements and system design documents, drafting and reviewing Interface Control Documents, and supporting programmatic milestones such as the System Requirements Review and Preliminary Design Review meetings. In addition, the team continues to support bi-weekly conference calls for status updates and coordination of the entire ATD project.

The Application Software portion of the ATD is being led by CIMMS staff and combines software developers and engineers from CIMMS and GDAIS. The goal of the Application Software is to generate weather- and aircraft-surveillance products, to provide scan control and high-level radar control, to enable system status monitoring, and to archive and display products. During FY15, CIMMS engineers were involved in creating a functional architecture and a Work Breakdown Structure (WBS) for the Application Software. The goal for the design of the Application Software is to maximally leverage existing NWRT PAR and ACRA software to reduce the risk in meeting the FAA initial investment decision timeline. For the first phase of the Application Software development, the GDAIS team migrated ACRA's distributed computing messaging layer to the Object Management Group's (OMG) Data Distribution Service (DDS). In parallel, the CIMMS team ported and reorganized their radar-independent weather signal- and adaptive-processing algorithms to run on 64-bit Linux (instead of 32-bit Linux used for the original NWRT PAR.) During the porting effort, many hardware, operating system, and software management issues were identified and resolved. Testing of the 64-bit port during this period included playing back archived data sets, validating signal processing algorithms with their MATLAB implementation, controlling the archiving function from the user interface, displaying base products at the user interface, and comparing base products with the operational NWRT PAR. CIMMS staff also led the design and development of the digital signal processing (DSP) portion of the application software. This includes the weather signal processing that will be extended from the NWRT PAR software and the air traffic control (ATC) software for detecting and tracking aircraft. In the past year, the CIMMS/GDAIS team discussed the current ACRA and NWRT PAR capabilities and determined the best way to meet the ATD goals by building upon the existing software. The team also had meetings with partners from Regulus and MIT/Lincoln Laboratory to develop the concept of operations for the ATC software and collaborated on a feasible design. Initial work on data simulators and an extension of the NWRT PAR weather DSP software for the ATD were also carried out.

The Facilities portion of the ATD is also being led by CIMMS staff and combines engineers from CIMMS, NSSL, MIT/Lincoln Laboratory, and Regulus. During FY15, CIMMS staff members were involved in creating the WBS for the Facilities tasks to support the removal of the current NWRT SPY-1A antenna and its replacement with the ATD one. The team was involved in creating drafts of the Heavy Lift Plan for decommissioning the SPY-1A antenna and begun work on preparing the facilities infrastructure for the eventual installation of the ATD. Lessons learned from the MPAR Dual-Polarization Demonstrator (see next project) have contributed to the physical layout design and characterization strategy for the full-scale ATD.



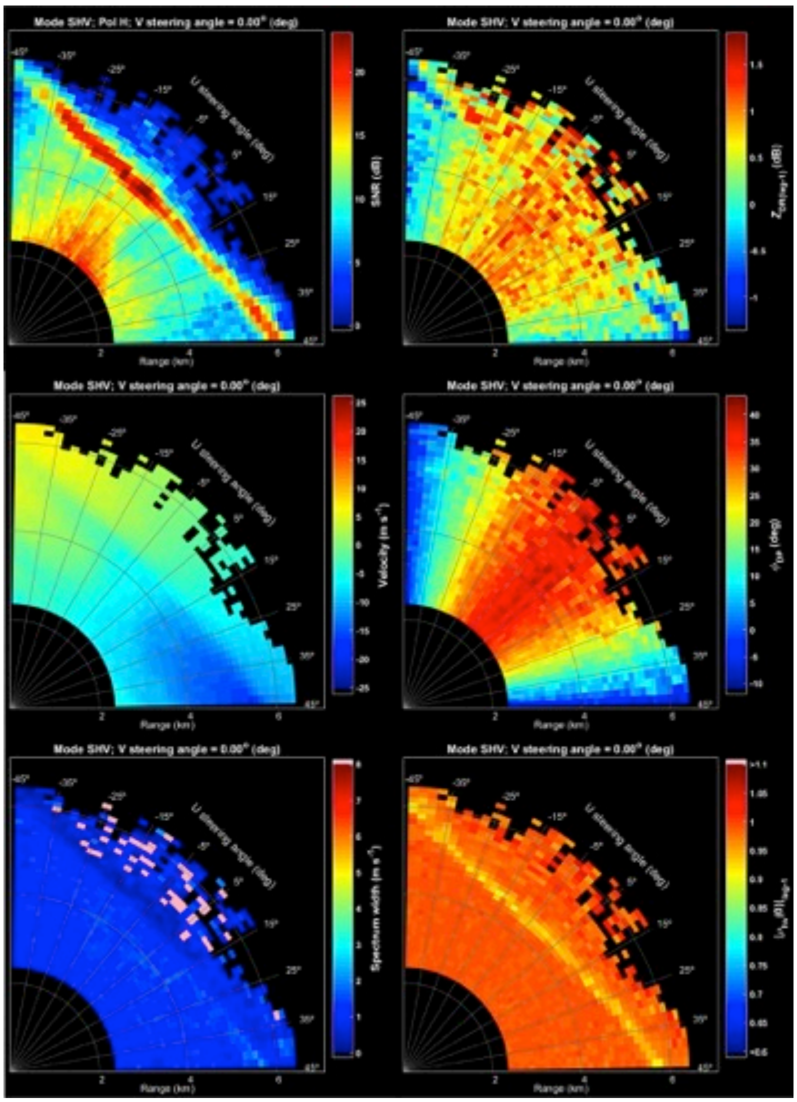
Conceptual dome layout for the MPAR Advanced Technology Demonstrator (image courtesy of MIT/Lincoln Labs).

b. MPAR Dual-Polarization Demonstrator

Igor Ivić, Daniel Wasielewski, and Brad Isom (CIMMS at NSSL), and Allen Zahrai and Kurt Hondl (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 project is to evaluate the performance of polarimetric planar phased array technology with respect to the national weather mission. For this purpose, NSSL and the FAA commissioned the construction of a 10-panel, mobile, polarimetric, phased-array system by MIT/Lincoln Laboratory to be used as an evaluation platform to assess the polarimetric performance of the planar phased array technology. A test plan was developed 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 (e.g., the polarimetric KOUN radar) 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 the replacement of the SPY-1A antenna on the NWRT PAR (see previous project). The construction of the dual-polarization demonstrator was recently completed by MIT/Lincoln Laboratory and delivered to NSSL. Test data collection and subsequent analysis by NSSL engineers and researchers revealed potential areas for system hardware improvements. These improvements are to be undertaken by CIMMS and NSSL engineers with assistance from MIT/Lincoln Laboratory personnel. Analysis of test data was initiated to evaluate the system's polarimetric behavior.



Test data collected with the 10-panel, mobile, dual-polarization demonstrator system. The array was pointed vertically and the beam was electronically steered ±44º along the x-axis while steered at 0º along the y-axis. The left column shows single polarization products in the following order from top to bottom: signal-to-noise ratio (SNR), Doppler velocity, and spectrum width. The right column shows polarimetric variables in the following order from top to bottom: differential reflectivity, differential phase, and co-polar correlation coefficient.

c. MPAR Program Support

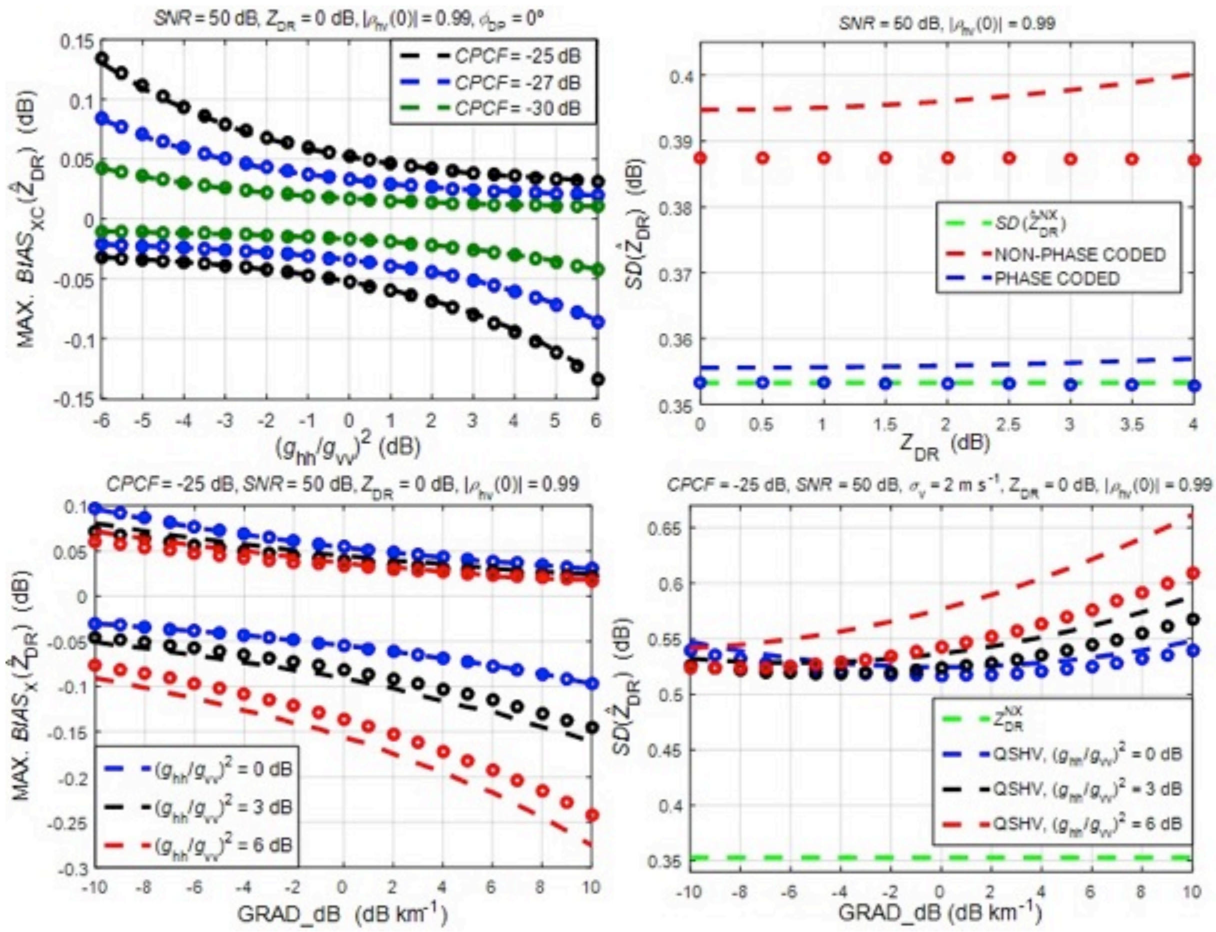
Sebastian Torres (CIMMS at NSSL)

CIMMS continues to support the MPAR program on several technical and programmatic fronts. Support consists of actively participating in the MPAR Government Engineering Team, 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.

d. PAR 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 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 have shown that such isolation cannot be achieved only by the antenna hardware. Hence, additional modifications to the radar system are required to attain supplementary isolation of orthogonal channels. To achieve this, the following two options are being evaluated: (1) pulse-to-pulse (or interpulse) phase coding of the transmitted pulses in the horizontal and vertical channels, and (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. Both schemes were investigated using analytical derivations and simulated and real time-series data. Pulse-to-pulse phase coding was shown to provide additional isolation with a small increase in the standard deviation of estimates (compared to the perfect isolation between orthogonal channels). The time-multiplexing scheme was found to perform comparably to phase coding if the spatial gradients of reflectivity are small, but its performance degrades as gradients increase. It was observed that the time-multiplexing approach also introduces a significant increase in the standard deviation of estimates. During FY15, the two schemes were further investigated, and two research papers were submitted to technical journals.



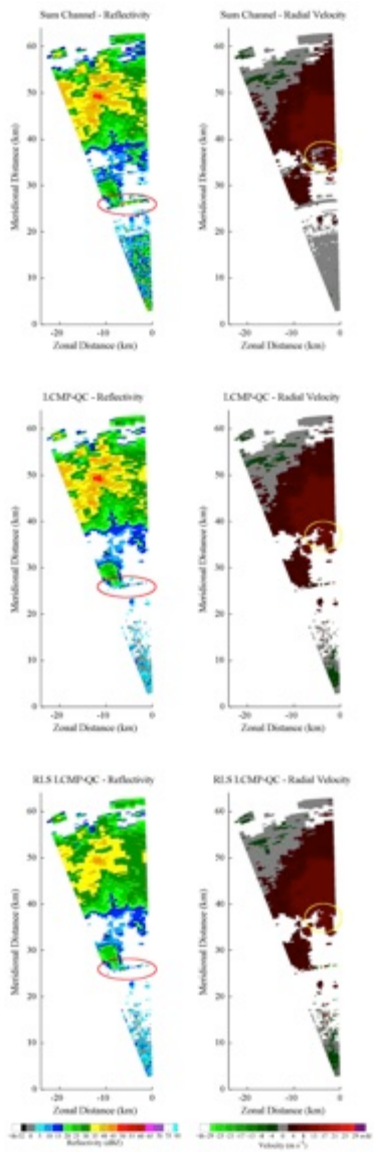
Differential reflectivity bias (left panels) and standard deviation (right panels) for the phase-coding (top panels) and time-multiplexing (bottom panels) schemes. Results were produced using simulated time series (dashed lines) and analytical derivations (circles). Results for phase coding are shown versus various ratios of horizontal and vertical antenna peak beams (g_{hh}/g_{vv}) for bias and versus a range of differential reflectivity values for standard deviation. Results for time-multiplexing bias and standard deviation are shown versus the differential reflectivity gradient in range. CPCF denotes the level of isolation between orthogonal channels. Green lines in the standard deviation plots show values for the case of perfect isolation between orthogonal channels.

e. PAR Adaptive Beamforming

Christopher Curtis (CIMMS at NSSL)

Adaptive beamforming is a promising area of research that is especially suited to phased array radars. Even though the NWRT PAR is not a modern active phased array, it has been used over the past few years to illustrate the feasibility of utilizing digital beamforming to mitigate ground clutter. In FY15, adaptive beamforming using different types of Linear Constrained Minimum Power (LCMP) algorithms was applied to radar data collected with the NWRT PAR in 2012. The results indicate that by properly

combining the data from multiple receiver channels, ground clutter can be significantly reduced or eliminated using spatial filtering before the data is processed with conventional algorithms. This research could be applied in the future to more modern arrays such as the MPAR Advanced Technology Demonstrator with the potential to improve the mitigation of ground clutter and possibly to filter out electromagnetic interference.



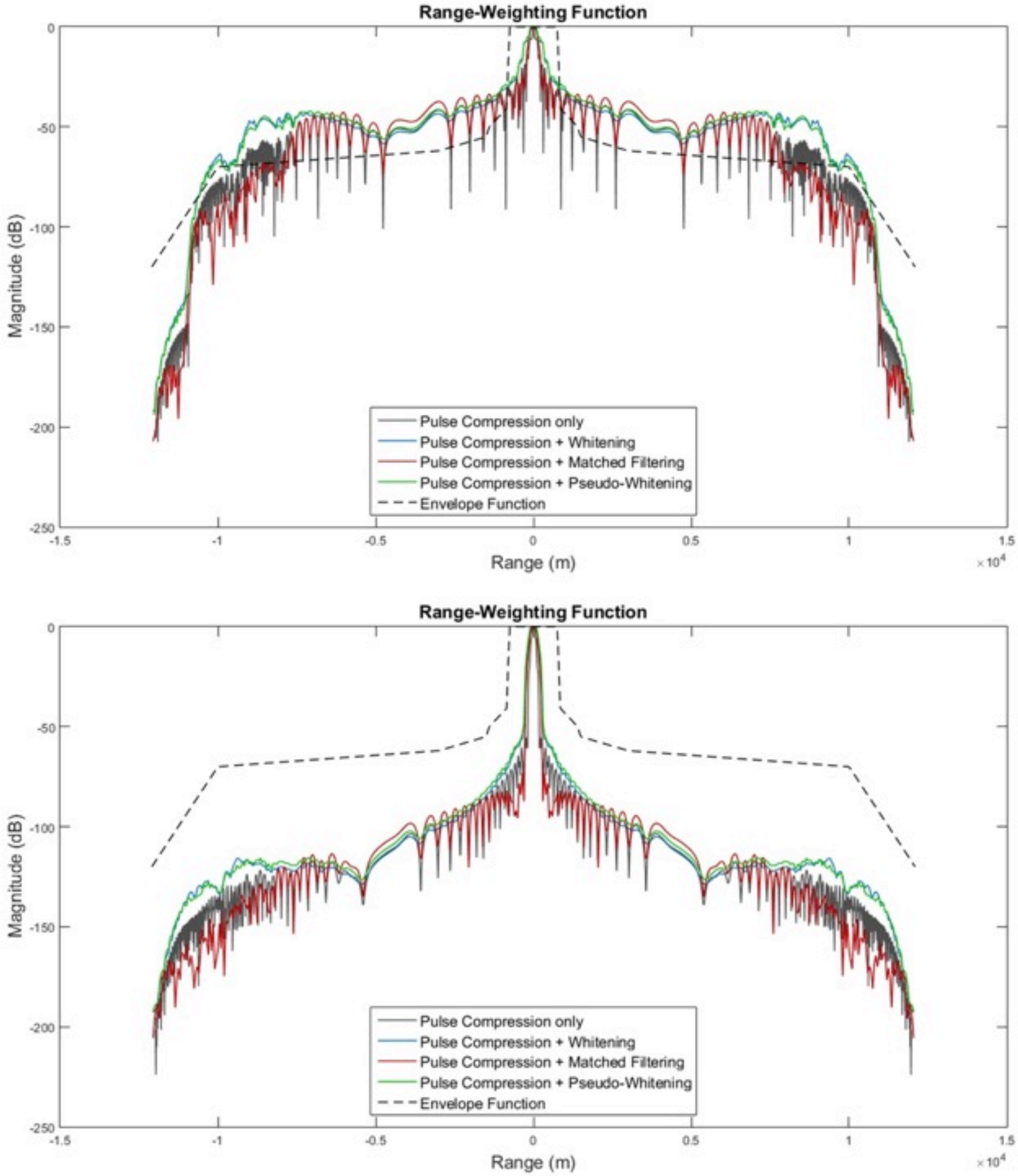
PPI plots of reflectivity and velocity at 4.0° elevation from data collected on 12 Oct 2012 at 19:18 UTC with the NWRT/PAR. The top two panels are computed directly from the sum channel (i.e., no adaptive beamforming), the middle two panels are computed using the LCMP-QC adaptive beamforming algorithm, and the bottom two panels are computed using the RLS version of the LCMP-QC algorithm. The red and yellow ellipses indicate obvious areas where ground clutter contamination is being mitigated by the use of spatial filtering.

f. PAR Pulse Compression

Sebastian Torres, Christopher Curtis, and Brad Isom (CIMMS at NSSL)

Weather radars based on low-power solid-state transmitters typically use pulse compression as a means to achieve the required sensitivity to detect weaker returns. Pulse compression works by lengthening the transmitted pulse and modulating the transmitted waveform. A longer pulse leads to increased sensitivity due to the higher average power being transmitted, and frequency or phase modulation can be used to recover the original range resolution after processing. As such, pulse compression waveforms require a larger transmission bandwidth and result in an extended blind range close to the radar, which is typically mitigated by the addition of a fill-in pulse. Although the resulting range weighting function has a main lobe with the desired width, it contains sidelobes that extend a few kilometers in range. Range sidelobes can impact the range resolution of the radar and are typically reduced by employing non-linear frequency-modulation transmission schemes at the price of an increased transmission bandwidth compared to conventional linear-frequency-modulation waveforms. Range oversampling processing has been used on radars with conventional high-power transmitters to reduce observation times without increasing the variance of estimates. It consists of sampling the received signals at a rate faster than the inverse of the transmitted pulse width thus producing complex voltages with a range correlation that depends on the modified pulse (i.e., the convolution of the transmitted pulse envelope and the receiver filter impulse response, which would include the effects of pulse compression.) This a-priori information about the range correlation is used to devise transformations to decorrelate sets of range-oversampled signals from which auto- and cross-covariances are estimated. In turn, these are averaged to match conventional range sampling and are ultimately used to obtain more precise estimates of all radar variables.

During FY15, we took a first look at combining pulse compression and range oversampling, which is applicable to the design of any weather radar system that uses pulse compression for enhanced sensitivity and needs range-oversampling processing for faster updates such as the upcoming MPAR Advanced Technology Demonstrator (ATD). Because both techniques involve processing in range time, it is important to understand how one affects the other. Since pulse compression determines the modified pulse, the performance of range oversampling is intimately tied to it. Our study has focused on providing a framework to quantify the performance of the combined techniques and on exploring possible complications for a practical implementation on the MPAR ATD.

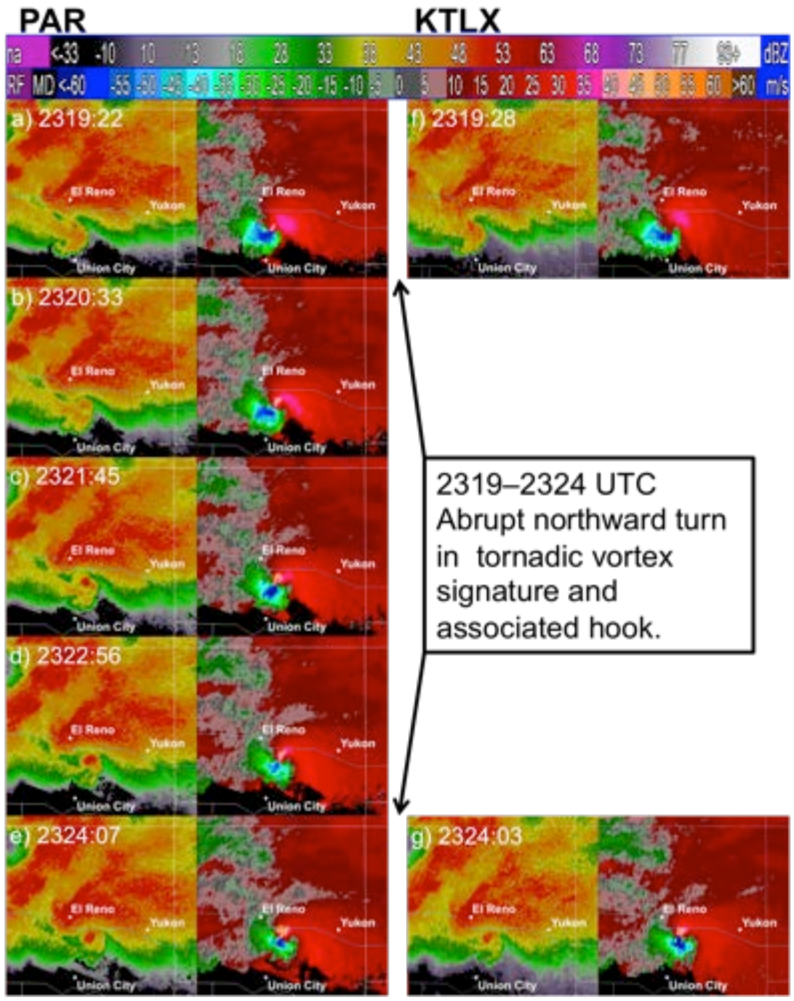


Examples of bad (top) and good (bottom) effective range weighting functions for radar that uses pulse compression and range oversampling processing (matched filtering, pseudowhitening, and whitening). Acceptable range weighting functions can be obtained by trading mainlobe width for peak-sidelobe levels in order to maintain the required range resolution (envelopes in the dashed lines indicate required performance).

g. Forecaster Use of Phased Array Radar Data

Charles Kuster (CIMMS at NSSL), Pam Heinselman (NSSL), and Marcus Austin and Doug Speheger (OUN)

In an effort to understand how NWS forecasters might use and benefit from rapid-update radar data provided by the NWRT PAR in specific situations, we interviewed and collaborated with two NWS forecasters who issued warnings in real time during a strong tornado event (31 May 2013) and a severe hail and wind event (8 July 2014). In each case, the forecaster pointed out key storm features important to their warning decision process and how rapid-update radar data could be helpful in observing these features. This input also guided a quantitative analysis, which further illustrated differences between rapid-update data and data from the WSR-88D network. In the strong tornado case, rapid-update data aided in better observing transition of the storm from a multicell thunderstorm to a classic supercell as well as observing tornadogenesis about three min earlier than that depicted by the WSR-88D radar (Kuster et al, 2015). Rapid-update data was also very important in more precisely tracking the location and movement of the tornado cyclone, which could be beneficial when issuing updates to existing tornado warnings (figure below). In the severe hail and wind event, rapid-update data better depicted the rapid growth and decay of upper-level high-reflectivity cores, which were important to the forecaster when issuing severe thunderstorm warnings in real time. Rapid-update data also better sampled downburst precursor signatures (i.e., descending reflectivity core and mid-level convergence) than the WSR-88D.



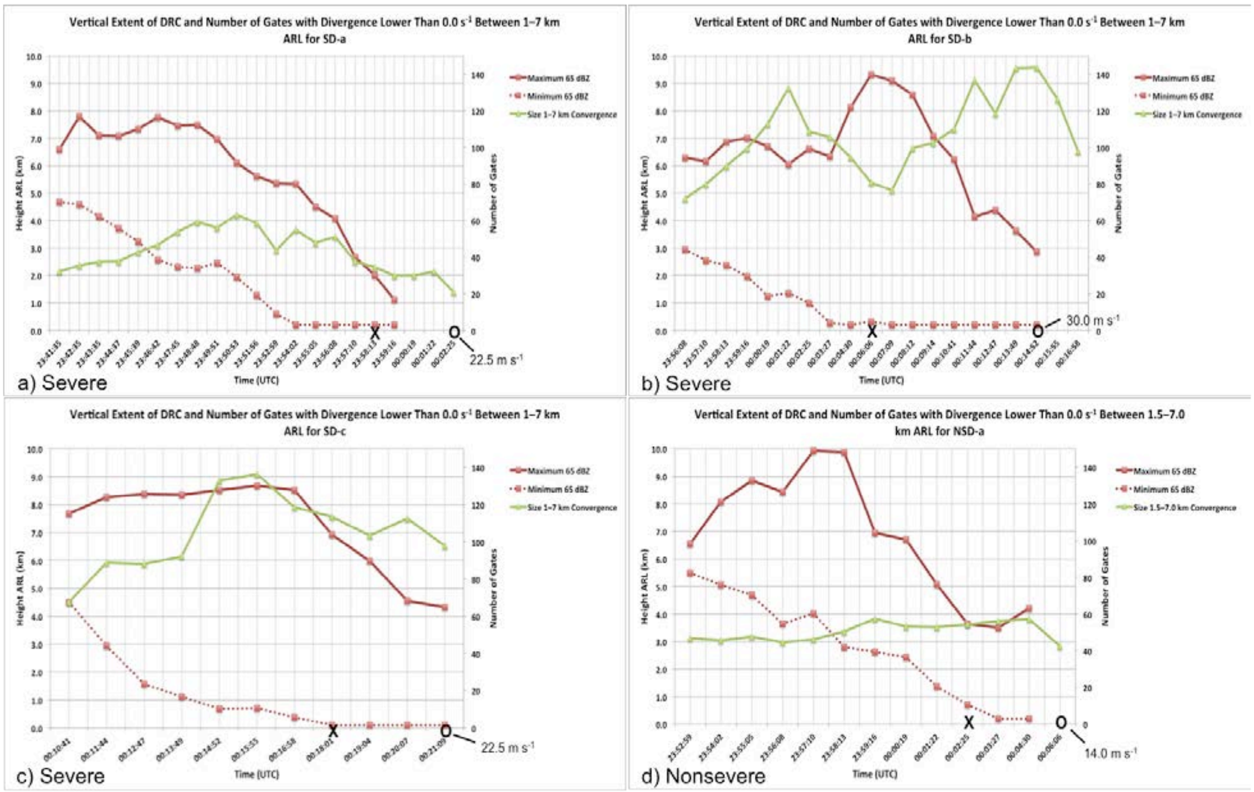
Rapid update PAR (a–e) and WSR-88D (KTLX; f, g) 0.5° base reflectivity and velocity at a) 2319:22, b) 2320:33, c) 2321:45, d) 2322:56, e) 2324:07, f) 2319:28, and g) 2324:03 UTC 31 May 2013. Distance from PAR to velocity couplet is 49 km and distance from KTLX to velocity couplet is 61 km. Reflectivity (dBZ) and velocity (ms^{-1}) color bars are located at the top.

h. Rapid-Update Radar Observations of Downbursts

Charles Kuster (CIMMS at NSSL), Pam Heinselman (NSSL), and Terry Schuur (CIMMS at NSSL)

Rapid-update radar data provided by PAR may be useful in sampling rapidly evolving storm-scale features such as downburst precursor signatures (i.e., descending reflectivity cores and mid-level convergence). To quantify this potential usefulness, we examined two cases with severe and nonsevere downbursts occurring within 100 km of PAR. Analysis of PAR data clearly showed a descending reflectivity core associated with all identified severe and nonsevere downbursts (n=8). Collapse of core top occurred on average 8.6 min prior to downburst maximum intensity. Mid-level

convergence also evolved in a distinct pattern where it increased to peak magnitude and then decreased as core top descended. The size of the mid-level convergence signature also followed a distinct pattern, though it differed between the severe and nonsevere downbursts. Increasing mid-level convergence magnitude and size occurred on average 7.3 min and 8.5 min prior to downburst maximum intensity respectively (figure below). Better sampling of precursor signature trends may allow NWS forecasters to better anticipate the onset of damaging downburst winds at the surface. This work has been submitted to *Weather and Forecasting*.



Evolution of the DRC and number of gates with divergence lower than 0.0 s^{-1} (i.e., convergence size) between 1.0(1.5)–7.0 km ARL for all analyzed severe (a–c) and nonsevere (d) downbursts on 14 June 2011.

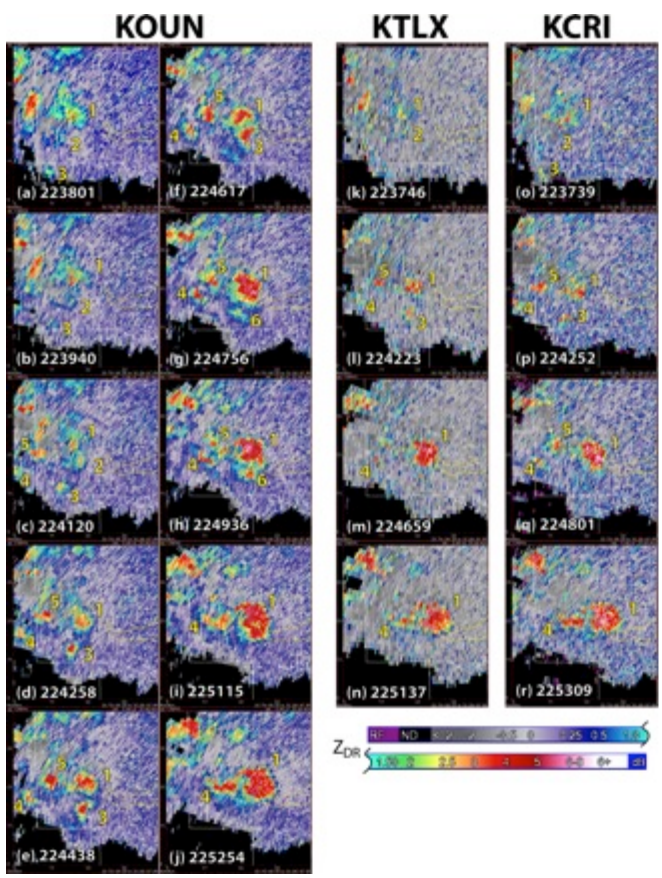
i. Rapid-Scan Dual-Polarization Observations of Tornadic Supercells

Robin Tanamachi and Charles Kuster (CIMMS at NSSL), and Pam Heinselman (NSSL)

In order to justify polarimetric capability in a phased array successor to the WSR-88D, rapid-scan polarimetric observations collected in the 31 May 2013 El Reno, Oklahoma tornadic storm complex were closely examined. Through specialized rapid-scan volume coverage patterns (sector scanning) using the research dual-polarization WSR-88D KOUN, multiple data sets have been collected of previously identified dual-polarimetric supercell signatures (e.g., Z_{DR} column, Z_{DR} arc, Z_{DR} ring). This research highlighted instances in which rapid-scan, polarimetric observations of the storms from KOUN

detected or better resolved (in a temporal sense) storm features that were either unresolved or poorly resolved by conventional WSR-88D scanning techniques (utilized by KTLX and KCRI). Overall, KOUN observations better resolved the Z_{DR} column signatures of merging midlevel updrafts (figure below), a rapidly descending giant hail core, a developing anticyclonic tornado, and a dissipating storm cell, than did those from KTLX and KCRI. A formal manuscript about this work is nearly ready for submission.

We hope to relate various dual-polarimetric supercell signatures to signatures frequently used by NWS forecasters during tornado warning operations (e.g., mesocyclone intensity, rear flank downdraft evolution) in an effort to include dual-polarimetric signatures into the operational conceptual model of tornadogenesis. Currently, we have quantified signatures from a strongly tornadic and weakly tornadic supercell on 31 May 2013 and we plan to extend this work to multiple cases with tornadic and non-tornadic supercells.



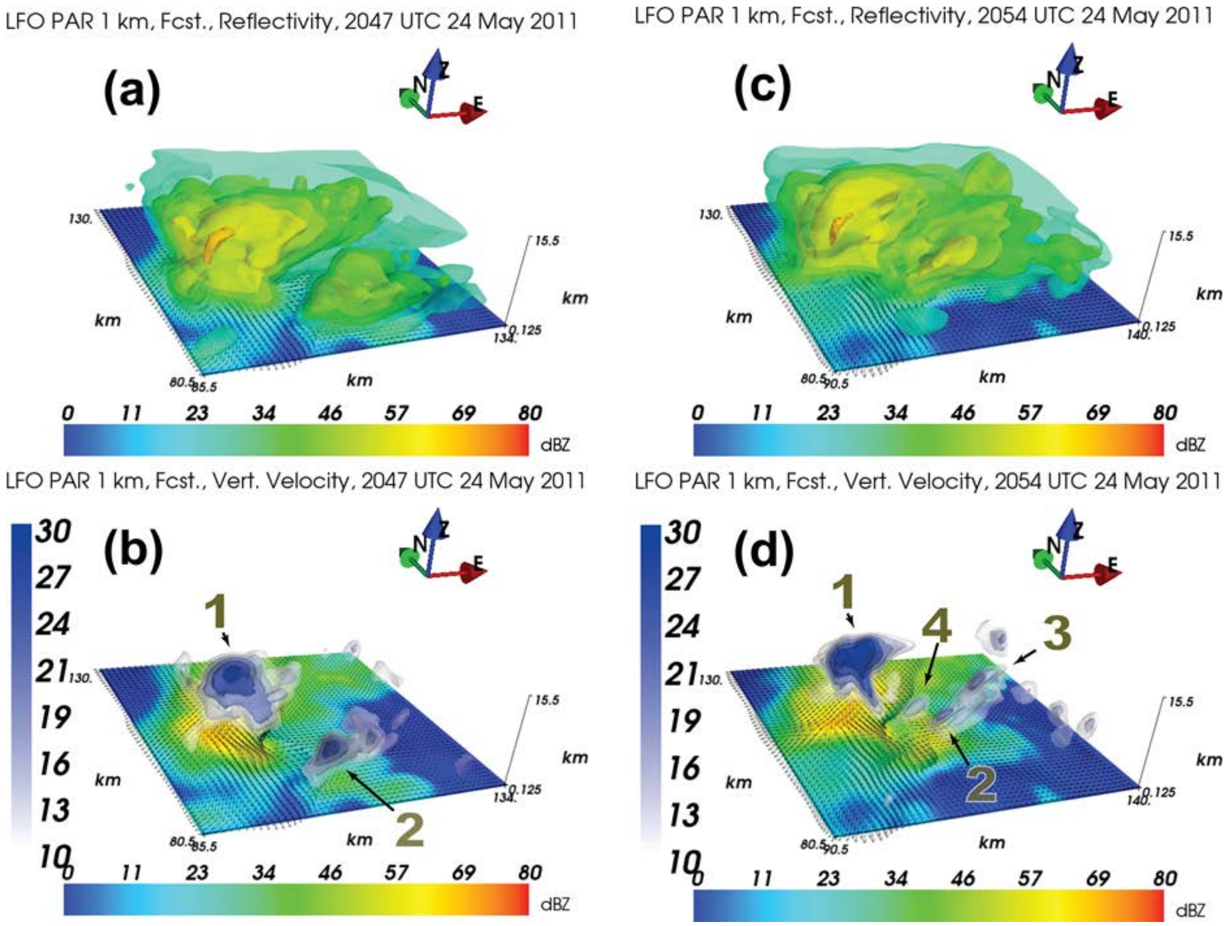
CAPPI plots of Z_{DR} (in dB) at 5 km AGL in the El Reno storm, as seen by (a-j) KOUN, (k-n) KTLX, and (o-r) KCRI. The times shown on each panel, given in UTC, are the times at which the lowest elevation sweep (0.5°) was collected in the volume used to generate the CAPPI. County boundaries are drawn in thin white lines; yellow contours are tornado tracks (courtesy of the NWS).

j. Assimilation of PAR Data for Analysis of Storm Mergers

Robin Tanamachi (CIMMS at NSSL), and Pam Heinselman and Louis Wicker (NSSL)

Tornadogenesis is governed by processes occurring on scales of a minute or less. However, the current WSR-88D network only collects a volume scan on the order of once every 5 minutes, limiting our ability to study in detail the relationship (if any) between storm mergers and tornadoes. PAR offers a promising pathway toward better understanding of these processes because it collects volume scans on the order of once every minute. As a case study, we assimilated PAR reflectivity and Doppler velocity observations of the 24 May 2011 El Reno, Oklahoma tornadic supercell into the NSSL Collaborative Model for Multiscale Atmospheric Simulation (NCOMMAS), using the ensemble Kalman filter (EnKF) technique, producing three-dimensional, cloud-scale analyses of the storm every minute. This storm underwent a merger with a smaller storm, a merger associated with the demise of one tornado and the formation of another a few minutes later. In the analyses, we identified updrafts and vortices using a previously developed general-purpose object identification technique.

We found that the storm merger process took approximately 10 minutes, and that, in this particular case, it coincided with more traditional, mid-level mesocyclone cycling already occurring in the El Reno storm. It was found that additional, “bridging” mid-level updrafts developed between the updrafts of the two merging storms, above their colliding outflow boundaries (figure below). These new updraft pulses tilted low-level horizontal vorticity into the vertical, augmenting the El Reno storm’s mid-level mesocyclone as it reorganized during the merger. We concluded that the storm merger did not cause the demise of the first tornado and may have delayed the onset of the second. This complex interplay between several different dynamical features is suggestive of a spectrum of situation-dependent storm merger outcomes related to tornadogenesis, consistent with what has been previously reported. This work, which lays the groundwork for a more extensive study of additional storm mergers, comprised the postdoctoral research of the lead staff member and concluded in 2015 with a formal publication (Tanamachi et al. 2015).



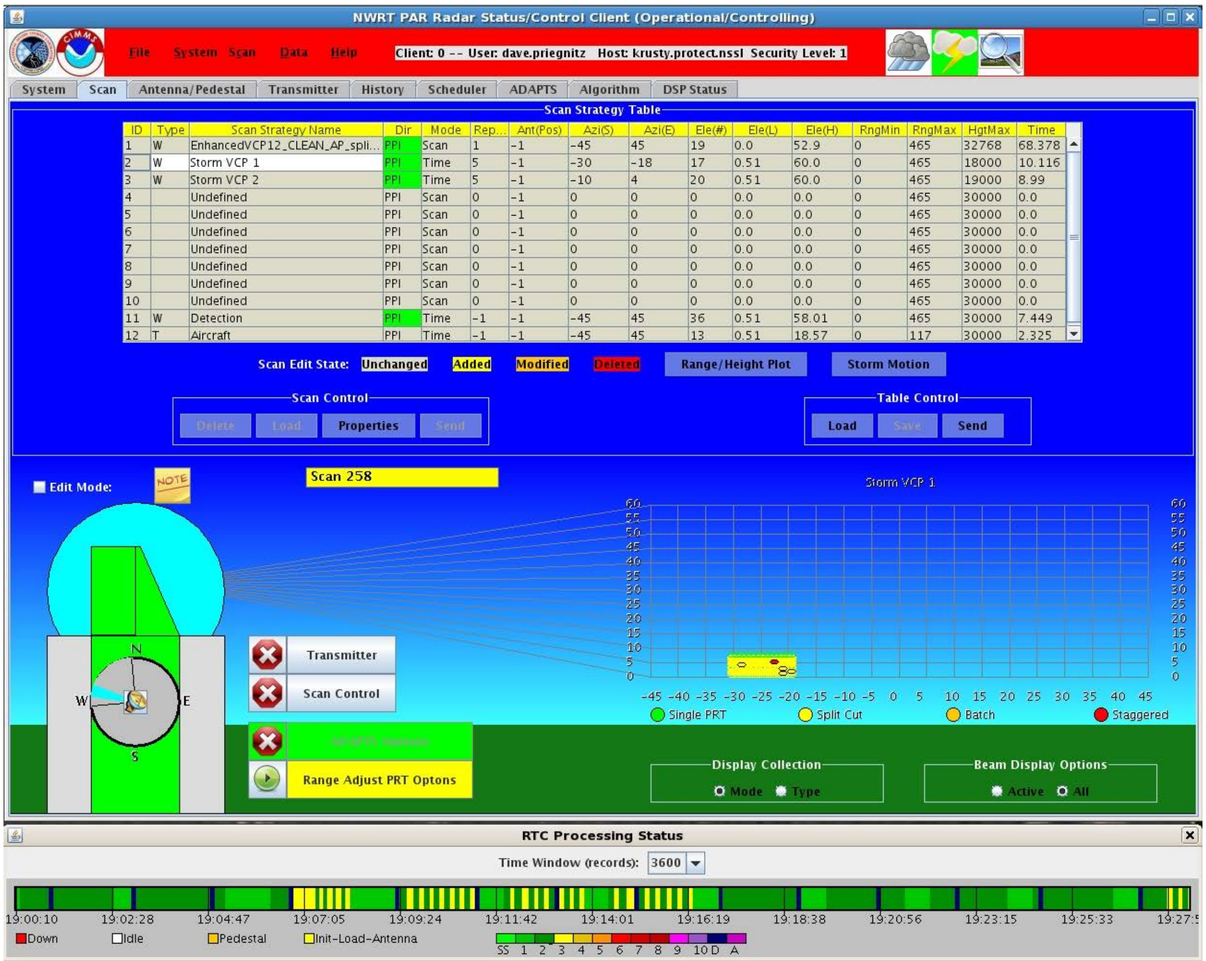
Ensemble mean (a) reflectivity (dBZ; colored isosurfaces) and (b) vertical velocity (m s^{-1}; blue isosurfaces, in increments of 5 m s^{-1}, starting from 10 m s^{-1}) before the merger, overlaid on surface reflectivity (dBZ; filled color contours on the lowest plane), and surface horizontal velocity vectors (black arrows on the lowest plane). The merging storm is at the lower rhs. The rendering is confined to a subdomain, 50 km on a side, near the center of the full model domain, which was 180 km on a side. The El Reno storm's updraft and the merging storm's updraft are shown (labeled 1 and 2, respectively). (c),(d) As in (a),(b), but at the start of the merger. Note that new midlevel updraft pulses (labeled 3 and 4) have formed between updrafts 1 and 2.

k. NWRT PAR Software Upgrades

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

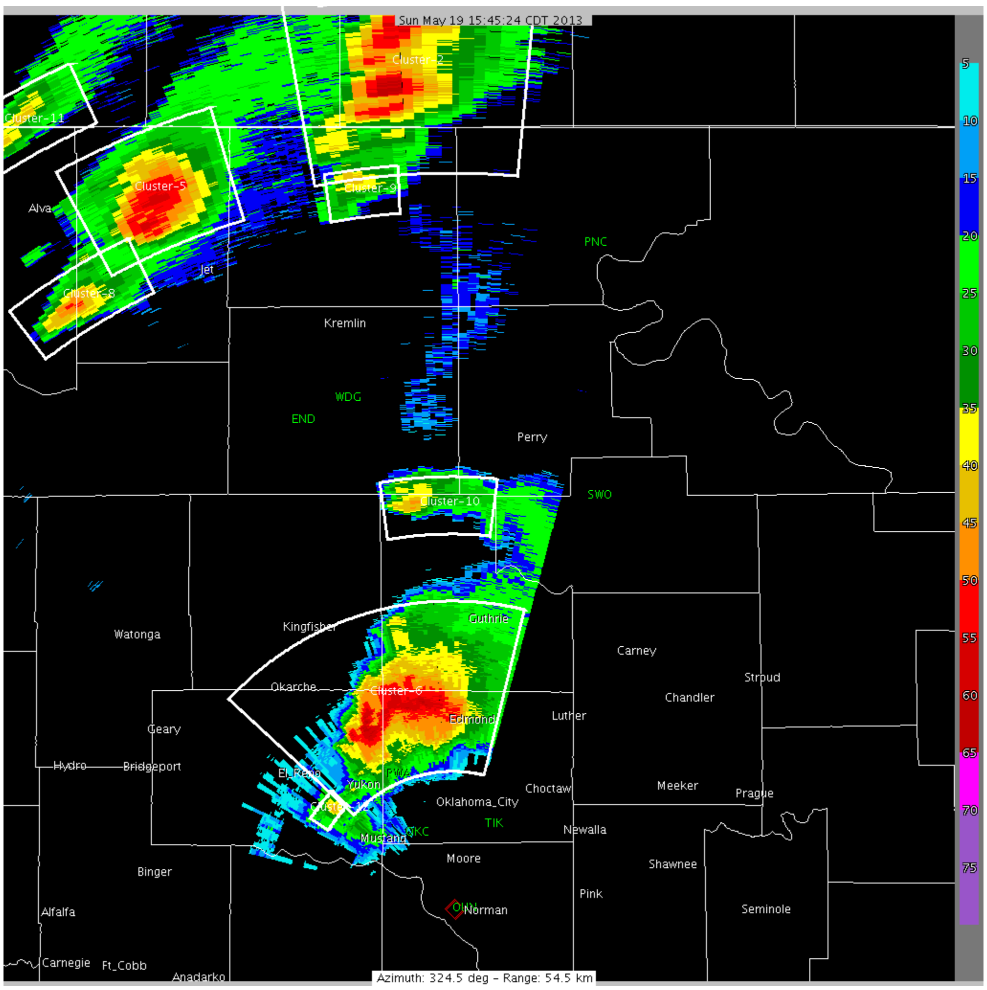
1) Adaptive Scanning. Last year, an adaptive scheduling function was added to the NWRT software to provide focused scanning of selected convective storms, including a storm cluster identification algorithm. This year, a number of improvements have been made to the identification, selection and scheduling components (first figure below). First, to improve identification of storm clusters, a height option has been added to the storm cluster identification algorithm. This is especially important in isolating individual

storm cells from large storm clusters and squall lines whose features tend to meld together at low heights and elevations. Second, a new storm mode was added to the Radar Control Interface (RCI) and Real-Time Control (RTC) software allowing the tracking and/or scheduling of up to 5 storm clusters simultaneously (second figure below). When storm clusters are scheduled in storm mode, a user-defined amount of time is allocated for focused scanning (in the test cases run so far the value has been two minutes). Focused scanning of all storm sectors is repeated until the allocated time expires.



Snapshot of RCI Processing Status windows during an active storm mode session. The scan table contains 3 weather VCPs: a surveillance weather VCP (full 90° sector) in slot 1 and two storm VCPs (slots 2 and 3). The ADAPTS detection scan occupies slot 11 (run once every ~2 minutes) and aircraft tracking scan in slot 12 (inactive). The storm VCPs alternated within a 2-minute time window. A beam map of the active VCP in slot 2 is displayed graphically. A one-hour time history of scan allocation at the Real Time Controller (RTC) can be seen at the bottom.

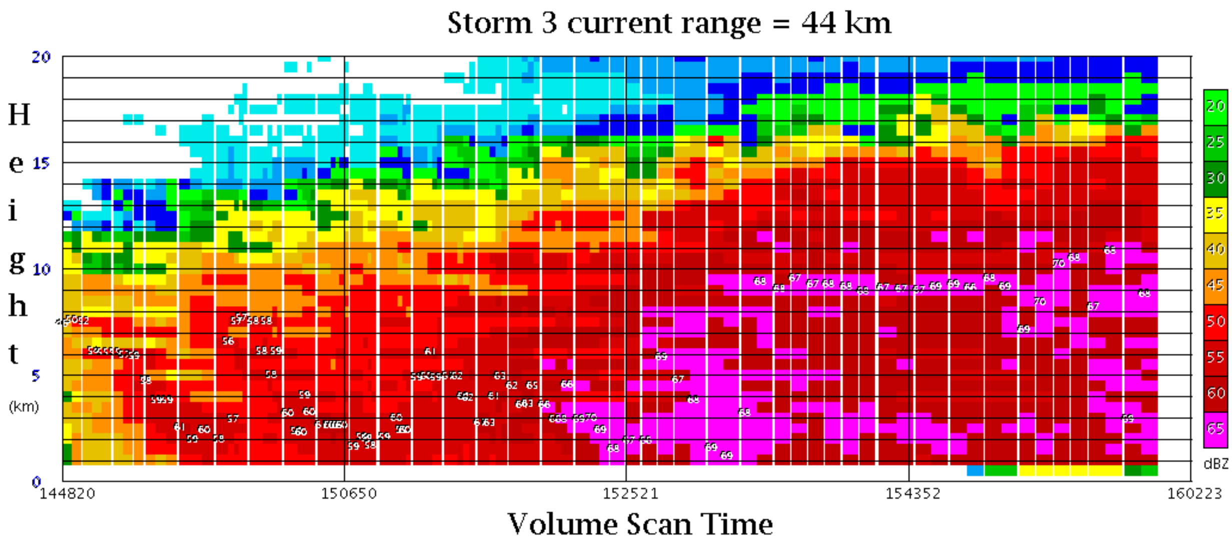
2) Product Generation. A new enhanced product generator task was developed, providing the capability to not only define new PPI reflectivity and velocity products in real-time, but also define Constant Altitude PPI (CAPPI) and Range Height Indicator (RHI) products as well. In addition to creating new products, the product generator task supports different types of data collection modes, including scanning vertically by azimuth (RHI) then horizontally by elevation (PPI). By doing so the vertical time separation between the top and bottom of a storm is less than one second. The time separation between beams at adjacent azimuths is still less than one second when scanning in this mode.



A 7 km CAPPI display of reflectivities at 15:45:24 CDT on 19 May 2013. Storm clusters, identified by the cluster identification algorithm, are outlined by white boxes.

3) Cluster Properties. One of goals in developing new adaptive scanning strategies at the NWRT is to automate the selection and scheduling process using algorithms instead of human operators. Storm cluster selection is typically based on identifying certain storm properties. Since the storm cluster identification algorithm collects volumetric information, a set of cluster properties is also maintained and sent to the RCI server. This information currently includes: maximum cluster reflectivity, height of maximum

cluster reflectivity, range of gate with maximum reflectivity, and vertical profile of maximum reflectivities within cluster volume from surface to 20 km in 0.5 km increments. A database of cluster properties is maintained by the RCI server and accessed by RCI client and server applications that require cluster history. The vertical reflectivity profile is used by a new algorithm to calculate storm cluster hail properties that can be used to trigger focused storm scanning automatically without human intervention (third figure below). It is anticipated that new storm cluster properties will be added to support additional severe weather detection algorithms and integrated into the storm selection process.



Time-height display of the vertical reflectivity profile during the growth phase of a tornadic supercell observed on 19 May 2013. Reflectivity properties were gathered by the cluster identification algorithm. The maximum reflectivities for each volume scan are displayed at the heights they were observed.

Publications

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**, 1229-1237. doi:10.1175/WAF-D-14-00039.1

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.

Kuster, C. M., P. L. Heinselman, and M. Austin, 2015: 31 May 2013 El Reno tornadoes: Advantages of rapid-scan phased-array radar data from a warning forecaster's perspective. *Weather and Forecasting*, **30**, 933-956.

Tanamachi, R. L., P. L. Heinselman, and L. J. Wicker, 2015: Impacts of a storm merger on the 24 May 2011 El Reno, Oklahoma tornadic supercell. *Weather and Forecasting*, **30,** 501-524.

Torres, S., and D. Warde, 2014: Ground clutter mitigation for weather radars using the autocorrelation spectral density. *Journal of Atmospheric and Oceanic Technology*, **31**, 2049-2066. doi: 10.1175/JTECH-D-13-00117.1.

4. Research-to-Operations Transition

Objectives

Support and ensure the development of the Multi-Radar Multi-Sensor (MRMS) platform for transition to National Weather Service operations.

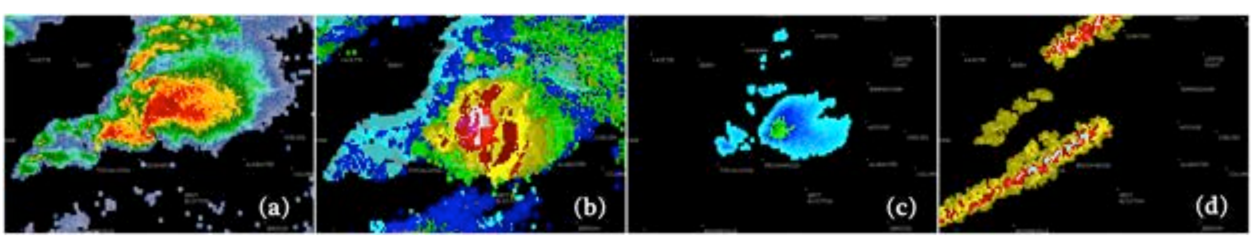
Develop AWIPS-2 and WDSS-II Visualization Networks for the MRMS Transition to NWS Operations

Darrel Kingfield, Jeff Brogden, Tiffany Meyer, and Robert Toomey (CIMMS at NSSL)

Accomplishments

The Multi-Radar Multi-Sensor (MRMS) system provides three-dimensional, quality-controlled, fields of reflectivity, velocity, and other radar and sensor-derived products with relevance in severe weather diagnosis, aviation impacts, and quantitative precipitation estimation. As part of NOAA's Hazardous Weather Testbed, several of these products have been evaluated inside AWIPS-2 (i.e., the primary NWS platform in the interrogation of weather data and issuance of advisories and warnings).

As part of the initial operating capability rollout to NWS operations, CIMMS scientists developed a floating, flexible framework that could be integrated within any NWS weather forecast office, river forecast center, center weather service unit, or national center of variable area of responsibility to be able to ingest and display MRMS data in real-time. As new products of variable resolution are pushed to operations, the framework is expandable to incorporate these new products with minimal re-engineering. This system was successfully integrated into the AWIPS-2 OB14.3.1 baseline build and is expected to have live operational products flowing through it by the late summer of 2015. Many of the changes and enhancements to the WDSS-II system were driven by requirements and requests to support the MRMS system. The GRIB2 product output process was completely redone so MRMS could deliver products in proper GRIB2 format. The ingestor system was enhanced to decode NEXRAD Level III products that use the Generic Data Format. The ability to ingest data from Gematronik radars in the Cayman Island was added as well. To make the WDSS-II/MRMS system more maintainable, the error logging system was improved and the internal coupling of data to indexes was modified to allow for more flexibility.



Four MRMS initial-operating products available in AWIPS-2, (a) reflectivity at the lowest altitude, (b) echo top height at 18 dBZ, (c) maximum expected size of hail, and (d) one-hour mid-level (3-6km AGL) azimuthal shear accumulation.

NSSL Project 2 – Hydrometeorology Research

NOAA Technical Leads: Jian Zhang and Kenneth Howard (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 centered on dual polarized radar and quantitative precipitation estimations (QPEs). Specifically:

- The operational implementation of the MRMS system
- Improved data quality control of radar data using newly upgraded dual-polarization capabilities
- Improved radar vertical profile of reflectivity via a neural network approach with satellite observations
- Developing a radar QPE approach using specific attenuation for two C-band dual-polarization radar
- Improved quality control and data filling in areas impacted by wind farms, terrain, and the zero isodop
- The development of precipitation data for the Multiple Year Reanalysis of Remotely Sensed Storms (MYRORSS) project
- Evaluate MRMS quantitative precipitation estimates with respect to other operational precipitation products
- Conducting site visits to NWS River Forecast Centers to facilitate the operations to research process with MRMS
- Improve the quality of national rain gauge data sets for QPE and QPE verification
- Evaluate the development of merged QPE products
- Improve multisensor estimation of intense rainfall in complex terrain using GOES-R with ground and space-based radars
- Develop advanced web-based tools and displays for QPE comparisons, verification, and radar calibration
- meteorological Phenomena Identification near the Ground (mPING)
- mPING random forest research

Accomplishments

1. Operational Implementation of the Multi-Radar Multi-Sensor System

Carrie Langston, Karen Cooper, Brian Kaney, Darrel Kingfield, and Heather Grams (CIMMS at NSSL)

On September 29, 2014, the MRMS system became operational at the National Centers for Environmental Prediction (NCEP) Central Operations (NCO) as part of the

Integrated Dissemination Program. This achievement is a culmination of months of work by CIMMS staff to migrate, configure, and document MRMS for implementation at NCO. NCO created a development environment for vetting the MRMS system. Once verified and tested, an operational system was built and configured. Only NCO staff members are allowed access to the operational system. Thus, CIMMS staff created a suite of documents for the NCO "on-boarding" team. 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 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.
- *NCO Server Spreadsheet* -- A spreadsheet with three worksheets detailing on a virtual machine (VM) by VM basis the assigned processing, computing resources, lists of input and output data, and system configuration files.

In total, the MRMS on-boarding documentation consists of approximately 200 pages and three companion worksheets. A copy of the documentation can be made available if requested. With the on-boarding documentation, NCO staff configured the MRMS operational system and began a 30-day test of its processes and products. During this period and throughout the year, CIMMS staff provided general and troubleshooting support to NCO.

The initial operating capability of MRMS includes the creation and distribution of over 150 individual products. All products are made available in GRIB2 format, and a subset is made available in specialty formats for specific NWS users. All products in all formats were verified for their correctness by CIMMS/NSSL staff and MRMS users. As part of the verification process, all products were imported and displayed in AWIPS2. Several new XML tables were created to properly configure AWIPS2 for MRMS data. These tables and example test data were submitted for code review to be included in a future AWIPS2 release.

Additionally, data connections were established for the transfer of products from NCO's operational and development MRMS systems to NSSL for the purpose of evaluating product quality. Products from the NCO are converted from GRIB2 to an internal format for display on a website managed by NSSL and hosted at OU (http://mrms.ou.edu/qvs.html). Due to resource restrictions, data is saved at a 10-minute frequency rather than the native 2-minute frequency.

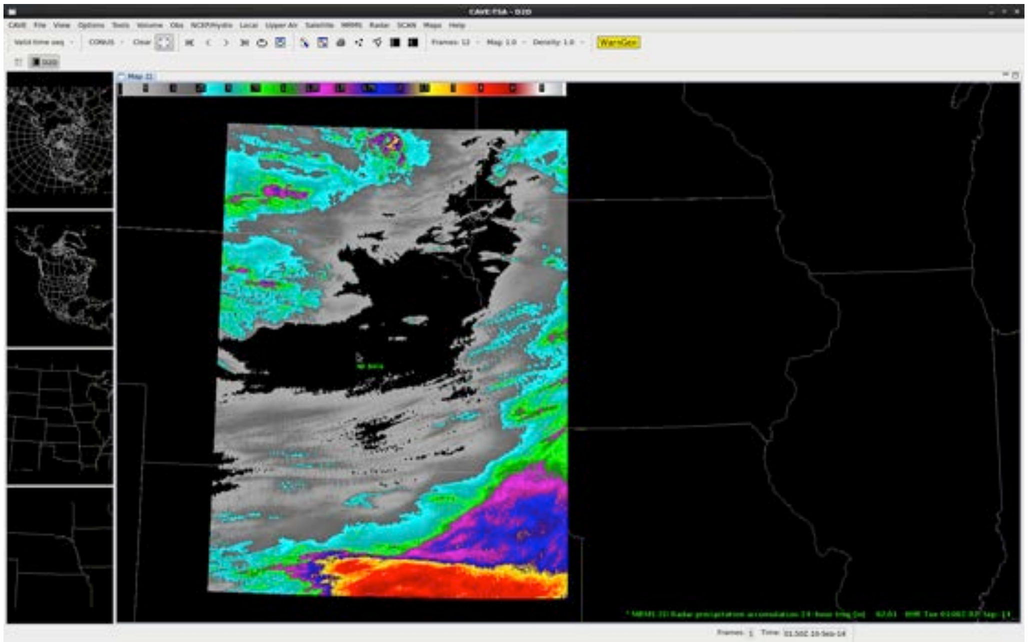
During efforts to verify MRMS products, several needed corrections came to light. These ranged from minor modifications of various format encoders to a significant overhaul of the MRMS GRIB2 encoder to satellite processing improvements. Several minor refinements to scientific algorithms were also included with the update package (referred to as MRMS-10.0.1). Details are listed below. MRMS v10.0.1 was implemented operational in early 2015.

- Revised MRMS GRIB2 encoder to use proper GRIB2 product identification numbers, more correct headers and better handle field data values
- Added new format encoders for data used by the operational High-Resolution Rapid Refresh (HRRR) model, the Aviation Weather Center (AWC) and the SPC
- Updated McIDAS based satellite-processing scripts to increase stability and improve parallax correction techniques
- Improved *DualPol QC* algorithm's quality control of reflectivity data for use in precipitation products
- Increased stability of *Polar Vertical Profile of Reflectivity (VPR)* algorithm
- Improved *Precip Flag* algorithm to better identify areas of convective rainfall
- Increased stability of *Gauge QC* algorithm and corrected minor data ingest bugs
- Added helpful metadata output to the *Local Gauge Correction* algorithm and corrected minor data ingest bug
- Corrected minor data ingest bug for the *Mountain Mapper* algorithm.

Once the operational MRMS dataflow was made available to outside users, access to the experimental MRMS data from NSSL was restricted to close partners (e.g., Global Systems Division of NOAA's Earth System Research Laboratory) and users (e.g., NWS River Forecast Centers). The operational system initially distributed data via LDM (http://www.unidata.ucar.edu/software/ldm/) only, which some users could not use. While NCO worked to establish an alternate data distribution method, NSSL began mirroring the data and providing it via HTTP.

Planning for the next MRMS build (v11) began in January 2015. Tasks included outlining data input needs, computing resource requirements, and working with outside groups to integrate their algorithms into MRMS or meet their product requirements. For example, CIMMS staff has worked closely with NWS Meteorological Development Laboratory to implement AutoNowCaster in MRMS and worked with NWS Southern Region to provide data for RIDGE2 (http://www.srh.noaa.gov/ridge2/). MRMS v11 will be implemented operationally in early 2016.

Previous versions of MRMS have been tested on a development system at NCO. NSSL is working to build an equivalent development system at the National Weather Center. Eventually, the new experimental MRMS system (called vMRMS) will be the sole testing ground for NSSL and CIMMS scientists to evaluate new and updated algorithms in real-time before they are implemented into operations. CIMMS staff worked with vendors and IT staff to setup and test the hardware needed for vMRMS. This project, including the setup and configuration of the vMRMS system, is ongoing.



The MRMS radar-only 24-hour QPE field as displayed in AWIPS2.

Publications

Zhang, J. , K. Howard, C. Langston, B. Kaney, Y. Qi, L. Tang, H. Grams, Y. Wang, S. Cocks, S. Martinaitis, A. Arthur, J. Brogden, and D. Kitzmiller, 2015P Multi-Radar Multi-Sensor (MRMS) Quantitative Precipitation Estimation: Initial operating capabilities. *Bulletin of the American Meteorological Society*, in press. doi:http://dx.doi.org/10.1175/BAMS-D-14-00174.1

Awards

CIMMS scientists were key contributors to winning the NOAA 2015 Silver Medal for the "successful transition of the Multi-Radar, Multi-Sensor system into operations to provide critical radar-based products to forecast weather hazards."

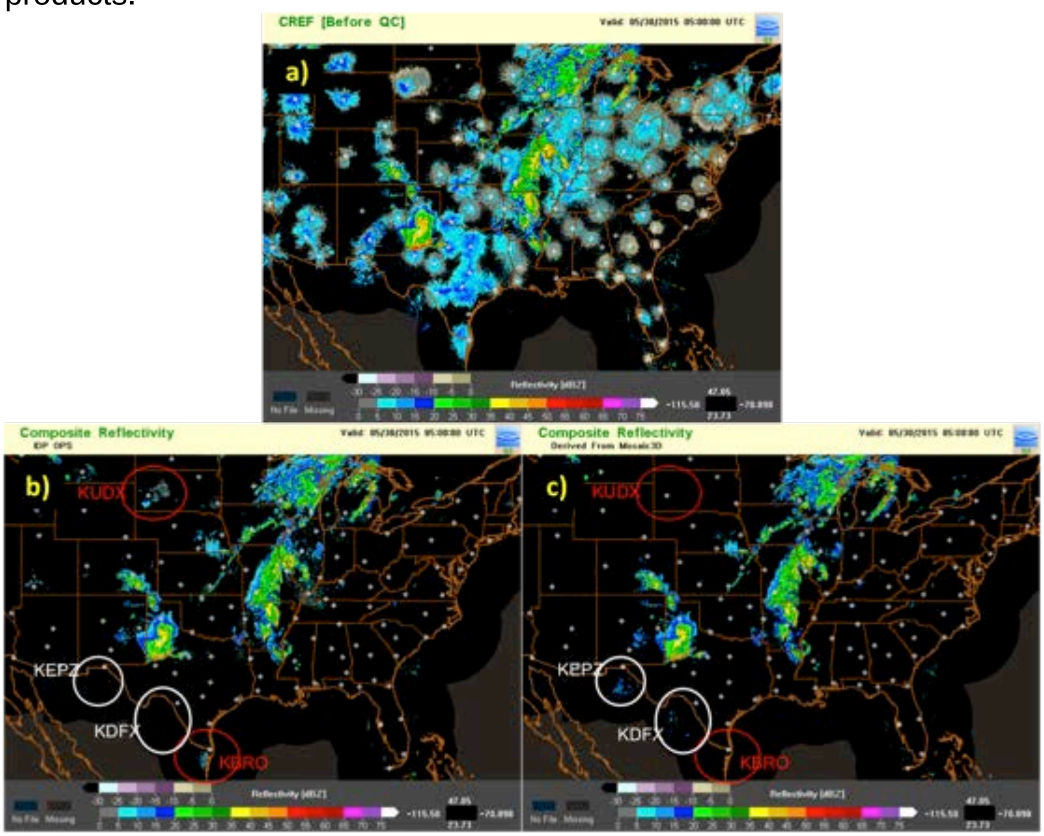
2. WSR-88D Data Quality Control Using Newly Upgraded Dual-Polarization Capabilities

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

Radar quality control process is important for both individual radar and MRMS products to mitigate effects of terrain, environmental conditions, biological presence (birds, bats, and insects), and radar maintenance practices, which can result in false weather radar presentations to aviation applications and users. Regarding polarimetric radar techniques for aviation weather applications, initial studies by the AWRT PDT have shown improved capabilities of polarimetric (or dual-polarization) radar data to discriminate between precipitation and non-precipitation scatterers over single-polarization radar observations. A new dual polarization quality control method (dpQC) was developed as the WSR-88Ds were upgraded with polarimetric capabilities. In this

task, the dpQC algorithm has been continuously improved for a superior capability of segregating precipitation returns from non-precipitation targets. The improvement includes: 1) a delineation scheme of two-dimensional melting layer to lower the false alarms caused by decreased ρ_{HV} associated with the melting hydrometeor target, 2) complete removal of the wind farms, and 3) other modifications to remove residual non-precipitation clutter to improve the process of sun spike and to better retain hail cores.

The dpQC has been refined for a robust performance of segregating non-precipitation from precipitation echoes. With the improvements, the updated algorithm is able to preserve precipitation echoes by correctly identifying the melting layer and the hail cores that associated with the decreased correlation coefficients, and it has the improved capabilities of further removing the residual clutter from biological migration or wind farms undergoing anomalous propagation of the radar beams. The updates of the QC algorithm show promising in effectively quality control the individual radar and MRMS products.

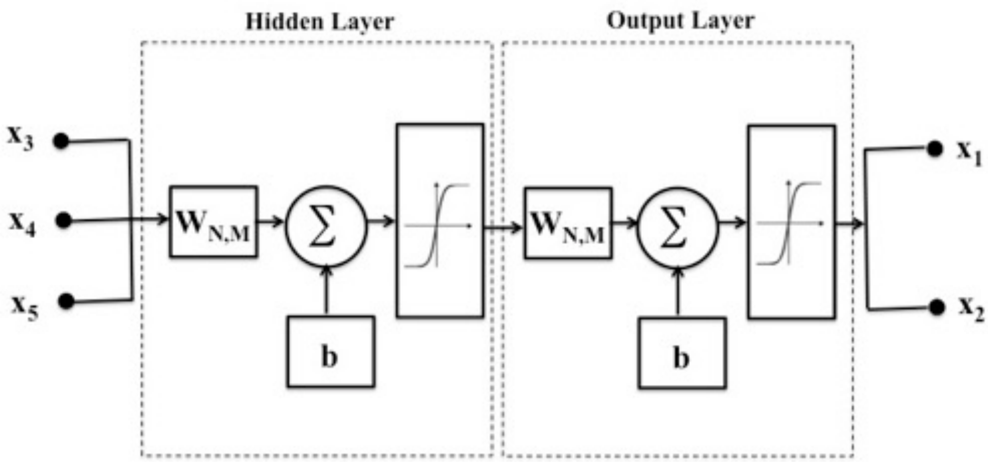


The mosaicked composite reflectivity (CREF) field across CONUS a) before any QC process, b) utilizing the previous version of dual polarization QC, and c) utilizing the new dpQC algorithm. The fields are observed at 0500 UTC 30 May 2015. The red circles highlight the non-precipitation echoes around KUDX and KBRO that are not fully removed in the previous QC process are removed using the new dpQC algorithm. The white circles highlight precipitation echoes close to KEPZ and KDFX that were inadvertently removed using the previous QC process were retained using the new dpQC algorithm.

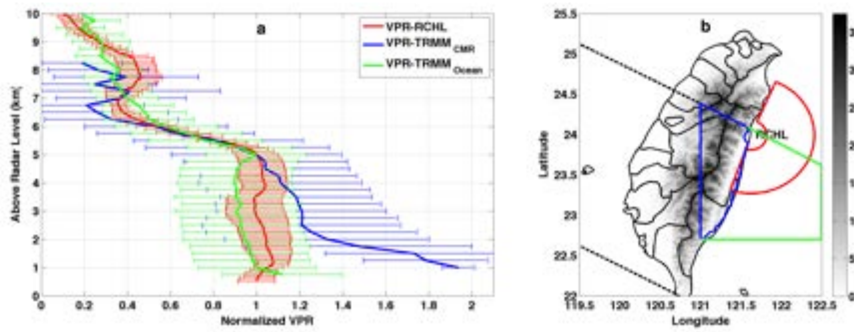
3. Radar Vertical Profile of Reflectivity Correction with Satellite Observations Using a Neural Network Approach

Yadong Wang (CIMMS at NSSL), Jian Zhang (NSSL), Pao-Liang Chang (Central Weather Bureau), and Qing Cao (Enterprise Electronics Corporation)

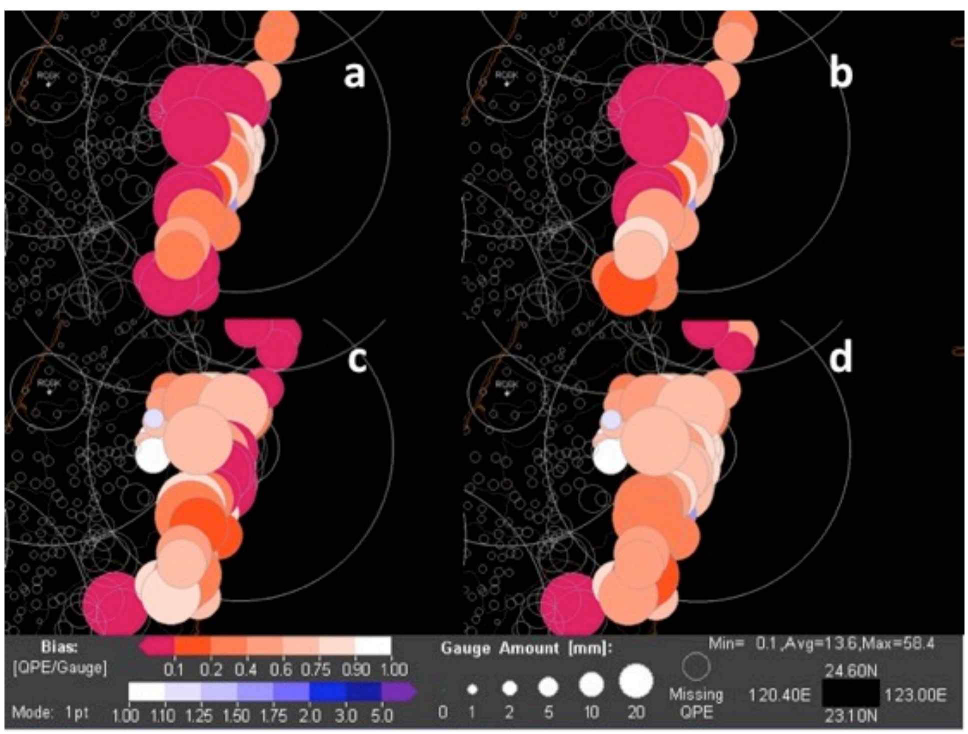
Complex terrain, which causes partial or total blockage on radar beams from the lower tilts, poses challenges to the ground based radar quantitative precipitation estimation (QPE). Although reflectivity values from higher tilts could be used in the QPE, biases will be introduced because of vertical variations in the reflectivity field. Space-borne precipitation radar carried by Tropical Rainfall Measurement Mission satellite (TRMM-PR) can provide good measurements of the vertical structure of reflectivity even in complex terrain, but the poor temporal resolution of TRMM-PR data limits its usefulness in real-time high resolution QPE. This study propose a novel vertical profile of reflectivity (VPR) correction approach to enhance ground radar based QPEs in complex terrain by integrating the space borne radar observations. In this work, climatological relationships between VPRs from S-band Doppler weather radar located on the east coast of Taiwan and the TRMM PR are developed using an artificial neural network (ANN). When a lower tilt of the ground radar is blocked, higher-tilt reflectivity data are corrected with the trained ANN and then applied in the rainfall estimation. Through the evaluation using three typhoon precipitation events, it was found the proposed approach could enhance the ground-based radar QPE performance.



Flowchart of the developed two layers artificial neural network for the VPR retrieval, where X_3~X_5 are the radar reflectivities from three higher tilts, X_1 and X_2 are the reconstructed radar reflectivities from the lowest two tilts. The weight matrix $W_{N,M}$ and the adjusting factor b are trained using the data from TRMM PR and RCHL.



a) The mean VPR sampled by RCHL (VPR-RCHL), TRMM-PR using the data from central mountain range region (VPR-TRMM$_{CMR}$) and ocean region (VPR-TRMM$_{Ocean}$) are plotted using red, blue, and green thick lines, respectively. The standard deviations at each height are included as thin bars. The mean VPR-RCHL was derived using a volume scan of reflectivity at 0758 UTC 28 August 2011, and the mean VPR-TRMM was derived using the TRMM-PR data from 0751 UTC 28 August 2011. b) The radar data used in the VPR-RCHL derivation are from the red lines region; the TRMM-PR data used in the VPR-TRMM$_{CMR}$ and VPR-TRMM$_{Ocean}$ derivation are from the blue and green lines region, respectively. The TRMM-PR swath is also inserted with black dashed lines.

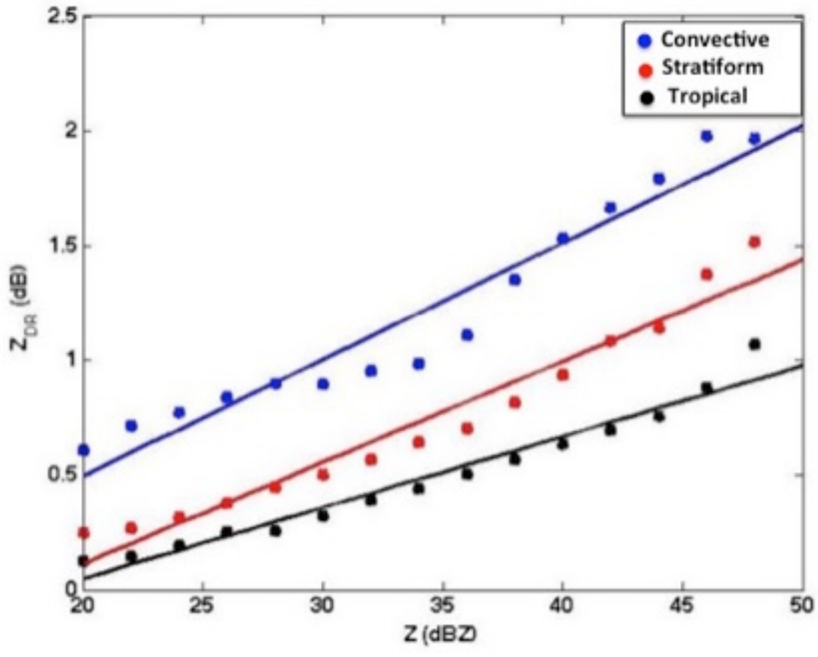


The spatial distribution of the radar QPE vs. gauge observations a) without VPR correction, b) with VPR correction where the VPRs derived using mean VPR-RCHL, c) using mean VPR-TRMM, and d) using VPR-TRMM reconstructed from ANN. 24-hour accumulated precipitation from typhoon Nanmadol (0000 UTC 28 August 2011) 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).

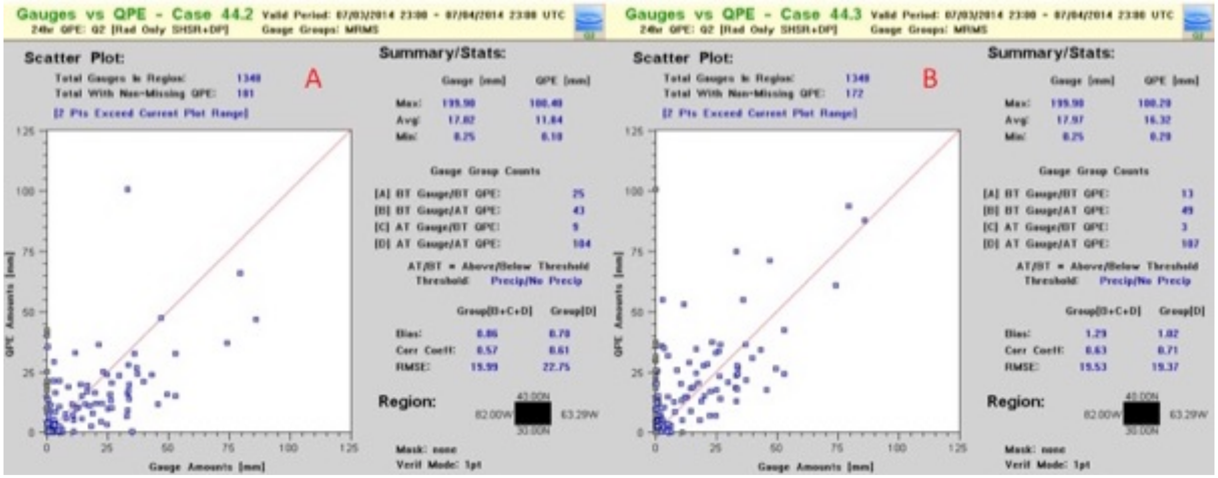
4. Development of a Novel Radar QPE Approach Using Specific Attenuation for Two C-Band Dual-Polarization Radars

Yadong Wang, Pengfei Zhang, and Alexander Ryzhkov (CIMMS at NSSL), Jian Zhang (NSSL), and Lin Tang and Stephen Cocks (CIMMS at NSSL)

A novel QPE algorithm using the specific attenuation, *A,* has been developed recently. As opposed to the conventional *R*(*Z*) algorithm, the *R*(*A*) estimate is immune to attenuation, radar miscalibration, wet radome, and partial beam blockage. Although the *R*(*A*) algorithm is more robust to the variability of drop size distribution (DSD) compared to other radar rainfall relations, the estimate of *A* from ZPHI procedure requires tuning the net ration $\alpha = A/K_{DP}$ along the radar beam where K_{DP} is the specific differential phase. The new version of the *R*(*A*) method incorporates automatic tuning α based on the rain type and the slope of the $Z\text{-}Z_{DR}$ dependency in a particular rain event. According to the new algorithm, precipitation region is first segregated into three rain categories: stratiform, convective, and tropical. For these regions, three values of α are calculated based on the $Z\text{-}Z_{DR}$ slopes in each of the three regions. The *A* field for an entire radar scan is first calculated using the α estimated from the largest region. Then the values of *A* in the other two smaller regions are adjusted with a factor based on the estimated α to match their precipitation types. Rainfall rate for the scan is computed using the adjusted *A*. Comparing to the *R*(*A*) using a fixed default value of α, the modified *R*(*A*) can provide better performance in terms of correlation coefficient, mean bias ratio, and the root mean square error.



The α estimation based on the slope of the $Z\text{-}Z_{DR}$ dependency.



The performance comparison between a) the R(A) using a fixed default value of α and b) real-time estimated α based on Z-Z_{DR} slopes.

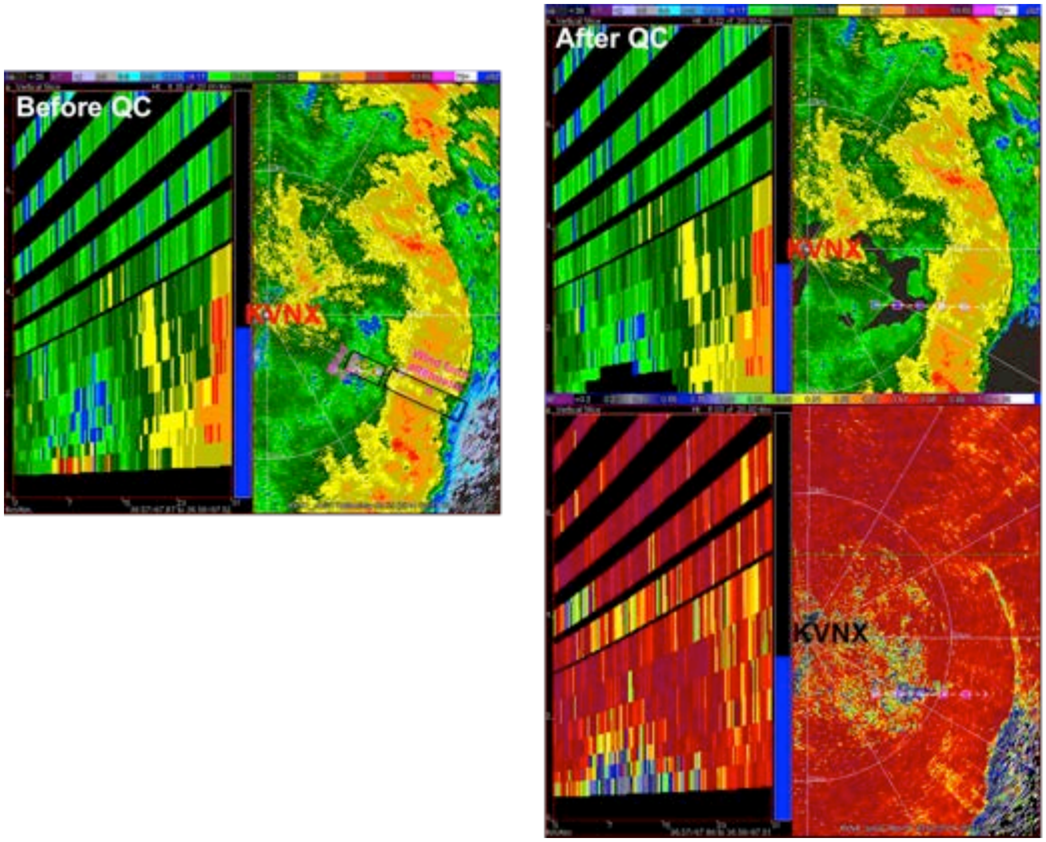
Publications

Wang, Y., J. Zhang, P.-L. Chang, and Q. Cao, 2015: Radar vertical profile of reflectivity correction with TRMM observations using a neural network approach. *Journal of Hydrometeorology*, in press.

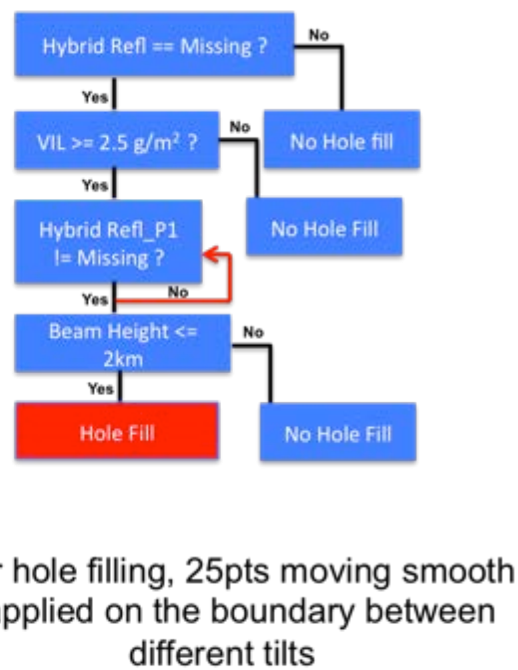
5. Quality Control and Data Filling in Areas Impacted by Wind Farms, Terrain, and the Zero Isodop

Youcun Qi and Lin Tang (CIMMS at NSSL), and Jian Zhang (NSSL)

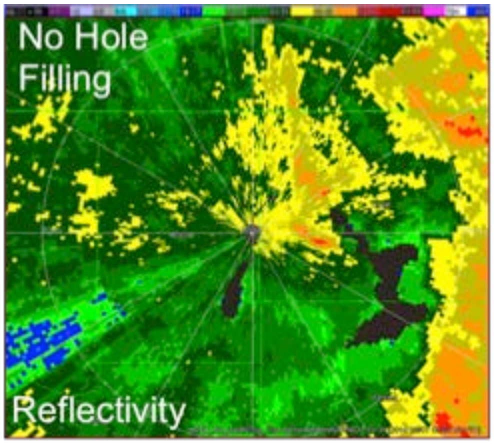
Wind farm contamination will usually enhance the intensity of the radar echoes, and this will bring large error in the radar QPE. The current study will remove the echoes contaminated by wind farm through "PhoHV" and model outputs. After removing the wind farm, the hole will be filled automatically with the hole-filling scheme. This hole-filling scheme is applied in areas where hybrid reflectivity is missing and where the vertically integrated liquid (VIL) and height of the radar beam meet certain criteria before applying the filling scheme and smoothing algorithm. This logic is also applied to areas where the beam is impacted by terrain and the zero isodop created by the radar velocity field.

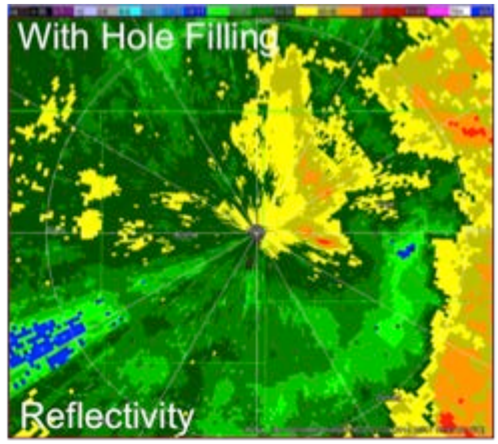


Reflectivity at 0.50° tilt (left) before quality control and (upper right) after QC with the corresponding PhoHV field (lower right).



Logic of hole filling scheme.





Radar reflectivity (left) without the hole filling logic and (right) with the hole filling logic applied.

6. Multiple Year Reanalysis of Remotely Sensed Storms – Precipitation (MYRORSS – P)

Youcun Qi (CIMMS at NSSL), Jian Zhang (NSSL), and Steven Martinaitis (CIMMS at NSSL)

Long-term records of high-resolution, high frequency QPE data are needed for many applications such as calibration of distributed and lumped hydrologic models, validation of numerical weather precipitation models, historic water census, and storm-scale precipitation climatology studies. The NSSL MRMS system has the capability of integrating data from ground-based radar, rain gauge, and atmospheric models to generate high-resolution and high frequency QPE products on a continental scale. A 11-year retrospective process of MRMS radar QPE products for the NEXRAD era (2001–2011) have been generated, which will provide high-resolution (1 km, 5 min), high-quality QPE products, including precipitation rate, type and accumulations of different time scales over conterminous United States. Gauge corrected radar QPE work is ongoing.

7. Evaluating MRMS Quantitative Precipitation Estimates Versus Single Source Radar QPE Products and NCEP Stage IV Estimates

Stephen Cocks and Steven Martinaitis (CIMMS at NSSL)

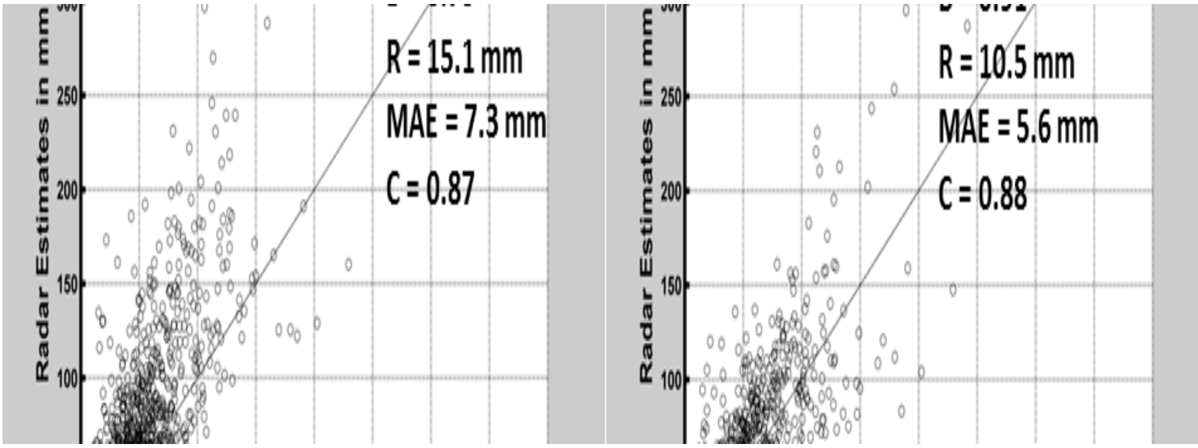
A systematic evaluation of MRMS QPE performance across the CONUS was conducted. For regions east of the Rocky Mountains during the warm season, precipitation events from 59 calendar days affecting 55 radars were collected with reference to single radars to highlight the advantages of a mosaic versus single radar QPE. Product performance was evaluated at a range of 230 km and 100 km from the radar location, the latter distance functioning as a proxy for a best-case scenario mosaic for the dual-polarization digital precipitation rate (DPR) and legacy Precipitation

Processing System (PPS) precipitation estimates. QPE products were also compared against NCEP Stage IV QPE mosaics, which include additional human quality control. Performance of all QPE products was assessed using Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) 24-hour accumulation gauge data while quality controlled hourly automated gauge data were used for spatial and time series analysis. QPE data were evaluated over five regions: Northern/Central Plains, Great Lakes/Midwest, the Northeast, the Southern Plains, and the Southeast/Mid-Atlantic.

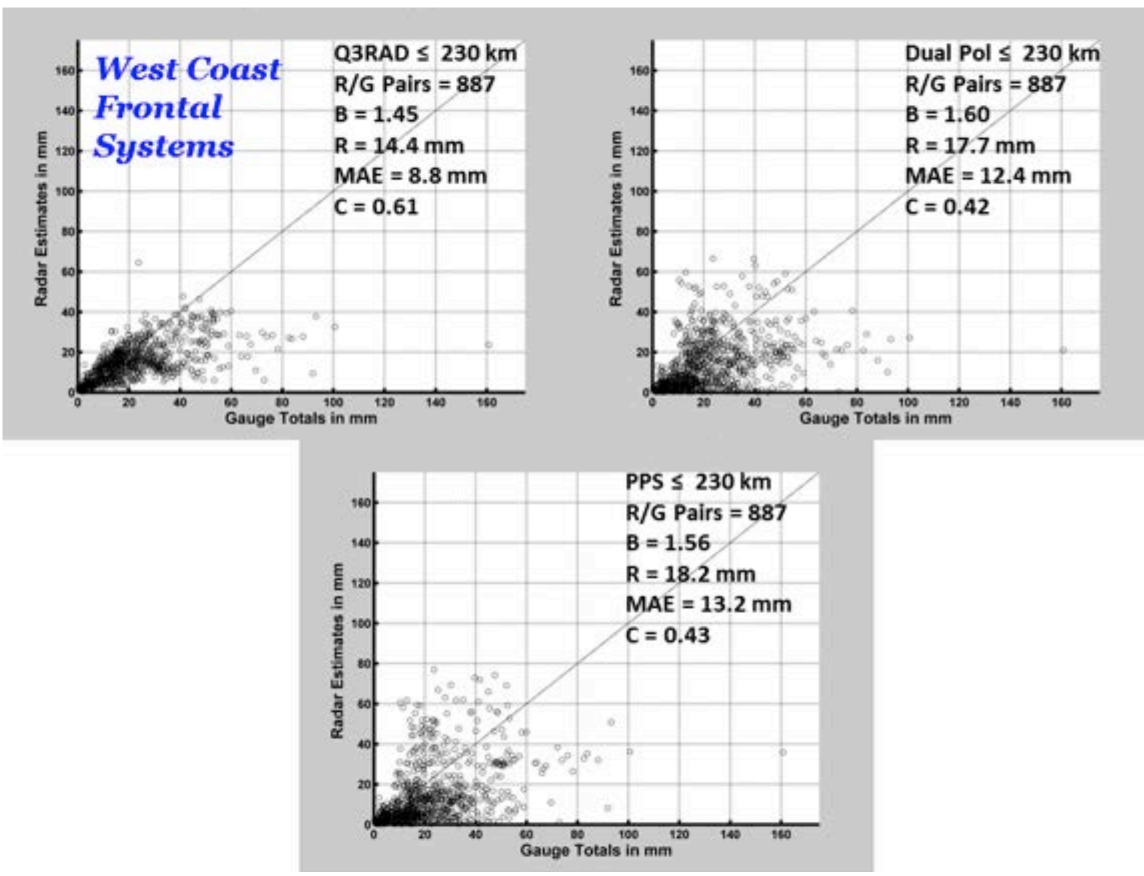
Results found that MRMS radar-only QPE (Q3RAD) performed better than DPR and PPS over the Northeast, Southern Plains and the Southeast/Mid-Atlantic regions, with overall performance statistics second only to the forecaster quality controlled Stage IV estimates. MRMS locally gauge corrected radar QPE (Q3gc) improved upon Q3RAD and were statistically close to Stage IV performance. Over the Great Lakes/Midwest and the Northern/Central Plains, a distinct Q3RAD overestimate bias was noted. A similar overestimate bias was also present with Q3RAD estimates during the latter summer over the Southeast/Mid-Atlantic region. The overestimate bias was primarily due to the MRMS system too often classifying radar echoes as tropical. The 850–500 hPa lapse rate requirement, which affects tropical precipitation classification, was adjusted to favor weak CAPE environments and revealed a significant reduction in the overestimate bias. The adjusted code should be operationally implemented before the 2016 warm season.

A similar study was conducted on 34 calendar days using 14 radars east of the Rocky Mountains. Precipitation products were substantially impacted by terrain blockage, radar beam overshoot, and gauge undercatch in windy conditions, especially during winter precipitation events. Q3RAD clearly outperformed DPR and PPS estimates at both a 230 and 100 km range from the radar during the cool season due to 1) MRMS applying a bright band correction for reflectivity in the melting layer and 2) the extra information provided by neighboring radars in a MRMS reflectivity mosaic mitigated terrain blockage/beam overshoot. DPR performed slightly better than PPS and Q3RAD during the warm season, likely because the precipitation was mostly convective and the additional hydrometeor information provided by the dual-polarization data enhanced the precipitation estimates. In both the warm and cool seasons, Q3gc provided some improvement upon the Q3RAD estimates, although the magnitude was less than expected, likely due to the sparse gauge density in some regions.

The findings from these evaluations are used to identify the strengths and challenges of the MRMS QPE product suite and determine how to improve upon the MRMS QPE algorithms. The project is ongoing.



Operational Q3RAD (left) and Q3RAD with the new tropical classification requirement (right) for five overestimate precipitation events. There is a significant reduction in error and the overall overestimation bias with tropical rain events.



Warm season results for Q3RAD (top left), DPR (top right) and legacy PPS (bottom) QPE for frontal systems west of the Rocky Mountains. All QPE products exhibited a distinct underestimate bias due to beam blockage/beam overshoot with Q3RAD having the least overall error and scatter.

8. Conducting O2R Site Visits to NWS River Forecast Centers

Stephen Cocks and Steven Martinaitis (CIMMS at NSSL)

Some of the MRMS QPE product suite, such as the radar-only QPE, Q3RAD, has been available to NWS River Forecast Centers (RFCs) for use in operations. NSSL research scientists with the MRMS project conducted one-day site visits to seven RFCs from January to April 2015. The in-person meetings between NSSL scientists and RFC personnel facilitated the "Operations to Research" (O2R) process for the advancement and development of new QPE products and techniques. The on-site visits allowed NSSL scientists to collect feedback from Hydrometeorological Analysis and Support (HAS) forecasters and hydrologists on MRMS QPE-related products, gain a better understanding of RFC operations, and determine the current operational challenges of precipitation estimation at varying RFCs. Topics related to QPE challenges and uncertainty included the estimation and coverage of light precipitation, determining precipitation in areas of poor radar and gauge coverage, orographically-induced events, and use within hydrologic modeling and analysis. Findings from these visits led to the improvement of QPE products, which were assessed in collaboration with RFC forecasters. Continued communications with RFC forecasters allows CIMMS and NSSL staff members to address enhancements to the MRMS QPE product suite to meet end-user needs. This project in ongoing.

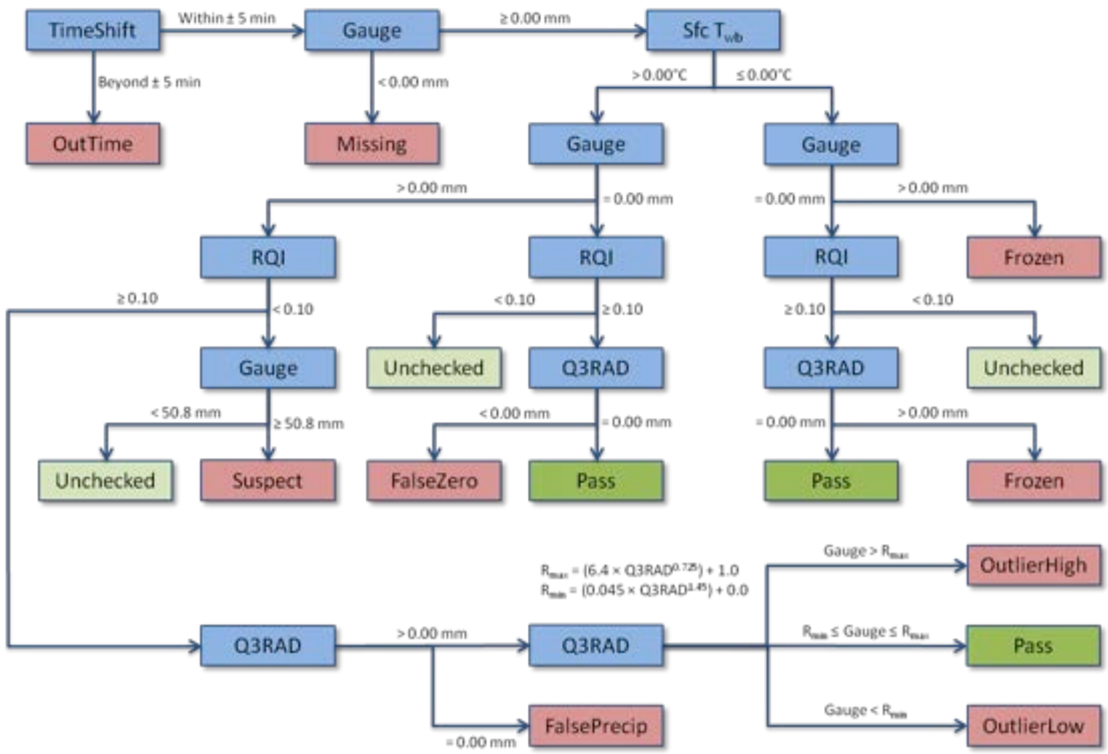
9. Quality Control Advancements of Hourly Rain Gauge Observations

Steven Martinaitis, Stephen Cocks, and Youcun Qi (CIMMS at NSSL), and Jian Zhang and Kenneth Howard (NSSL)

Surface rain gauge observations are regarded as "ground truth" when used to verify and calibrate radar-derived QPE. However, gauges not properly vetted by a quality control (QC) procedure can introduce erroneous statistical results and bias calibration. Continued advancements were made to the rain gauge QC algorithm to allow for a greater quantity of gauges to undergo QC and to modify decision-tree logic in the executable coding.

The QC algorithm utilizes a Radar Quality Index (RQI) product to denote when a gauge observation can be compared against radar-based QPE to determine if the gauge observation is erroneous. The RQI product ranges from 1.0 (considered very good quality that is unblocked and below the bright band layer) to 0.0 (very poor or non-existent radar coverage). The 2015 version of the algorithm increases the effective area that radar can be used to determine suspect gauge values by changing the RQI value from 0.5 to 0.1. For areas where RQI = 0.0, CIMMS scientists determined that over 97% of hourly gauge observations that were at least 2.00 inches would be deemed in error; thus, those gauge observations were considered as suspect and removed. Overall results from these changes meant that fewer gauges did not go unchecked, which allowed for the increased removal of erroneous observations.

Continuing long-term collaboration between NSSL and other NOAA partners will address the collection and QC of gauge metadata, the identification of quality gauge observations within winter precipitation regimes, and the ability to display the QC results for each hour along with a time series of QC flags to determine history of gauge observational quality. This project is ongoing.



Logic tree of the MRMS gauge QC algorithm. Gauges that are flagged and removed from use in MRMS product production include those outside of a time window, missing, frozen, and false or outlier observations.

Publications

Martinaitis, S. M., S. B. Cocks, Y. Qi, B. T. Kaney, J. Zhang, and K. Howard, 2015: Understanding winter precipitation impacts on automated gauge observations within a real-time system. *Journal of Hydrometeorology*, in press. doi:10.1175/JHM-D-15-0020.1.

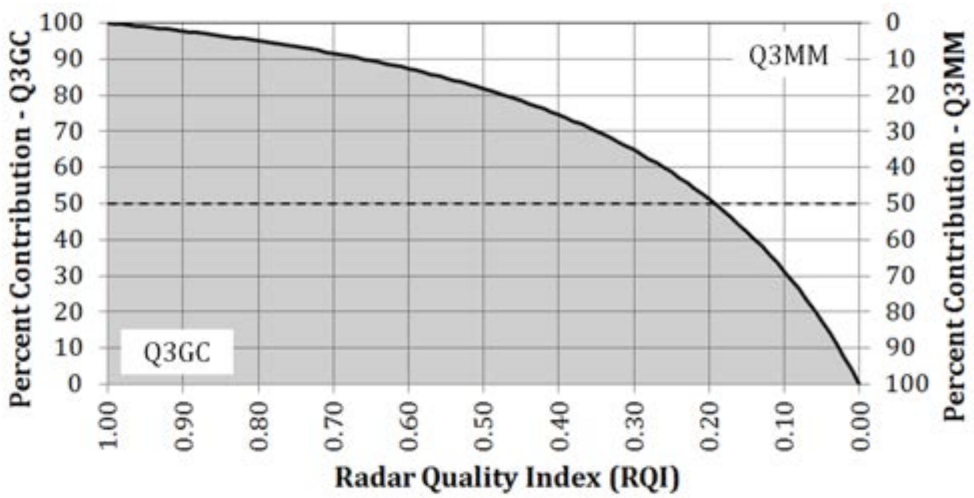
10. Combining Multiple Precipitation Products to Generated a Merged QPE

Steven Martinaitis, Youcun Qi, and Stephen Cocks (CIMMS at NSSL), and Jian Zhang and Kenneth Howard (NSSL)

Different sources of QPE have varying strengths and challenges in generating deterministic surface precipitation values. These challenges are magnified in the western United States where there are significant gaps in radar coverage due to less dense coverage and beam blockage from complex terrain along with a sparse network

of gauge observations. CIMMS scientists are developing a scheme to merge a radar-derived QPE with gauge observations and a climatology-based QPE to provide a more accurate and comprehensive QPE coverage across the conterminous United States.

The current scheme under development would merge the MRMS local gauge corrected radar QPE (Q3GC) with the MRMS Mountain Mapper product (Q3MM), which is created by interpolating gauge observations onto background rainfall climatology. Both Q3GC and Q3MM were evaluated over a nine-month period to determine an appropriate interpolation method. The prototype-merging scheme would utilize a modified Radar Quality Index product as a primary weighting factor to seamlessly blend the QPE sources. Other factors that would influence the weight of each QPE source will include Rapid Refresh (RAP) model surface wet-bulb temperature (T_{wb}), reflectivity coverage, and the radius of influence of gauge values based on surface precipitation types. The merged QPE product will undergo extensive testing and evaluation prior to operational release. This project is ongoing.



Theoretical contribution of Q3GC and Q3MM to the merged QPE product based on a modified RQI product and outside of a gauge radius of influence for areas where the RAP model surface T_{wb} > 2.50°C.

11. 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 (NSSL), Pierre Kirstetter (CIMMS at NSSL), and Bob Rabin (NSSL)

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 QPE product is under development that uses a simple, steady state microphysics model to simulate near-surface drop size distribution moments (reflectivity and rain rate) in areas where radar coverage is poor or non-existent. The model is initialized from cloud top properties derived from the ABI, as well as analyses of temperature and relative humidity from the High Resolution Rapid Refresh (HRRR) model.

During 2015, development of an initial prototype of the satellite-based rain rate model was completed. A prototype "merged" multi-sensor QPE product was also developed that uses the MRMS Radar Quality Index to blend the satellite and radar-based QPE fields. This project is ongoing.

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

Brian Kaney and Carrie Langston (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). Several updates and improvements were made to both systems in 2015.

a. Maintenance Updates

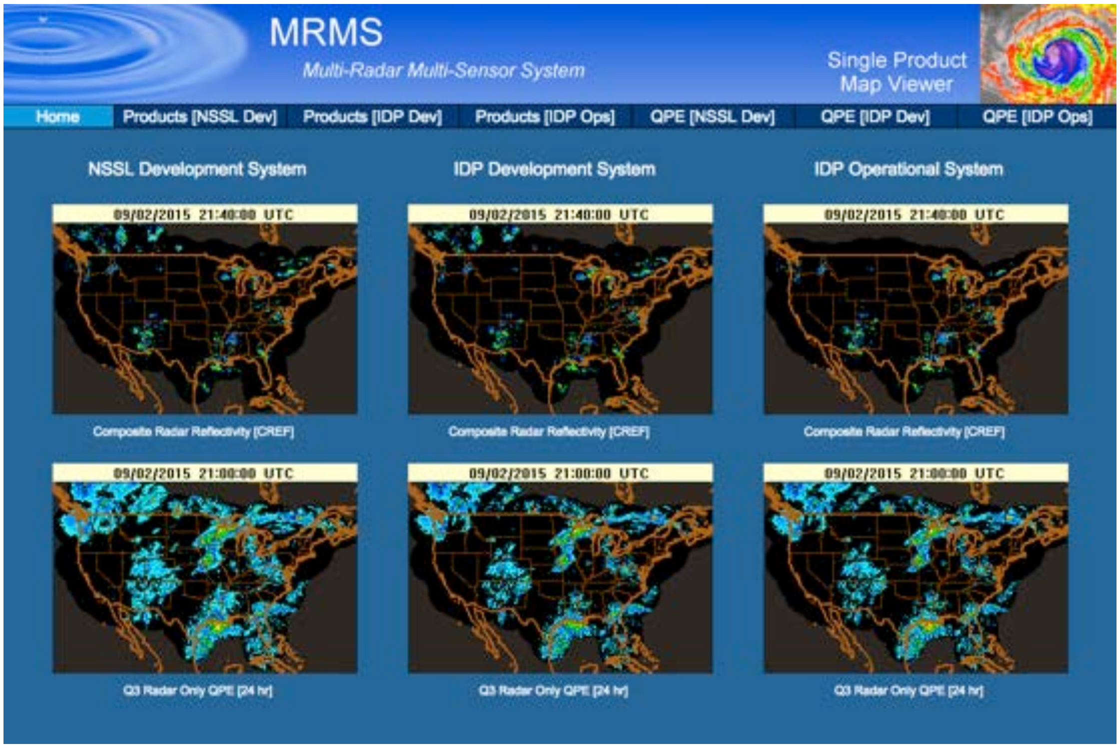
Maintenance work performed for all of the systems or tool sets listed below, which included bug fixes, navigational and display tweaks, addition of new products, trouble-shooting of problems, user training, and data back-filling.

- NSSL QVS Page
- QVS for MYRORSS Project
- TRMM vs. Q3 Comparison Tool
- Level 3 Adaptable Parameter Display for the Radar Operations Center

Initial work has been done on a more robust case study capabilities system that uses the latest generation of QVS functionality by cloning a couple pieces of the current QVS and pointing it to a case study data repository. Although in its infancy, it has already proved useful for assessing test QPE's against gauges.

b. QPE Verification System (QVS) for NSSL Mirror of MRMS Products at NCO

A QPE verification system (QVS) was set up that pointed to a mirror of the newly operational MRMS products at NCEP Central Operations (NCO) sent via LDM to NSSL while waiting for other display options to mature. It is specifically designed to have a highly parallel structure for the NSSL MRMS, the IDP Developmental MRMS, and the Operational IDP MRMS for rapid comparison and assessment of the products.



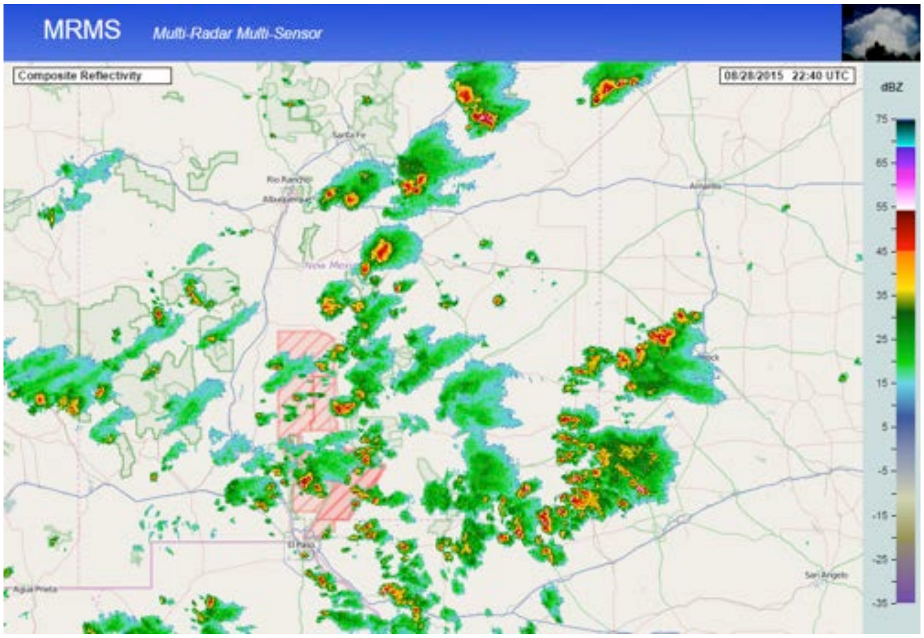
Snapshot of the Single Product Map Viewer at http://mrms.ou.edu/qvs.html. Products are broken down by source (NSSL development, NCO/IDP development, NCO/IDP operational systems) and type (general products and QPE products).

c. Next Generation QVS

In late winter 2014, significant QVS work began to overhaul the whole mapping strategy and engine to incorporate the most modern approaches. Significant training was obtained and other relevant projects were researched. The latest QVS MRMS web maps are now built in layers that can include a Google or Open Street Maps layer along with MRMS products and a variety of overlays and custom tool layers. These currently include a distance tool and a mPING report layer. Other layers are planned. This new generation will eventually replace all of our current QVS tools, but the focus initially has been on a simple viewer for operational QVS to be installed at the NCO.

On the technical side, many changes have been made in the underlying code and structure. The need for a 'submit' button has been removed with the page responding

immediately to any navigational change. With the use of map layers, not everything needs to be reloaded as often. A change to the overlays only causes the overlay layer to be swapped out. A change in time does not require background maps of fixed geographical information to be replaced. The web tools are now more fully AJAX applications, with the use of web services that return a JSON object.



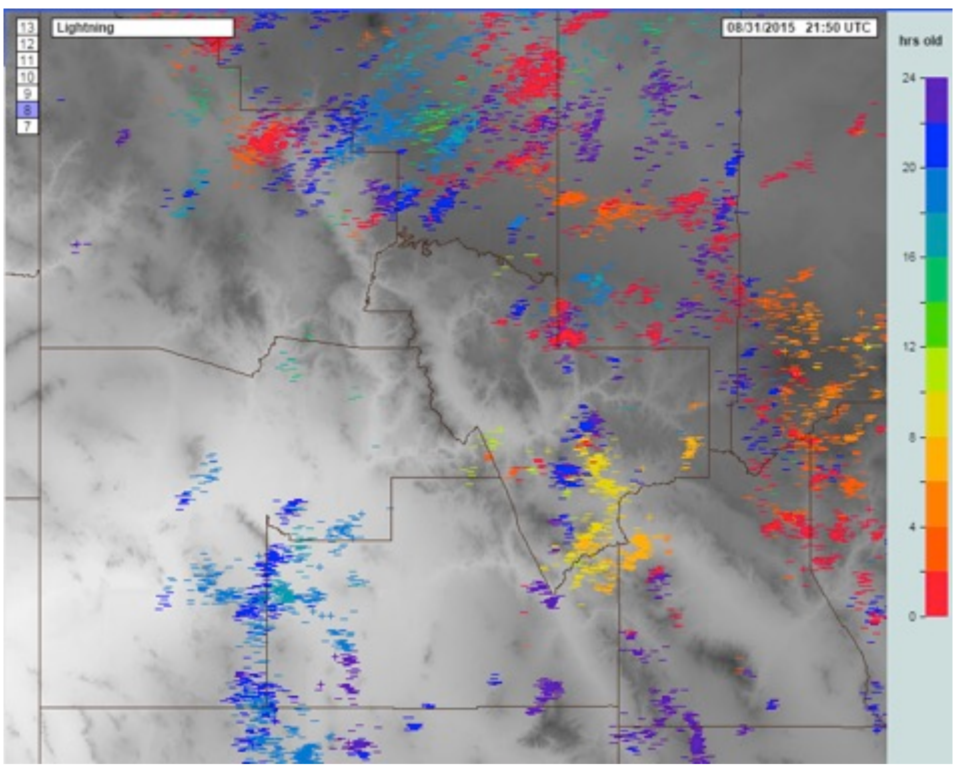
Sample QVS product with Open Street Map background.

Sample QVS products with plain black background, mPING reports, and Distance Tool layers active.

d. Hydromet Viewer for Salt River Project

The Salt River Project (SRP) water and power utility operate in a very challenging QPE/QPF environment and had the first WSR-88D installation in the mountain west. With significant mountain blockages, complex terrain, large areas of orographically enhanced precipitation, significant winter precipitation from low based clouds, significant summer thunderstorms from high based clouds, and even tropical storm remnants, central Arizona is well suited to test the limits of multi-sensor QPE and the new dual-polarization capabilities in MRMS.

This project involves completely revamping the internal meteorology web tools used by SRP. The work dovetails nicely with the previous item discussed here, the next generation of the national QVS. The two systems will ultimately share much of the same functionality; however, at this stage of development, there are also some importance differences. SRP has access to quality lightning data, which is not yet in place in the MRMS national system. Their priorities differ as well. For instance, mPING is less useful as participation in the far west is much lower, but they have a good surface mesonet that is key to their operations. This kind of dual development is useful in designing a flexible set of tools with modular units that can be easily added or subtracted. This project allows CIMMS and NSSL scientists to work closely with SRP and obtain valuable feedback from operational users.



Sample lightning strike display from the Salt River Project Hydromet Viewer. 24-hours of strikes are shown and color-coded for the time of day.

13. meteorological Phenomena Identification near the Ground (*mPING)*

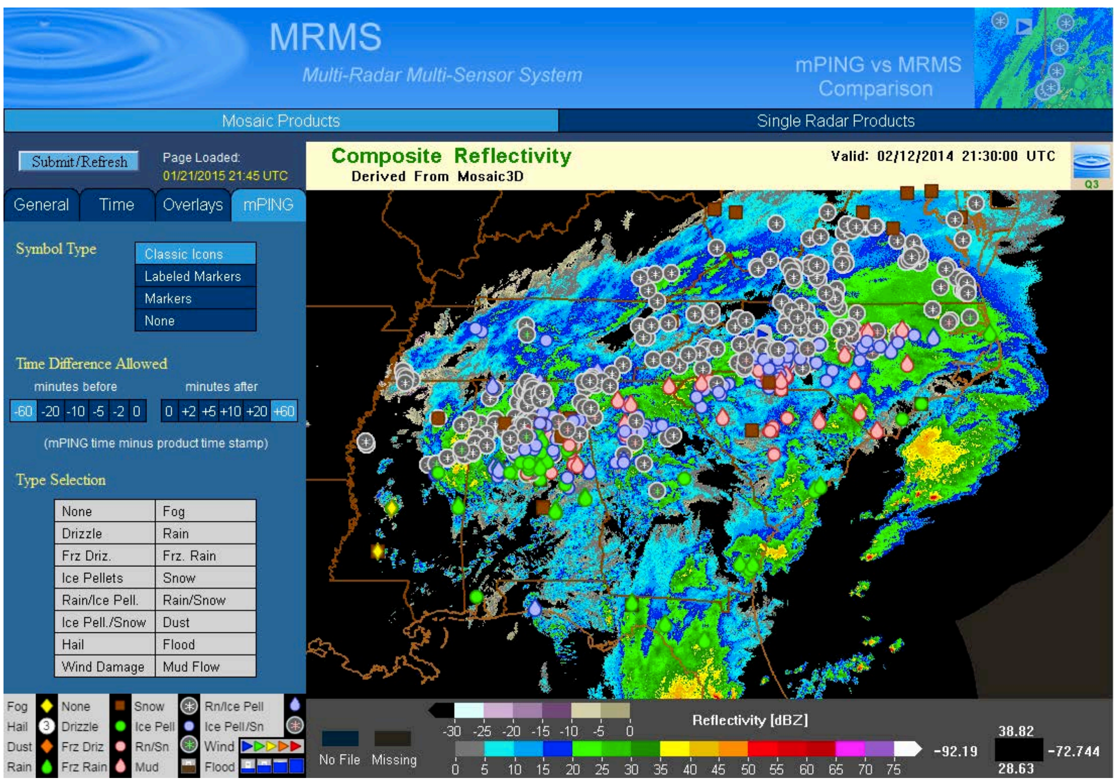
Kim Elmore, Heather Grams, and Jeff Brogden (CIMMS at NSSL)

Objectives: Use citizen scientists to crowd-source reports of winter precipitation type, hail occurrence and size, flood severity, weather-related damage and restrictions to visibility.

Accomplishments

The mPING (meteorological Phenomena Identification near the Ground) crowd-sourcing smart-phone app has continued to gain users (now approximately 91,000 download) and has generated over 910,000 report submissions. Three peer-reviewed paper have resulted from mPING data. In addition, the mPING data revealed an error in the Rapid Update Cycle (RAP) model precipitation type diagnostic that resulted in changes in the operational model.

In addition, hosting of the mPING incoming and outgoing data servers has been changed to the OU Research Computing Services, allowing enhancements to the data ingest and display capabilities. The application program interface is set to be released in early fall, which will allow other developers to include the ability to submit mPING reports from their own apps. This is particularly important for apps developed and used by television stations that want to display mPING data but do not want to encourage use of apps that compete with their revenue generation.



mPING observations displayed within the Multi-Radar Multi-Sensor system.

Publications

Elmore, K. L., Z. L. Flamig, V. Lakshmanan, B. T. Kaney, V. Farmer, Heather D. Reeves, Lans P. Rothfusz, 2014: MPING: Crowd-sourcing weather reports for research. *Bulletin of the American Meteorological Society,* **95,** 1335-1342.

Reeves, H. D., K. L. Elmore, A. Ryzhkov, T. Schuur, J. Krause, 2014: Sources of uncertainty in precipitation-type Forecasting. *Weather and Forecasting,* **39,** 936-953.

Elmore, K. L., H. M. Grams, D. Apps, and H. D. Reeves, 2015: Verifying forecast precipitation type with mPING. *Weather and Forecasting,* **30,** 656-667.

14. mPING Random Forest Research

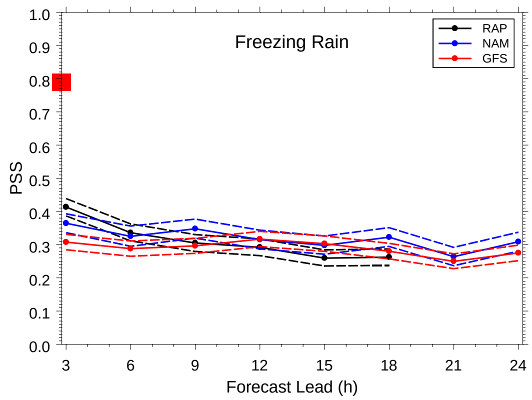
Kim Elmore, Hoyt Burcham, and John Krause (CIMMS at NSSL)

Objectives

Use mPING observations linked with model data and machine learning/artificial intelligence techniques to develop a better winter precipitation type algorithm.

Accomplishments

The random forest technique has been used to generate precipitation type diagnoses from the high-resolution rapid refresh (HRRR) analyses. This work indicates that significantly better precipitation type diagnoses and possibly forecasts may result from driving supervised machine learning algorithms, such as random forests, with mPING observations. Work in the 2014-2015 period centers on transferring the random forest precipitation type classification methods to operational software. The operational software generates a background precipitation classification field for the new winter surface hydrometeor classification algorithm under development at NSSL.



Example of freezing rain Peirce skill scores (PSS) for the Rapid Update Cycle (RAP), North American mesoscale forecast system (NAM) and Gridded Forecast System (GFS) computed using mPING data. The dashed lines representthe 95% confidence intervals for the various skill scores. The red square centered on a score of about 0.78 represents the perfromance of an experimental random forest classifier using data form the initial analysis of the HRRR model. The vertical width of the red square shows the 95% confidence interval for the random forest score. While this is a potential improvement of almost a factor of 2 in skill, it should be considered an upper bound of the potential improvemnts.

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: Richard Doviak, Allen Zahrai, and Dusan Zrnic (NSSL)

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

Funding Type: CIMMS Task III (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 and Nik Luetkemeyer (ARRC at OU), and Igor Ivić (CIMMS at NSSL)

Objectives

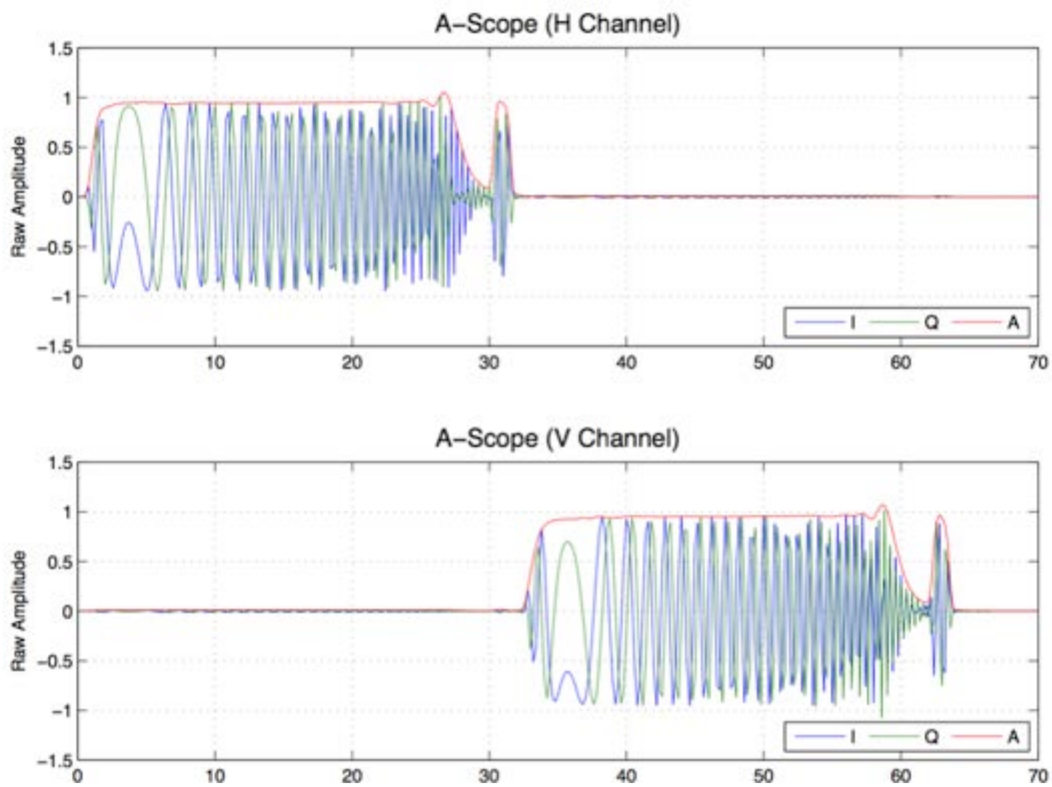
One of the key missions of the MPAR is to provide high-quality weather observations, which require high-quality measurements of polarimetric variables. Traditional dish-like systems currently provide cross-polar isolation on the order of 30 dB, which would be extremely challenging for patch antenna design to accommodate. An alternate solution to improve this deficiency is the use of a software coded transmit scheme that leverages the transmit agility available to an MPAR system. The primary objective of this project is to improve polarimetric isolation through the use of alternative pulsing schemes.

Accomplishments

A pulsing scheme called quasi-simultaneous horizontal and vertical (QSHV) 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 the radar system's blind range, 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 QSHV scheme introduces minimal blind range.

As mentioned in the previous report last year, significant effort will be devoted to the primary test platform, which is the ARRC PX-1000 solid-state radar, to enable the implementation of the QSHV scheme. A graduate student has successfully completed

the effort. The figure below shows an example of the transmit signal collected with the PX-1000 radar using the proposed QHV scheme. Collection of weather data using the proposed QSHV scheme will follow in the very near future.



Example of the transmit waveform capture through the forward couplers on the transmit chain. These are actual samples on transmit. The long-short combination is the currently practiced time-frequency multiplexed (TFM) waveforms on the PX-1000 system. For the QHV scheme, the entire long-short waveform is considered a single transmit waveform.

2. Optimal Pulse Compression Waveforms for MPAR

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

Objectives

Multi-sector arrays have been used for decades in various configurations, but they generally achieve spatial isolation through strategic sector placement. The MPAR proposal has typically assumed a multi-sector approach on a single platform. With the goal of allowing each sector to independently operate, isolation is a major concern for MPAR sectors operating on different missions. Waveform-based isolation is a proposed area that can lead to a solution for this problem.

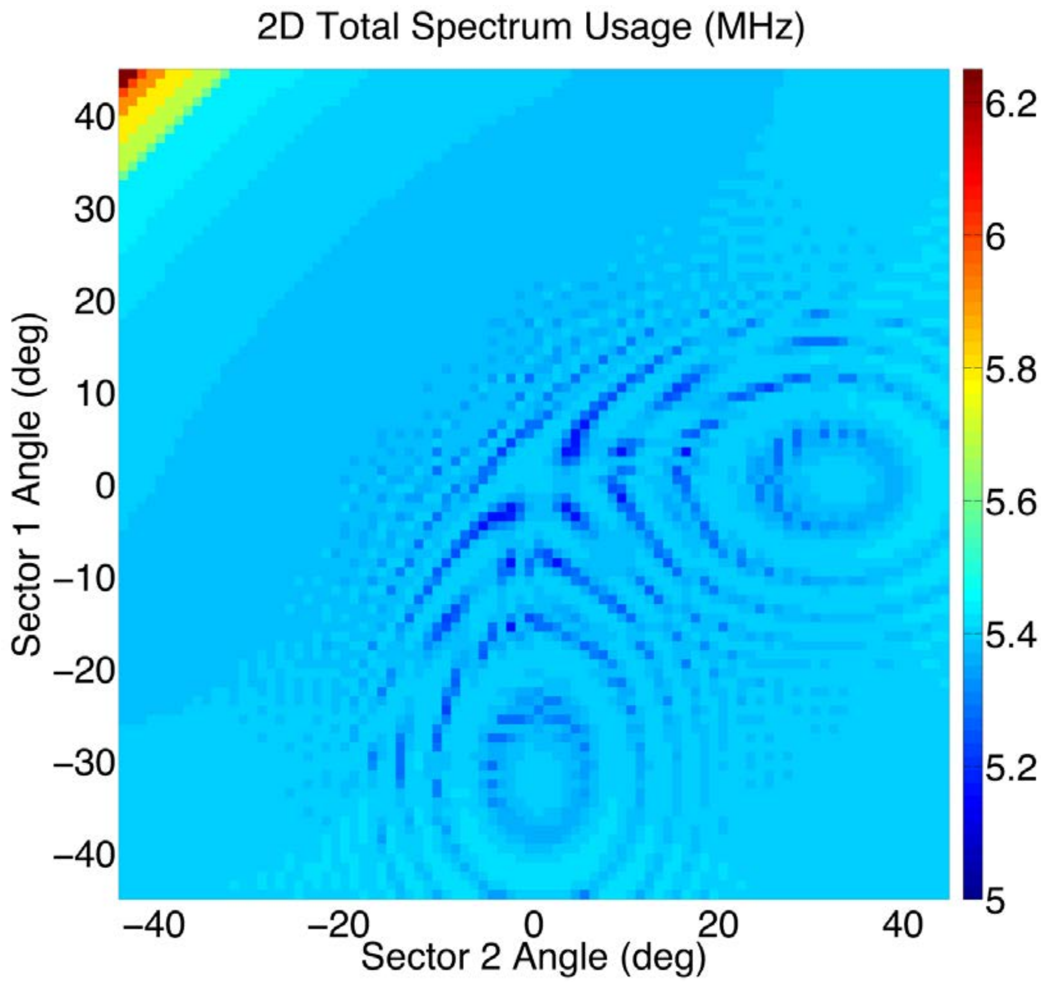
Accomplishments

The background for this work has been based around the single-waveform design described in Kurdzo et al. (2014) using Bézier curves to design highly non-linear frequency functions for pulse compression. An extension of this method has been developed that can design multiple waveforms simultaneously, providing the possibility to optimize based on both individual waveform performance (sidelobe levels, resolution, power efficiency, etc.) and waveform-to-waveform isolation metrics.

This study has separated isolation into three types: spatial, waveform, and frequency. Spatial isolation at all possible pointing angles has been determined using a simulated MPAR beam pattern based on the notional function requirements (NFR). As the beams steer in the same direction (+/- 45 degrees in a two-sector planar array), spatial isolation becomes zero. At broadside and further, the isolation is roughly -45 dB, with a transition zone between 0 and -45 dB between +/-45-deg pointing angles and +/-25-deg pointing angles. With NFR specifications indicating the desire for 80 dB of total isolation, a significant amount of necessary isolation remains.

Waveform isolation is the additional possible isolation provided by pure waveform design. In the optimization process, two waveforms have been designed that can achieve between 10-20 dB of waveform-only isolation. This is not as high as an up/down chirp would generate, but the up/up methodology affords the ability to avoid any frequency overlap in time with minimal frequency separation. As a representation of an extremely conservative approach, waveform isolation values of 10 dB have been assumed during the frequency isolation step.

The final piece of the optimization is minimizing the frequency separation to gain the required remaining isolation after accounting for both spatial and waveform isolation. In the case of most pointing angles, this results in the need to generate roughly 25 dB of additional isolation. Due to the up/up nature of the chirps, frequency overlap can be completely avoided, resulting in extremely minimal chirp offsets to gain acceptable isolation. In the majority of possible pointing angles, frequency savings can be as high as 46% (see figure below) by using this methodology, possibly indicating spectral savings for a future MPAR application.



Total spectrum usage for all possible steering angles of a two-sector array utilizing 5-MHz offset frequency modulated chirps and optimizing for minimal spectral footprint. Total spectrum is generally held under 6 MHz rather than the expect 10 MHz total, possibly indicating spectral savings as high as 46% at most pointing angles for a future MPAR application.

3. Calibrated and Computationally Efficient Adaptive Beamforming

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

Objectives

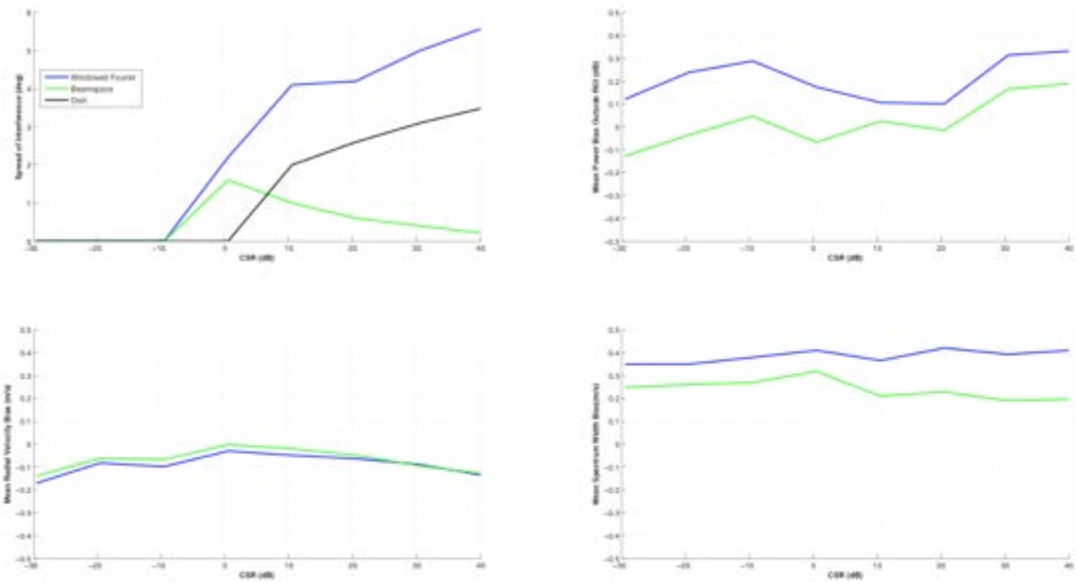
The future MPAR system is required to concurrently perform aircraft and weather surveillance functions with update times of 4.8 seconds and one minute, respectively. To meet these demanding update-time requirements, an MPAR system will likely employ multiple simultaneous beams. One way to achieve this is to transmit a spoiled beam and use digital beamforming to form multiple simultaneous receive beams. However, this solution has difficulties in meeting the data-quality requirements for weather observations due to increased sidelobe levels in the two-way radiation pattern compared to similarly sized dished antennas. An alternative solution is to use adaptive

beamforming so that the sidelobe levels are automatically lowered in the directions with significant weather return. Traditional adaptive beamforming algorithms are computationally expensive, and their adaptive patterns cause significant challenge for reflectivity calibration. As a result, a calibrated and computationally efficient adaptive beamforming algorithm must be developed to help future MPAR system to meet its update-time and data quality requirements simultaneously.

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 have been evaluated for weather applications. These algorithms operate on the received signal from each antenna elements, and their computation complexity makes them unattractive for real time implementation. More importantly, these algorithms were developed using signal models consisting of discrete point targets, and applying these algorithms in the presence of distributed scatterers results in significantly biased reflectivity results. Furthermore, due to the adaptive nature of the beam pattern, reflectivity calibration becomes more difficult compared to the calibration process for a fixed beam pattern.

Research is underway to develop an adaptive beamforming algorithm that operates in beamspace that solves the reflectivity calibration problem and produces accurate estimates of the meteorological variables. Unlike traditional adaptive beamforming algorithms, beamspace processing operates on the received signals from a set of deterministic beams, which allows beamspace processing to produce calibrated meteorological data while retaining the capability of performing spatial filtering of interfering signals. In addition, compared to element-space adaptive beamforming algorithms, beamspace adaptive processing is computationally simpler and requires fewer samples to achieve comparable estimation accuracy. Preliminary simulation results displayed in the figure below show that beamspace adaptive processing can significantly reduce the spatial spread of an interfering signal compared to Fourier beamforming and dish antenna system for large CSR cases. For directions away from the interference, it is shown that beamspace adaptive processing produces estimates that are close to the estimates produced by dish antenna systems that meets the data quality requirements for MPAR. Beamspace adaptive processing will be applied to data collected by the Atmospheric Imaging Radar to evaluate its performance with real data.



From top left, clockwise: angular spread of an interfering signal, mean signal power, spectrum width, and radial velocity bias for directions away from the interfering signal. The plotted average biases are measured against estimates by a dish antenna system. The results for Capon beamforming are not shown due its large biases. Beamspace adaptive processing has superior ability to reduce the angular spread of interfering signals for large CSRs compared to a dish antenna system and Fourier beamforming. For directions away from interference, estimates produced by beamspace adaptive processing have small biases compared to estimates by dish antenna systems.

4. Scalable and Reconfigurable Polarimetric Array Modeling and Measurement

Yan (Rockee) Zhang and Jorge Salazar (ARRC at OU), Richard Doviak and Dusan Zrnic (NSSL), and Tyler Mansur, Ridhwan Mirza, and Sudantha Perera (ARRC at OU)

Objectives

The objective of FY15 research was to gain fundamental knowledge of polarimetric phased array antennas with multiple manifold configurations (planar and cylindrical) and similar aperture sizes. Testing a new electric-magnetic dipole radiating element concept, as well as investigating an innovative phase-shifter-less electronic scanning concept, are also part of goals.

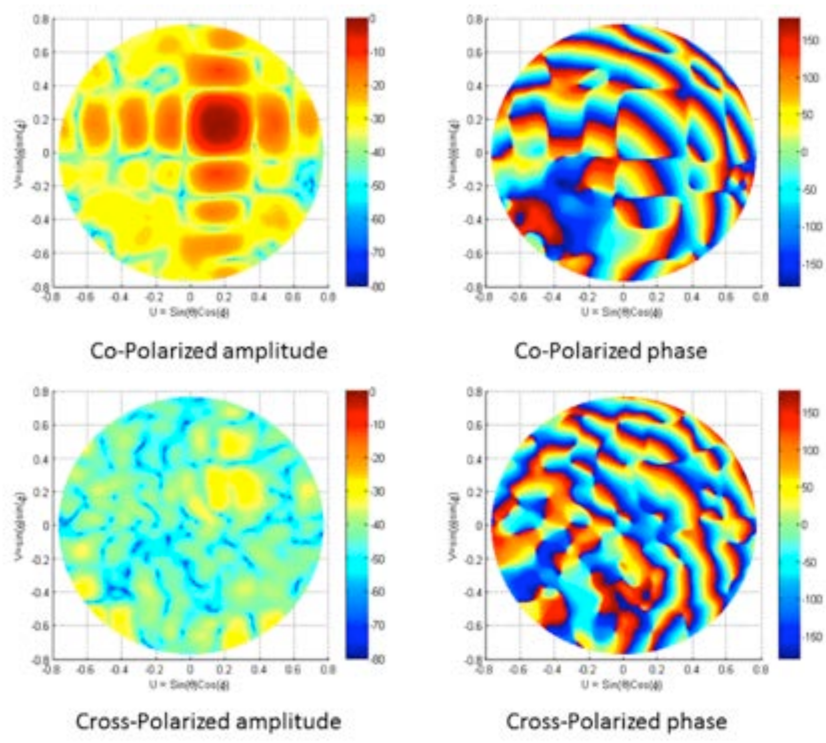
Accomplishments

The team built a planar polarimetric array (8 by 8) and an 80-deg cylinder polarimetric array (8 by 8, see figure below), both have same projected planar aperture size and use simple single layer patch antenna elements. The two arrays were measured (see figure below) using the active radiation pattern method in the OU-RIL's near-field range. Planar and spherical ranges are used for both measurements. Although probe compensation has not been done at this point, the measurements provide the first insight into the direct comparison between the two manifolds.

In order to achieve rigorous calibration performance, the team developed a software-based calibration procedure for both arrays. We also developed our own FDTD (Finite Difference Time Domain) solver implementation to compare with measurements. Reasonable agreements between simulation and measurements in co-pol and cross-pol patterns (power and phase) are achieved, and the solver is scalable based on the periodic boundary condition applied. More work is to be done to improve the code execution speed and the cylindrical coordinate support.

The conclusion at this point is that in term of cross-pol levels, the actually implemented cylindrical manifold does not show significant benefits in polarimetric isolations (when the same antenna element is used). This is also true for the electronic beam-steering cases. However, the main-beam invariance of the cylindrical manifold is a clear advantage (especially when cross-pol patterns are compared). Also, a small-scale cylinder (meaning strong curvature) introduces more artifacts along the end-fire direction, which can be reduced by using a larger cylindrical structure. Design of appropriate cylindrical mounting structures can also reduce the impact of surface waves. A larger scale test structure is necessary to further validate these observations.

The team also designed a unique ring-based magnetic dipole antenna (currently being optimized and tested) to support an EM-dipole array concept and to improve the existing EM dipole array design from Lockheed Martin. As a new exploratory effort in low-cost, phase-shifter-less arrays, extensive modeling on array mutual coupling (with generic dipoles and patches) has been done using a commercial EM tool to support a novel Electronic Steerable Parasitic Array (ESPAR) concept.



(Top) Measured 3D radiation pattern of an 8×8 dual-polarized planar CPAD array, with 30° azimuth and 20° elevation beam steering. (Bottom) An 8 × 8 dual-polarized CPAD cylindrical array (with the same aperture size as the planar array) is mounted on the RIL's NSI cylindrical near-field positioner.

5. Scalable Real-time Backend System for MPAR

Yan (Rockee) Zhang (ARRC at OU), Allen Zahrai (NSSL), Mark Weber (CIMMS at NSSL), and Xining Yu, Hernan Suarez, and Ankit Patel (ARRC at OU)

Objectives

The objective of FY15 research was to investigate a scalable, real-time, parallel backend High Performance Embedded Computer (HPEC) system architecture based on hybrid processing nodes (DSP, FPGA and GPGPU) and SRIO (serial RapidIO) data communication protocols. The main task for FY15 is feasibility investigation and identification of parallelism in the generic MPAR signal processing chains to mitigate the real-time latency risk of future large-scale MPAR systems.

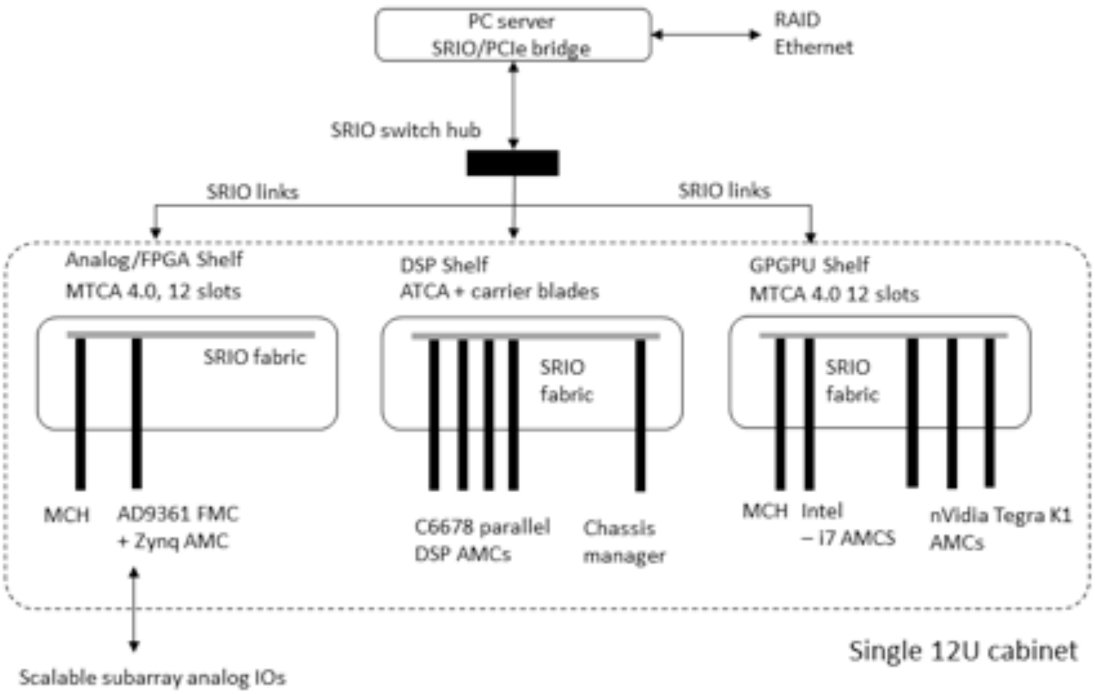
Accomplishments

The team studied the latest backend functionality plans provided by BCI, and developed the partition of functions/processing tasks to different processing platforms. It achieved real-time beamforming and pulse compression implementation for small-scale problems on Xilinx FPGAs. The team also improved the real-time timing analysis of MPAR and related requirements.

Both task parallelism and data parallelism were identified and analyzed on MPAR function diagrams, and the team developed different scheduling tools and algorithms to support parallel programming for different types of parallelism.

The team completed prototyping tasks of using SRIO Gen 1 testbed and low-level data link driver developments based on TI's devices. Reliable communication bandwidth of 3.125 Gbps among all nodes was achieved in the network topology provided in the testbed. The source codes and interfaces can be directly reused in the generation 2 testbed, which was designed as shown in the figure below.

Risk mitigation analysis for the scalable backend focused on comparing ARRC's HPEC solutions with industrial vendors' server cluster solutions in term of the "hard real-time" performance expectations of MPAR demonstrators. Initial benchmarking with parallel computing models was developed. A series of DSP-based implementation techniques are proposed (and being documented) to accelerate the data handling performance with minimum power consumption. Finally, the team has initiated the integration of a new Gen 2 testbed system with an FPGA, DSP and GPGPU integrated into same form factor (MTCA) system.



Second Generation HPEC hybrid testbed for MPAR backend risk mitigation studies.

6. Characterization of and Edge Diffractions on a High Performance S-Band Dual-Polarized Finite Phased Array Antenna

Jorge Salazar (ARRC at OU), Caleb Fulton (OU ECE), Dusan Zrnic (NSSL), and Nafati Aboserwal, Javier Ortiz, and Jose Diaz (ARRC at OU)

Objectives
Identify and characterize the effects of diffracted fields on the antenna patterns (co- and cross-pol) in a finite array antenna; characterize the effect field disruptions in the antenna array patterns due to ground plane discontinuities in a finite array; and design and characterize a S-band antenna array with high performance scanning performance at the element and array level.

Accomplishments
The adverse effects of a finite ground plane on co-polar and cross-polar radiation patterns in finite array antenna structures have not been addressed in prior research. From previous experience using finite arrays in X-band and C-band, we learn that ground plane discontinuities in finite arrays significantly affect the antenna patterns of the element, especially the cross-polar patterns near the edges of the array. In order to minimize the distortion of the diffracted fields, especially at the elements positioned near the edges, two or three dummy elements are typically added. The limitation of this approach is the fact that dummy elements cannot be added in internal sub-arrays.

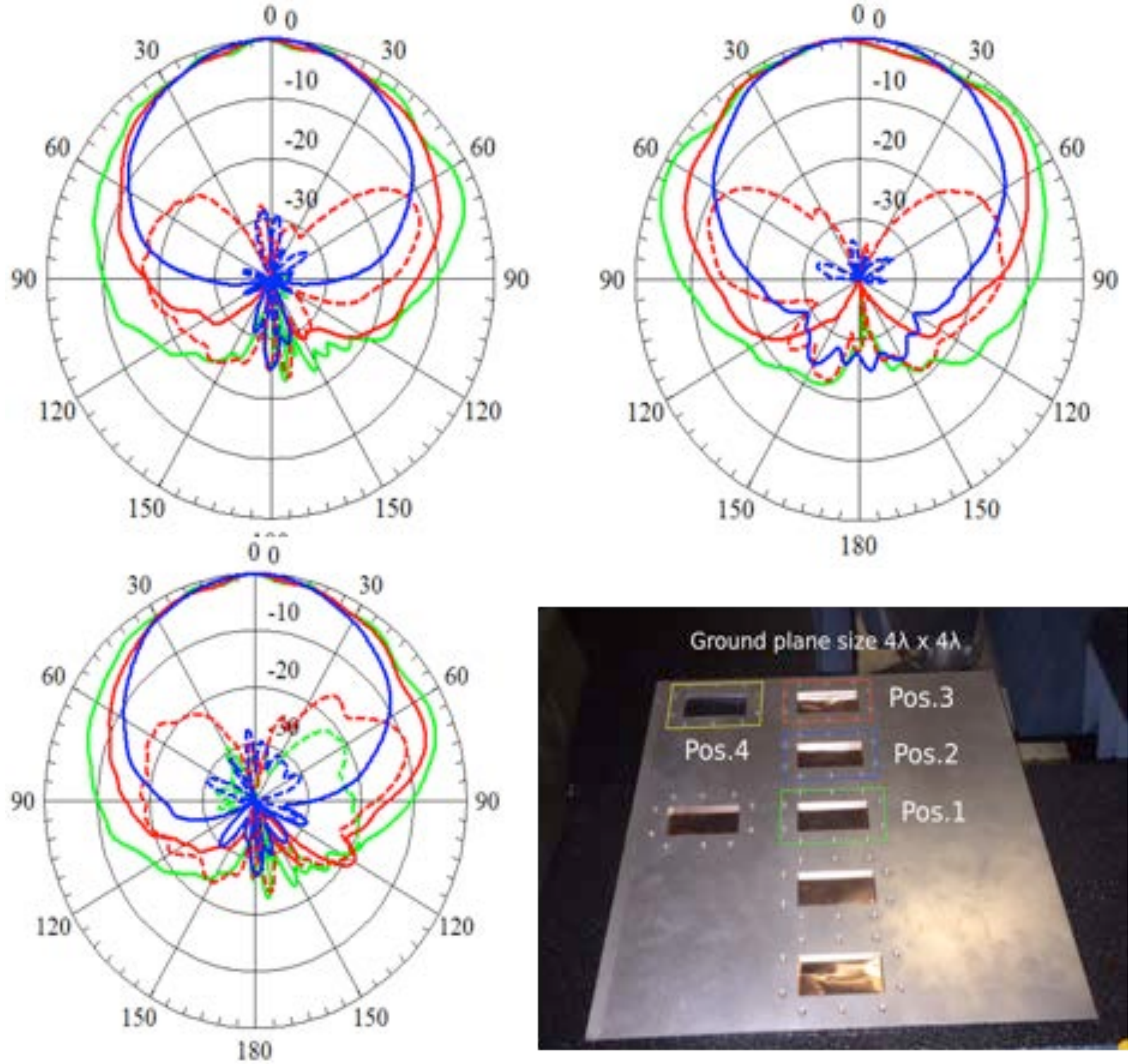
During the last four-months, our team was focused on the evaluation and characterization of the antenna patterns (co- and cross-polar) in the presence of diffracted fields produced at the edges of a finite ground plane. The approach used consisted of using two types of radiating antenna elements; a rectangular aperture and a microstrip patch antenna. The aperture was placed on a finite ground plane with different dimensions (2λ x 2λ. 3λ x 3λ and 4λ x 4λ). In addition, we also evaluated the effect of diffracted fields in the antenna patterns when the antenna aperture was located at different positions in the 4λ x 4λ ground plane (see first figure below). The Uniform Geometrical Theory of Diffraction (UTD) was used to understand and characterize the finite-ground-plane edge affects in the rectangular slot and also in the microstrip patch element in the array. Then, a full wave analysis based on HFSS was used to characterize the fields produced in D-plane and also to characterize the effect of the ground discontinuities between finite arrays. To validate our results, five antenna prototypes were designed, fabricated and tested. Results presented in the first two figures below show significant changes in the antenna element patterns, especially in the mismatch between H and V and cross-polarization.

The third figure below illustrates the diffracted fields at the edges of a rectangular aperture and a microstrip patch antenna array. The bottom part of figure shows a comparison of theoretical results, HFSS simulations and measurements from the Near-Field NSI system. Excellent agreement was found between the UTD theoretical method, simulation, and measured results in the main beam patterns. Small disagreement was found in the back lobe measured patterns due to the RF absorber needed to cover the spherical positioner in the Near Field NSI system (See left image in the fourth figure below).

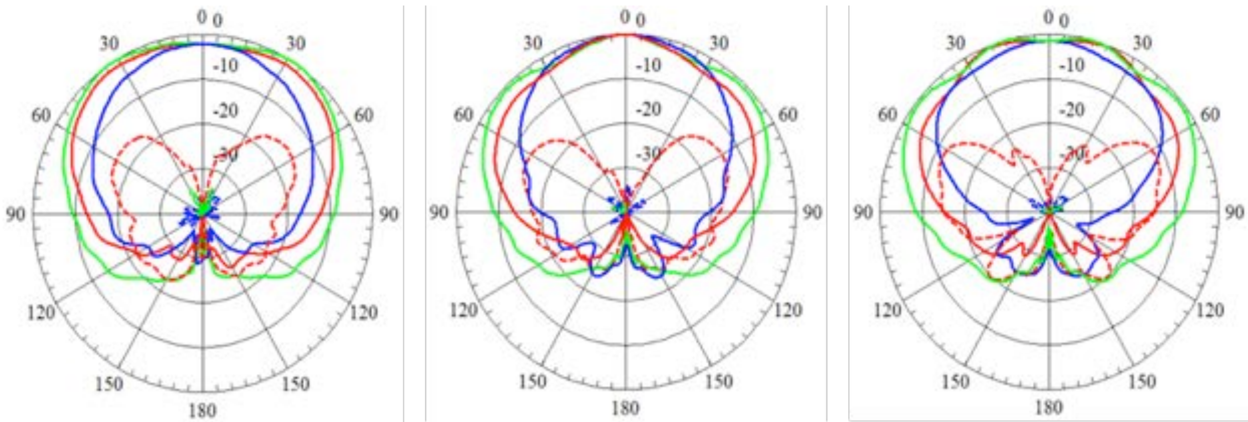
Measured antenna patterns of four antenna prototypes were fully characterized at the RIL Near-Field chamber. Results in second figure below show the antenna pattern cuts for E- (green), H- (blue) and D- (red) planes respectively. In all cases, the overall cross-polarization patterns in the E- and H-planes are below -35 dB and the worst value of -15 dB is at 45 degrees in theta in the D-plane. Changing the size of the ground plane from *2λ x 2λ, to 4λ x 4λ* diffracted fields introduce stronger more ripples in the beam patterns. At *4λ x 4λ* the amplitude of the ripples is about ~ 4dB peak to peak in the E-plane. Cross polarization in the E-, H- planes is not sensitive to the size of the array, this is due to the symmetry of the ground plane with respect of the position of the element. However a small increase was observed in the H-plane since the contribution of the diffracted fields are predominant in the E-plane. In the D-plane the cross-polarization level increases by about 5 dB. This is due to the fact that diffracted fields present rapid phase variations that make these fields interfere both constructively and destructively.

By changing the position of the rectangular aperture in a ground plane with a size of *4λ x 4λ* (as it is illustrated in the fourth figure below), unbalanced diffracted fields at the edges degrade the symmetry of the antenna patterns significantly. Co-polar mismatch for H and V polarization differs on the order of 4 dB and the cross-polarization degrades up to 15 dB in the planes where fields are stronger in comparison with the center element.

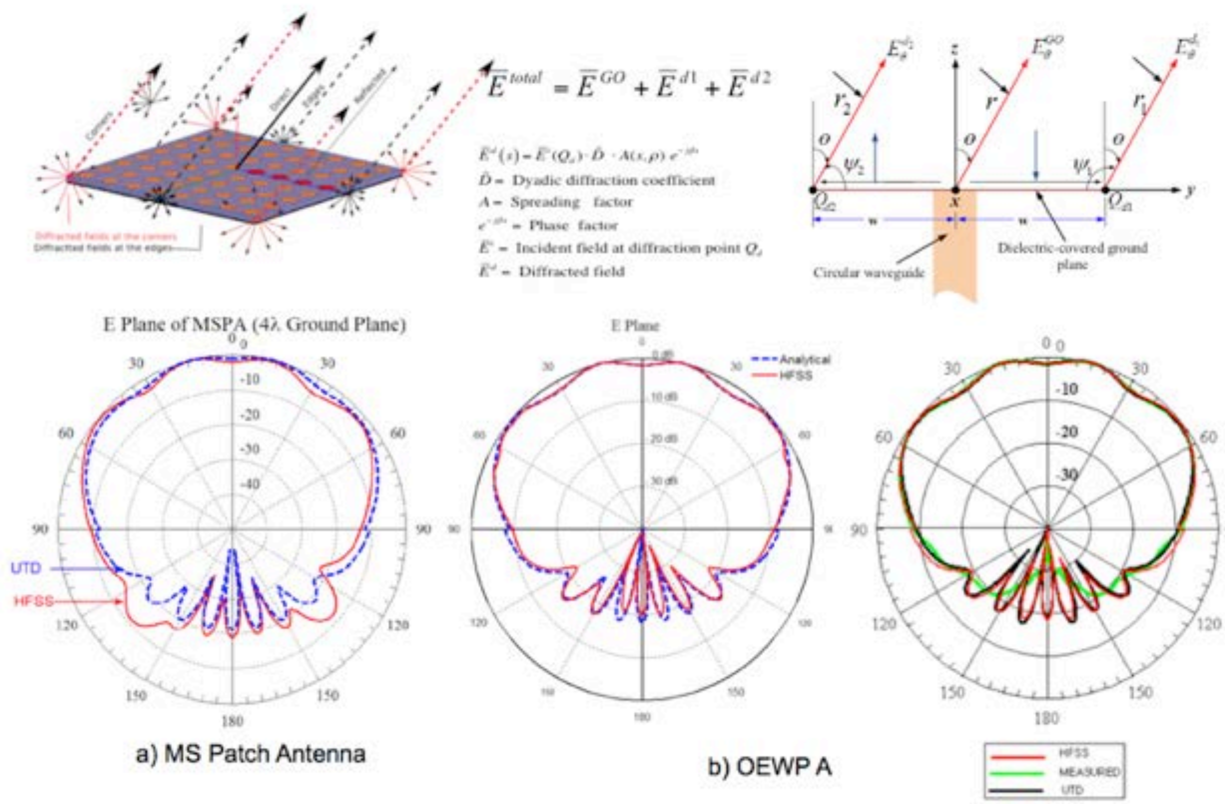
In addition to the diffracted fields study, our team was focused on the design of a high performance S-band radiating element embedded in a finite array antenna of 8x8 elements. The design is based on the microstrip cross-stacked aperture coupled patch antenna element. The goal of this effort is provide well-matched antenna patterns (below ±0.1dB) and very low cross-polarization (below -40 dB at the array level) across ± 45 degrees scanning in the D-plane. To achieve these goals, a cross-patch and parasitic radiating element were optimized for a bandwidth of 10%. A cross-patch with a width larger than its length reduces the impact of potential higher modes that commonly affect the cross-polarization performance in the E-, H-, and, most of all, the D- plane. Cross-slots in the ground plane were used to couple the energy of the two independent feed networks for H and V to the radiating patches. This helps to minimize spurious radiation and also to obtain a symmetric current distribution in the patches. The fifth figure below summarizes the development of the array antenna. On the left, we illustrate the geometry of the antenna at the element, subarray and array levels. On the top-right, the active reflection coefficient versus scan angle is shown. About 120 degrees (± 60 degrees) scanning range is usable for this array in the E-, H-, and even the D-plane. This figure also shows the performance of the antenna element at the subarray level (2x4 elements). At this size, the diffracted fields at the edges are not symmetric and the edge effects significantly impact the co-polar mismatch and cross-polarization performance. However the results of the embedded patterns in this small array show the well-matched beam patterns with cross-polarization level below -24 dB at the element level. At the bottom-right, we show the estimated array antenna patterns for the 8x8 array size using the embedded element pattern of the 2x4 subarray antenna. The patterns present a matching error below 0.2 dB in the main beam and cross-polarization below -40 dB in the E-, H-, and D- planes at the broadside position.



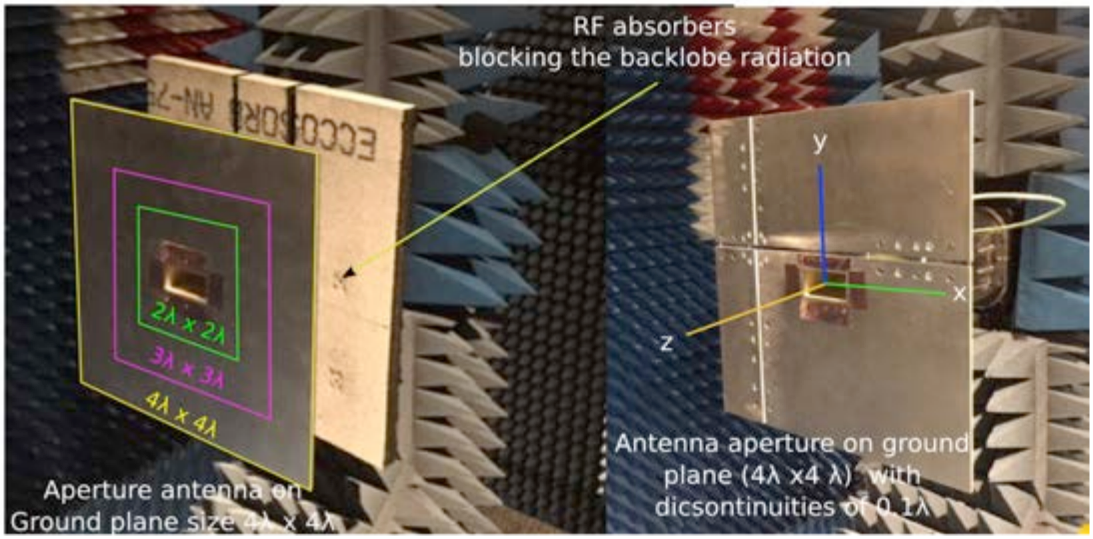
Measured antenna element patterns (co- and cross-polar) of the rectangular aperture antenna in E-plane (green), H-plane (blue) and D-plane (red) for different positions on the 4λ x 4λ finite ground plane. Patterns for the center position (Position 2) are represented at the top left. The other patterns are taken from Position 4.



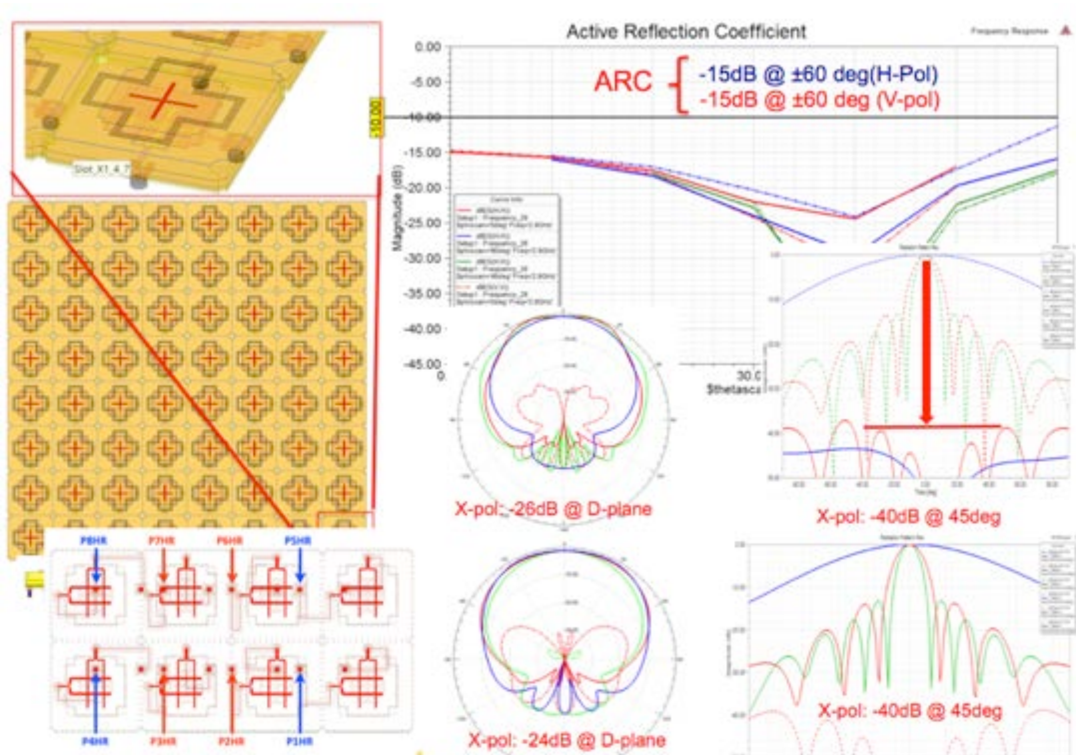
Measured antenna element patterns (co- and cross-polar)) of the rectangular aperture antenna in E-plane (green), H-plane (blue) and D-plane (red) as a function of the size of the finite ground plane. The left image shows results for 2λ x 2λ, the middle is 3λ x 3λ, and to the right is 4λ x 4λ.



Representation of the diffracted fields at the edges of a finite array antenna in an aperture antenna and a microstrip patch array. (a) and (b) show antenna patterns (calculated, simulated and measured) of a rectangular aperture antenna on finite ground.



Two pictures of the setup of the rectangular aperture in the near-field chamber. The left image shows a representation of the ground plane size, and to the right is a setup to characterize effect of diffracted fields due to ground discontinuities in finite array antennas.



Representation of the S-band array antenna design and preliminary simulated results of the embedded element patterns (H and V), active reflection coefficient, and array antenna patterns.

7. MPAR Resource Management and Adaptive Weather Sensing

Tian-You Yu (ARRC at OU), Sebastian Torres (CIMMS at NSSL), and David Schvartzman (ARRC at OU)

Objectives

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

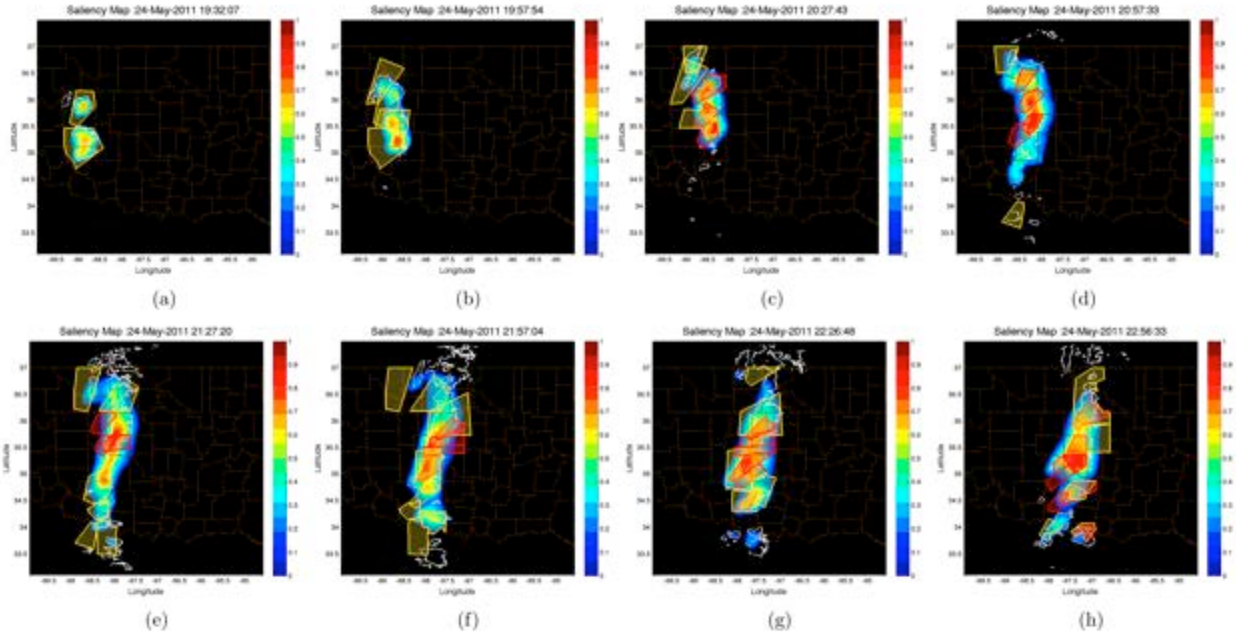
One of the major challenges for adaptive sensing is the complexity of the trade spaces in terms of temporal resolution, spatial sampling, and data quality. To address this issue, a novel analysis tool that provides the amount of spatial and/or temporal information contained in weather radar images was developed, which is termed Weather Radar Spatio-Temporal Saliency (WR-STS). Saliency has been used in many fields to model the attention system of human beings in order to better allocate the limited resources on relevant information. WR-STS was designed based on information theory that is tailored for application to constant-elevation reflectivity images. Specifically, the spatial features in WR-STS include the intensity, contrast and orientation at a number of different spatial scales. In addition, temporal features are considered to process the time series of resulting spatial-saliency maps using mutual information.

Subsequently, the impacts of model parameters and various radar acquisition parameters on the performance of WR-STS were investigated. By studying the model parameters, recommendations on the number of orientation filters, scales, and activation functions were given. For acquisition parameters, impacts caused by the number of samples used to compute reflectivity images were shown to be negligible, as are the impacts caused by range down sampling. On the other hand, azimuthal down sampling distorts many features in radar-reflectivity images and can significantly affect WR-STS. A fine temporal resolution allows WR-STS to more accurately highlight fast-salient regions. Coarser temporal resolution could mislead WR-STS.

The behavior of the WR-STS was also analyzed for different types of weather phenomena, and its performance in non-severe and severe weather events was studied by comparing regions of elevated WR-STS with regions of importance as defined by expert NWS forecasters. In summary, non-convective storms typically exhibit less salient features. For example, widespread, uniform and slow evolving weather echoes lack spatial and temporal features and draw less attention from WR-STS. On the other hand, convective storms display more features and attract more attention. Three convective severe-weather environments were studied including a severe tornado outbreak in which multiple tornado-producing thunderstorms were present. Warning polygons issued by NWS forecasters during the event were compared with the regions

highlighted by WR-STS. It was shown that WR-STS assigned medium-to-high scores to regions in which severe-thunderstorm warnings were active and high scores to regions were tornado warnings were active. Time-composite WR-STS maps were determined to summarize the most salient regions during the event, and the warning polygons were plotted on top of them. These also showed a good general agreement. An example of selected WR-STS maps (spaced by about 30 minutes) for a tornado outbreak in Oklahoma on 24 May 2011 is included. The yellow superimposed polygons are severe-thunderstorm warnings that were active at the time of the scan, and the red polygons are active tornado warnings. At 193207 UTC, two severe thunderstorm warnings were active. Looking at the WR-STS map (the figure below, panel a) we notice that both severe thunderstorm polygons achieved medium-to-high scores, with the storm cell outside of the polygons roughly disregarded. At 202743 UTC, three tornado warnings were issued and were active at the time of this scan. The storms for which these warnings were issued were exhibiting strong rotation features (e.g., hook-like signatures). WR-STS assigns very high scores to the storm regions within the tornado-warning polygons, with a slightly higher score assigned to the southernmost storm. At 205733 UTC, the funnel cloud that evolved into an EF-5 rated tornado was about to touch down in Canadian County to the West of El Reno. Warnings were issued in west-central Oklahoma. WR-STS scores as shown in panel d were considerably higher in that warning polygon compared to the other three active warnings. At 212720 UTC the WR-STS scores, again assigned to weather echoes inside of the warning polygons, are noticeably higher than the scores for severe thunderstorm warning polygons (which are also relatively high), even though most of the storm cells have comparable reflectivity values. At 225633 UTC (panel h), the EF-5 tornado had dissipated and the Grady (EF-4) tornado was starting to decay. WR-STS indicates a highly informative region over McClain and Cleveland counties as the tornado crosses over.

The potential of WR-STS to drive the implementation of an adaptive-weather-sensing framework on phased arrays was demonstrated. An application of WR-STS to AWS was proposed and demonstrated. The algorithm is denominated FOCUS (Focused Observations by Configuration of Update-times using Saliency) and can be used to adaptively define update times for sectors of interest through the use of WR-STS. The update times are defined as being proportional to the average WR-STS contained within each sector of interest. By design, only the remaining available radar occupancy is used to determine these update times, and therefore the radar's occupancy is always 100%. The update times obtained in this fashion were shown to be suited to the weather echoes encompassed by the respective sectors of interest. The RIF (Revisit Improvement Factor) was calculated as a means of comparing the improvement of FOCUS over conventional scanning.



An example of selected WR-STS maps (spaced apart about 30 minutes) for a tornado outbreaks in Oklahoma on 24 May 2011. A detailed description is provided in the text.

8. Multi-Channel Interference Mitigation Techniques & Real-Time Studies

Mark Yeary (ARRC at OU), Chris Curtis (CIMMS at NSSL), and John Lake (ARRC at OU)

Objectives
In brief, the goals were to investigate linearly constrained minimum power (LCMP) beamforming and its ability to mitigate RF interference (RFI), and in the process to explore other ways to find the inverse of the covariance matrix on the NWRT in Norman, OK. Developing an adaptive algorithm on a sample-per-sample basis, rather than a block approach, was the novel feature of this work. It will allow for real-time implementation in the future. Additional goals were to collaborate with partners to collect multi-channel IQ data with interference sources from phased array radar and to explore using a directional constraint to enhance beamformer performance.

Accomplishments
Multi-channel receiver data collected from the NWRT phased array radar were processed using LCMP beamforming with a quadratic constraint (QC). The constraints were chosen to reject data common to the sidelobe canceller channels and the sum channel, introducing nulls in the direction of ground clutter into the received beampattern and filtering out the clutter. This method has been effective in other fields, but had not yet been applied to meteorological surveillance radar.

Two methods of LCMP QC beamforming were implemented: the classic LCMP QC beamforming as described in Van Trees (2002) and a simplification of LCMP QC

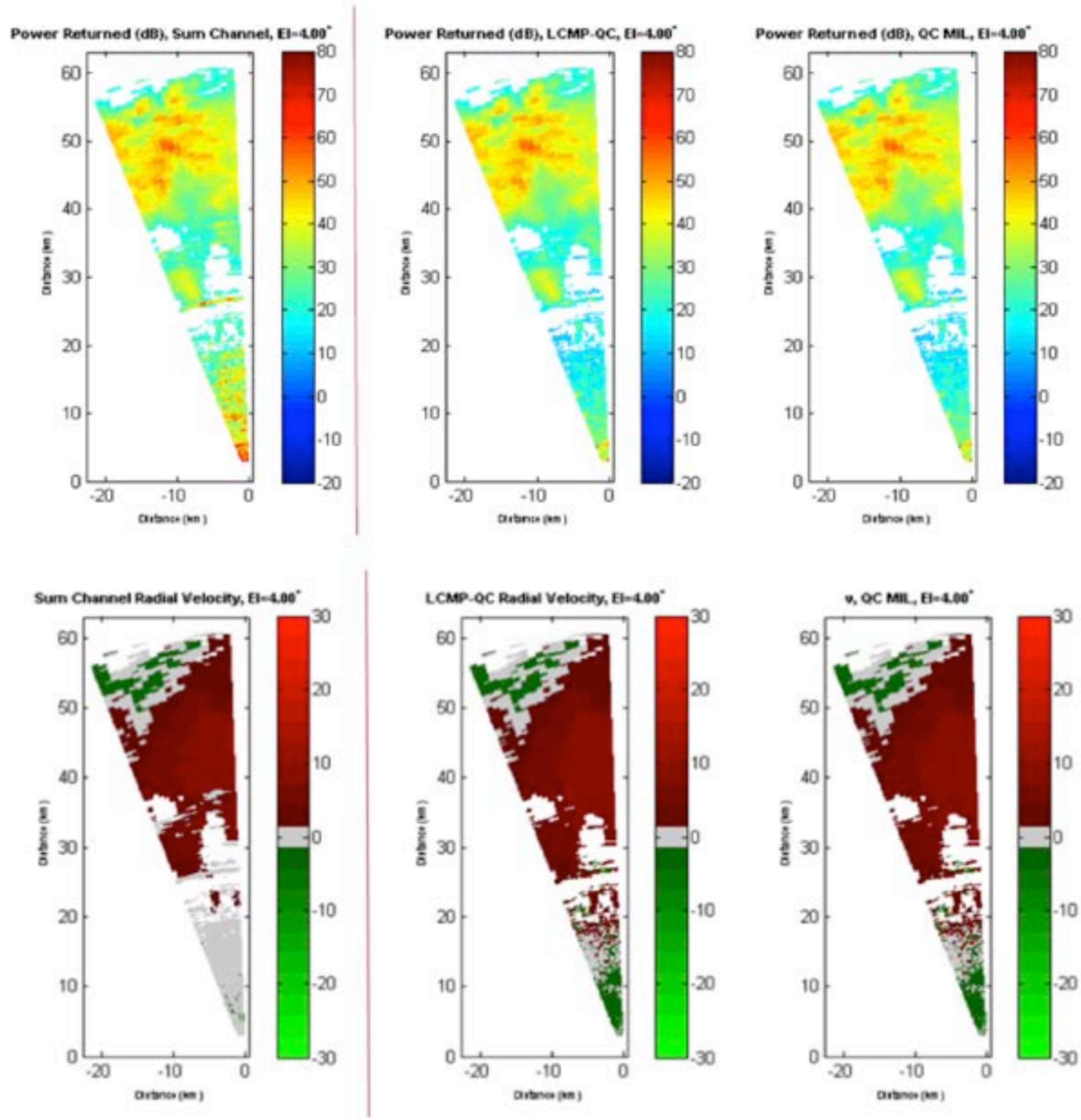
beamforming, called variable loading recursive least squares (RLS) LCMP QC beamforming, as described in Tian et al. (2001). Both methods produced comparable results. Before beamforming, the ground clutter is very apparent in the spectrum and the velocity is very biased towards 0 m/s instead of being roughly centered in the weather spectrum. After beamforming, the ground clutter signal has been attenuated or removed from the velocity spectrum with little to no effect on the weather spectrum, and the velocity estimate is no longer so biased towards 0 m/s.

After testing on those spectra, the LCMP QC beamforming was applied to data from a whole dwell. The left column of the first figure below shows the reflectivity (top) and radial velocity (bottom) from the data. Noticeable ground clutter contamination is present, especially between 25 and 40 km from the radar. After beamforming, the ground clutter is filtered out while the weather signal is recovered, as shown in the right two columns.

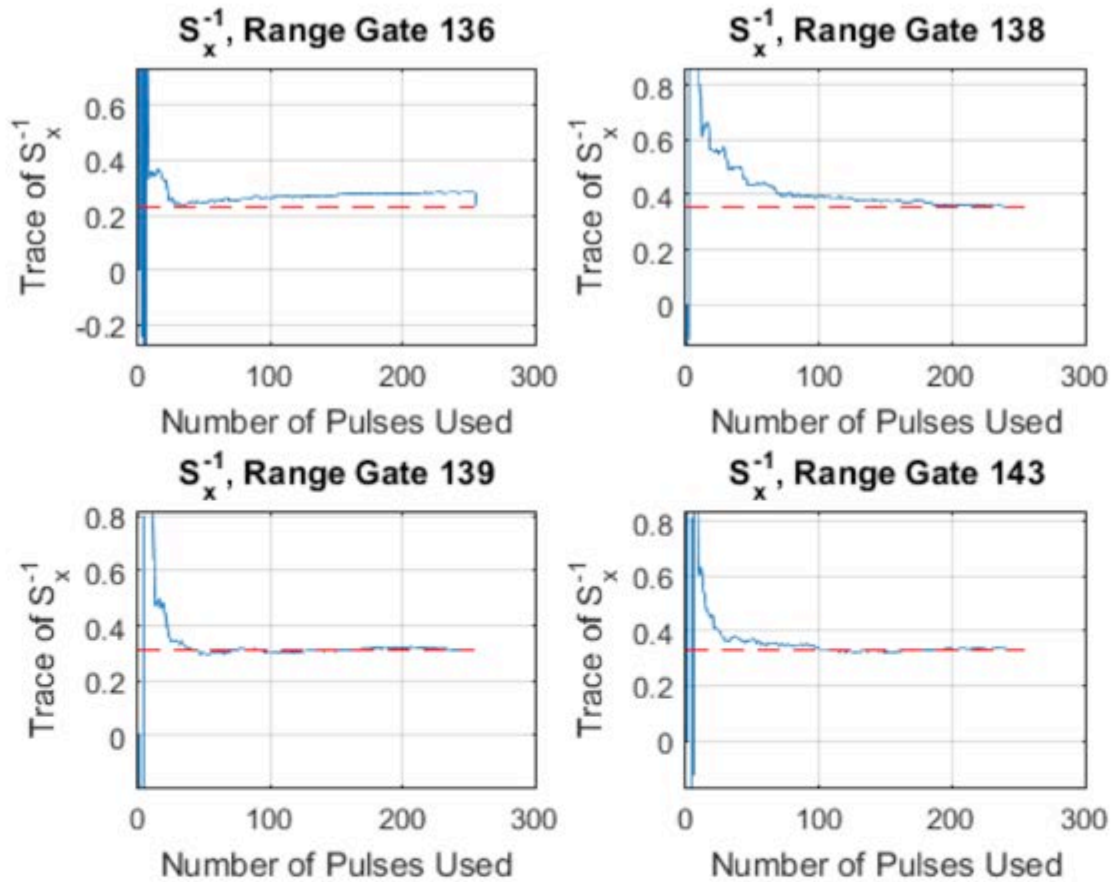
Both methods of LCMP QC beamforming require an estimate of S_x^{-1}, the inverse of the received signal covariance matrix. Matrix inversion is a computationally costly operation, and time requirements could impede operational implementation of LCMP beamforming. Using the matrix inversion lemma to keep a running estimate of S_x^{-1} was explored and developed as a potential option to mathematically streamline the beamforming operation. To keep an iterative estimate of S_x^{-1}, the Sherman-Morrison formula:

$$\mathbf{S}_x^{-1}(i) = \mathbf{S}_x^{-1}(i) - \frac{\mathbf{S}_x^{-1}(i-1)\mathbf{X}_i\mathbf{X}_i^H\mathbf{S}_x^{-1}(i-1)}{1+\mathbf{X}_i^H\mathbf{S}_x^{-1}(i-1)\mathbf{X}_i}$$

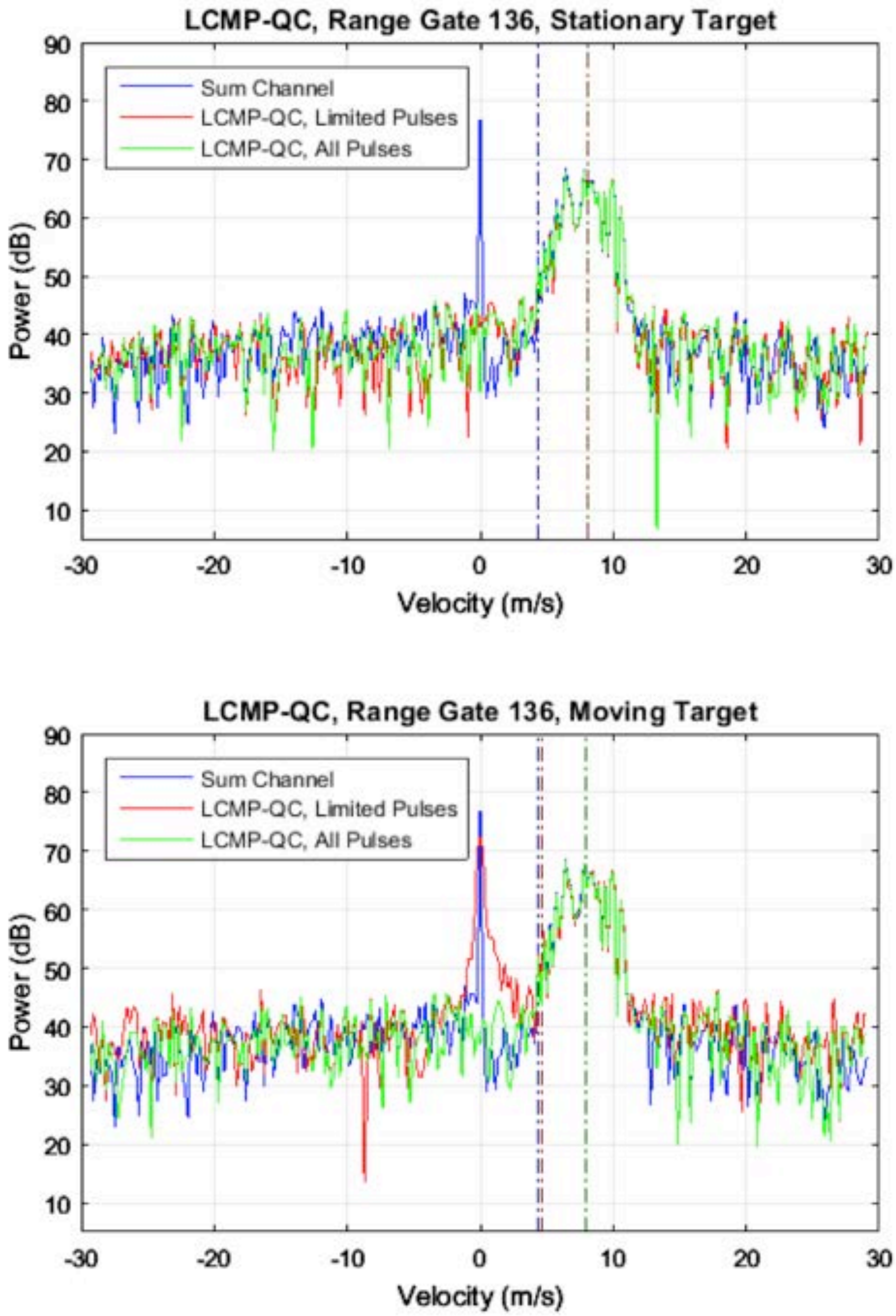
was employed, where the $S_x^{-1}(i)$ is the new estimate, $S_x^{-1}(i-1)$ is the previous estimate, X_i is the signal received during the i^{th} pulse, and H is the Hermitian (conjugate transpose) operator. As the second figure below shows, this iterative estimate of S_x^{-1} is very close to the final estimate after the first 100 pulses. To explore this further, tests were done to examine the performance of LCMP beamforming using only the first 100 pulses to form the estimate of S_x^{-1} but applying the weights to all pulses; the results are in the third figure below. For relatively stationary targets, like weather data observed here, using fewer pulses to estimate the covariance matrix yielded good results, as shown in panel a of the third figure below. However, if the signal in the sidelobes changed significantly after the covariance estimation had been performed, the beamforming would yield poor results. If all pulses were used to estimate the inverse of the covariance matrix, results were good, as shown in in panel b of the third figure below. For relatively unchanging environments, it appears that using fewer pulses to estimate the covariance matrix can be used to speed up the computations without significantly affecting the performance of LCMP QC beamforming.



Reflectivity (top) and radial velocity (bottom), both before (left column) and after classic LCMP QC beamforming (center column) and RLS LCMP QC beamforming (right column). Ground clutter is particularly apparent embedded near 35 km from the radar in the velocity PPI, but after LCMP QC beamforming the velocity of the weather signal is recovered.



The trace of the iterative estimates of S_x^{-1} compared to the trace of the estimate using all pulses. Much of the convergence takes place in approximately the first 100 pulses.



LCMP QC beamforming can fail if not enough pulses are used to characterize the target. For a stationary target (top), using the only the first 100 pulses (red) to get the weights needed for the beamforming yields similar results to using all pulses (green), with the ground clutter spike filtered out and the velocity estimate restored to the center of the weather spectrum. However, if the received beampattern changes (bottom) after the first 100 pulses are collected, then the estimate using only the first 100 pulses (red) can have trouble filtering out the ground clutter; by contrast, using all pulses to estimate the covariance matrix (green) yields the results we desire, filtering out the ground clutter and removing the zero bias of the velocity estimate.

9. Simulation of Weather Observations With Polarimetric Phased Array Radars

Robert Palmer (ARRC at OU), Igor Ivic (CIMMS at NSSL), and A.D. Byrd (ARRC at OU)

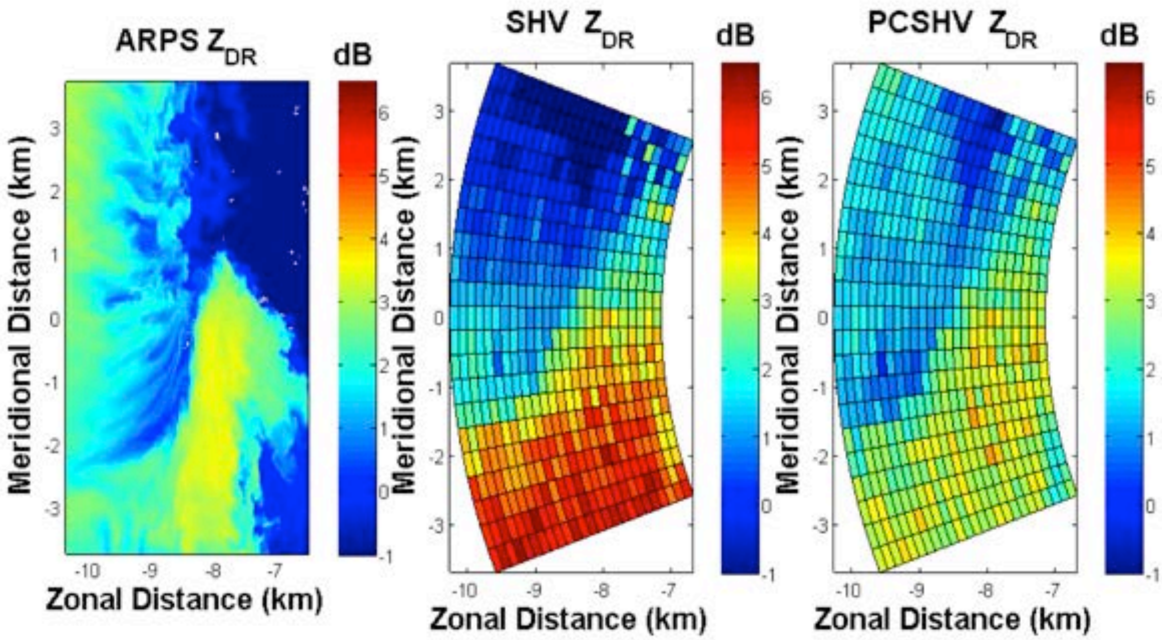
Objectives

The objective for the past year of research was to develop a radar simulator capable of accurately emulating polarimetric phased array radar (PPAR) observations of weather systems, with particular emphasis on the cross-polarization radiation effects that present the largest challenge in PPAR development. Additionally, it was desired that the simulator incorporate a highly flexible system model to allow for the investigation of factors like array geometry, element characteristics, waveform design, and transmit scheme on PPAR data quality.

Accomplishments

The single polarization weather radar simulation framework originally developed with the ARRC was expanded upon in order to meet the above objectives. The simulator's ability to extract radar observables from the Advanced Regional Prediction System (ARPS) atmospheric model was further developed to include the polarimetric variables Z_{DR}, Φ_{DP}, and ρ_{HV}. In order to improve the realism of the simulation, as well as allow for the implementation of ρ_{HV} observation, the deterministic method used in the original simulator for determining the amplitudes and phases of scattering coefficients for simulated scatterers was replaced with a weather like signal based stochastic method.

Once the capability for parameterization of radar observables had been suitably expanded to allow for polarimetric observations, the radar system model was modified to allow for realistic modeling of cross-polar biases and mitigation methods. The original simulator was capable of modeling arbitrary array geometries, but could only emulate imaging radars. Transmit beamforming capabilities were added to the simulator. In addition, the idealized single-polarization element pattern originally used was replaced with functionality for loading a full set of arbitrary dual-polarization element patterns. Currently, the simulator uses HFSS simulated patterns for the elements in the Lincoln Laboratory Generation 2 panels that are currently in service on the Ten Panel Demonstrator and slated for use on the Advanced Technology Demonstrator. In addition to improving the array model, the radar system model was modified to allow for arbitrary waveform designs (with the ability to account for quantization effects) as well as 3 additional dual-polarization transmission schemes to complement the simultaneous horizontal and vertical (SHV) mode used in the original simulator. These transmit modes are alternating horizontal and vertical (AHV), phase coded simultaneous horizontal and vertical (PCSHV), and quasi-simultaneous horizontal and vertical (QSHV). These last two modes have been proposed specifically for the purpose of mitigating problems with cross-pol bias while retaining many of the benefits of the SHV transmit mode. Some illustrative results from the simulator are shown in the figure below. The figure shows a single elevation plot of Z_{DR} values extracted from the ARPS model, and two PPIs of Z_{DR} values obtained through simulated scans of the same region. The polarimetric biases introduced through SHV scanning are evident, as is the PCSHV mode's effectiveness in reducing them.



The ARPS data shown represents a single elevation slice intersecting the volume scanned by the simulated PPAR. The scans were taken at broadside in azimuth with the array mechanically pointed 30° away from the scan direction in elevation. This was done to increase polarimetric steering biases to visually significant levels. The biases introduced in the SHV mode are evident through comparison with the ARPS data. Likewise, the PCSHV mode's effectiveness in mitigating these biases is extremely clear.

10. Cylindrical Array Design through Phase Mode Analysis and Careful Pattern Synthesis

Caleb Fulton (OU ECE), and Jorge Salazar and Lal Mohan Bhowmik (ARRC at OU)

Objectives

Improve modeling techniques that inform the design of cylindrical arrays for dual-polarization weather radar applications as well as the trade space between these and their planar equivalents; extend previously reported cylindrical array techniques to include active reflection coefficient estimates for active arrays (unlike CPPAR demonstrator) and, critically, to enable 2d pattern prediction; analyze different array element types within a cylindrical array framework; and explore fundamental limitations to grating lobes, front-to-back ratios, pattern efficiency, synthesis algorithm efficacy, and surface wave suppression in cylindrical (and also planar) arrays.

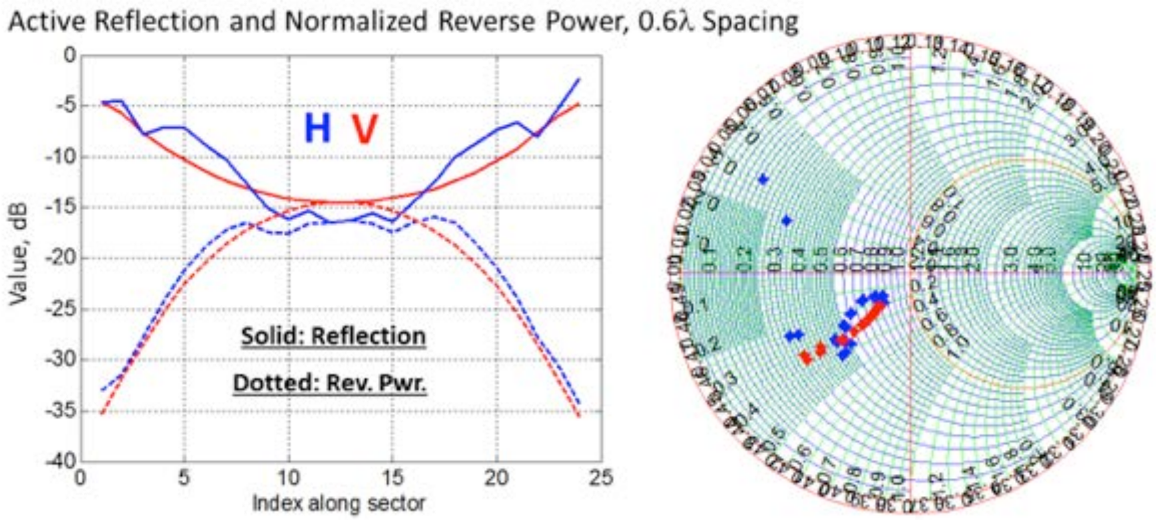
Accomplishments

In continuing to develop and refine several previously reported computational electromagnetics-based modeling techniques for cylindrical arrays, one of the focuses of the last year has been in using this framework to explore practical considerations that are related to the underlying embedded element pattern and mutual coupling between

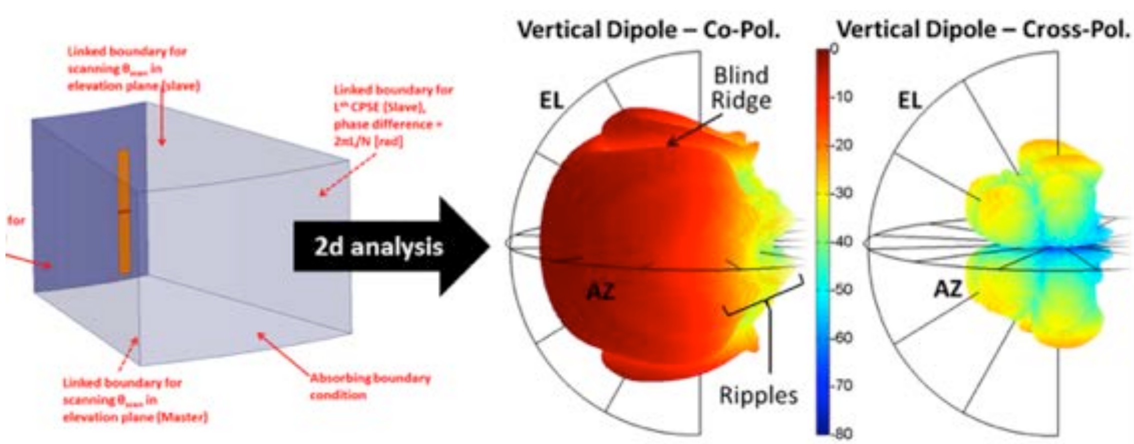
elements. In particular, past confirmation of the presence of strong surface wave effects associated with the use of thick patch-based elements motivated a study into the implications that this has for front-end electronics and system-level efficiency. The first figure below shows an example of such an analysis that used pattern-optimized excitation weights and derived S-parameters to determine the active impedance and reverse power flow situation at each column of an array built of CPPAR-like elements that were re-tuned for active, element-level excitation. The wide element spacing and thick elements present impedance problems near the array edge, though it is unlikely that these would be destructive. It was also shown, through related analysis in a paper at the Allerton Antenna Applications Symposium, that the efficiency and beamwidth of the CPPAR demonstrator would actually be improved by reducing the element spacing from 0.6 wavelengths to 0.48 wavelengths (with an overall diameter reduction from 2m to 1.6m), leading to a 1.6 dB increase in EIRP. Subsequent but simplified analysis of ideal embedded element patterns indicates that this could be improved even further, eventually achieving a 1 degree beam with as little as a 9.4 m diameter cylinder at S-band, much less than earlier 12m estimates.

Further investigations are underway surrounding the CPPAR, including continued studies into methods to reduce surface waves without reducing element sizes. So far, no simulations have shown a practical means of doing so, but not all avenues have yet been explored. A previous limitation to the phase mode analysis technique was that it focused on a single elevation pattern cut at a time. In the last year, it has been extended theoretically and in an automated fashion to extract 2D patterns. This has initially been applied to an array of vertical dipoles, as shown in the second figure below. This process, however, has revealed that some elements, particularly those that are directly driven at their terminals, have convergence issues on the specific phase modes corresponding to surface wave harmonics; this leads to limits in estimating back-sector isolation. Thus, this is now a focus of further study.

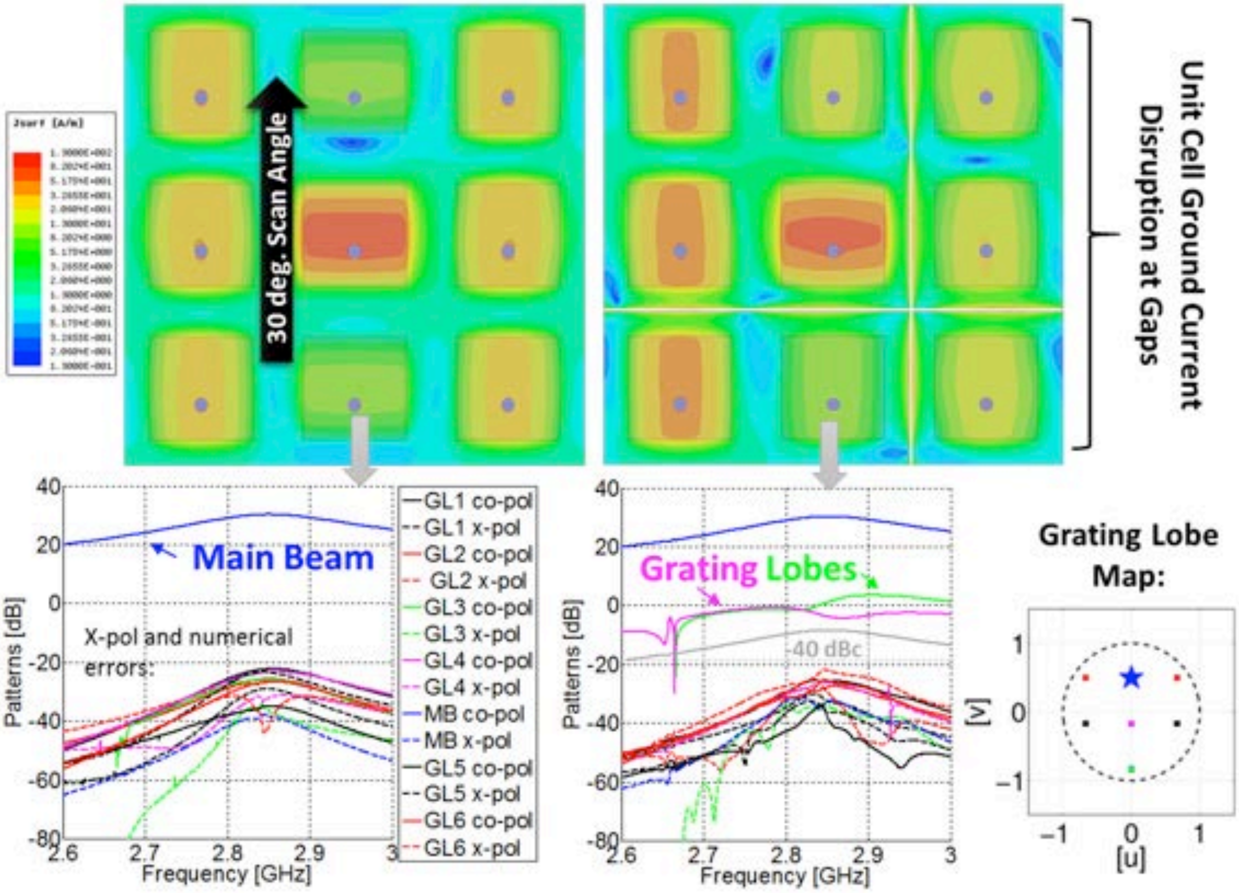
A related investigation has begun into the effects of gaps between subarrays (on either a planar or cylindrical array) on the resulting grating lobes caused by the disruption of the overall periodic structure. An example of recent results is shown in the third figure below. Current efforts are limited to simple elements and small subarrays because of the memory limits associated with the excitation of tens or even hundreds of Floquet modes within the finite element unit cell (one subarray). Alternative techniques are therefore being investigated for extracting equivalent information from other computational electromagnetic methods in order to extend this to more representative and practical subarray sizes (e.g. 8x8 elements).



Example of active reflection coefficient and reverse power calculations as part of overall efficiency and feasibility study, using an active array version of the CPPAR element. Analysis reveals that while mutual coupling effects lead to poor impedance match near edges, total reverse power there is low because of array tapering.



Extension of finite element method phase mode analysis to include 2D pattern prediction, shown here for an array of vertical dipoles on a thick dielectric substrate. A blind ridge in elevation can be observed, as well as clear cross-polar lobe patterns.



New investigation into grating lobes as a result of gaps in the ground plane between finite subarrays in a large array. Disruption to the current distribution caused by the gaps is traced, through a Floquet mode framework, to the resulting grating lobes that it causes. Here, grating lobes appear at a level that is insufficiently low for an MPAR-like application, with only a 1mm gap for this particular example element.

11. Risk Mitigation for Large-Scale, Low-Cost, Highly Digital Phased Array Systems

Caleb Fulton (OU ECE), and Matt McCord, John Meier, Redmond Kelley, and Blake James (ARRC at OU)

Objectives

Work in tandem with the OU Horus All-Digital Dual-Pol Phased Array development effort in exploring fundamental limitations to the low-cost digital approach; and identify and explore hardware-based risk factors to the adoption of this kind of technology for MPAR applications, focusing on dynamic range, bandwidth, cost, beamforming implications, synchronization, etc.

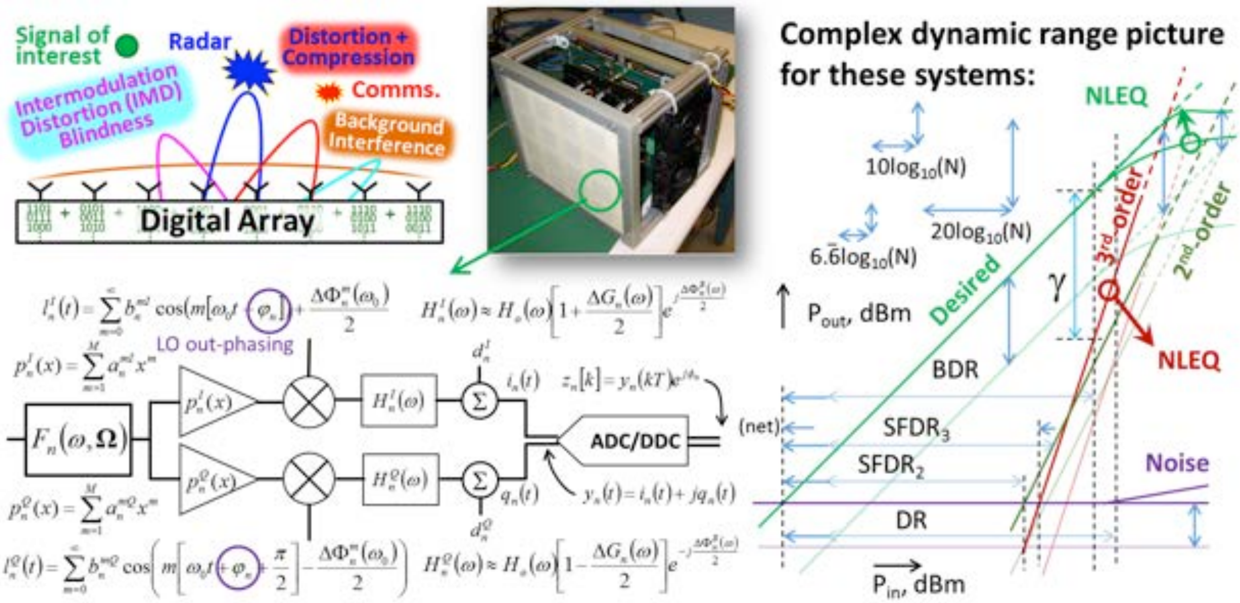
Accomplishments

Much of the development-oriented work that went into this year's risk mitigation activities shifted to the engineering team as part of the All-Digital Polarimetric Phased Array (Horus) effort at OU. This included explorations into mechanical, front-end electrical, and digital beamforming design concepts, culminating in the current overall Horus concept that is documented elsewhere in this report.

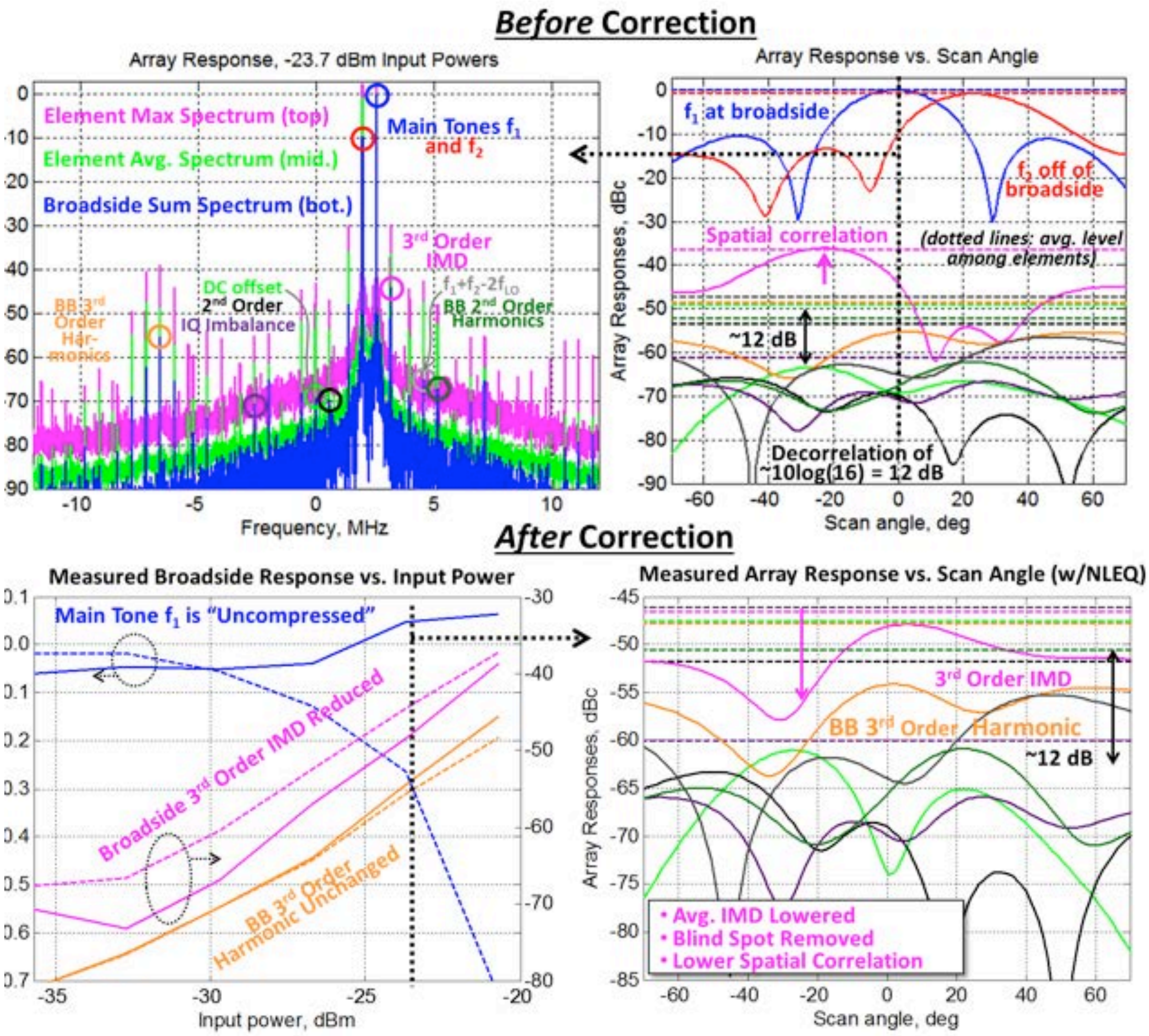
The fundamental research focus has since been in modeling and understanding potential analog limitations imposed by the use of low-cost digital transceivers at each element in a large phased array. One aspect of this study has been to explore the limits to phase noise scaling as a function of the number of local oscillators (LOs) used in the system. This was initially done using the Analog Devices ADF4351, and it was shown that, as previously measured on the Army DAR, the phase noise reduces by roughly $10\log_{10}(N)$ dB with N oscillators at frequencies outside of the loop filter bandwidth. The testbed has recently been modified to use the ADF5355, which is the primary candidate for use on the Horus project. Testing has also begun in order to verify that the phase "resync" feature on these devices will work for this phased array application, and this will require new software development to synchronize multiple chips. This effort has been slow, but this is primarily because throughout the last year (and continuing on to the next), this has been an undergraduate research project, and much of the time has been spent on training students how to use the microwave/RF equipment, and teaching them the fundamental behavior of phase-locked loops and phase noise.

A much more critical effort has focused on ensuring that the dynamic range and noise parameters of the digital T/R modules are set such that the eventual large-array system satisfies MPAR-like requirements without excessive cost or power consumption at the element level. This required a detailed study into the fundamental performance limitations of direct-conversion digital transceiver arrays. The fundamental threat, here, is that because each element in a digital array is exposed to all angles of view, intermodulation distortion (IMD) may generate spurious products that limit the effective dynamic range of the overall system in certain directions. The general view of this situation is shown in the top left of the first figure below, where there are two interferers (a radar and a communication system) leading to reduced dynamic range at a third angle through a complex mechanism that requires analysis of the relative phases of induced IMD products in the array. For many radar applications, the interference is dominated by clutter, and this limits dynamic range due to clutter at each scan angle. The research into how to mitigate these effects first modeled an array that is very similar to Horus (the Army DAR) as shown in the figure, and then focused on the correlation and mitigation of spurious products at the array level through the use of I/Q balancing, LO out-phasing and subsequent digital correction, and nonlinear equalization (NLEQ) at each of *N* elements in a large array. The goal – dynamic range scaling with the number of elements without being limited with IMD – leads to the dynamic range picture shown on the right of the figure. Initial measurements made with the Army DAR exhibited behavior that agreed with the model in terms of spurious product correlation, as shown on the top of the second figure below, after careful study of each product. The primary concern, shown in magenta, is correlation of 3rd order IMD, as this limits dynamic range.

A novel, lightweight NLEQ/calibration routine was then executed at each element, resulting in the reduction of this 3rd order product by effectively more than 12 dB (overall $SFDR_3$ improvement of 4 dB), and removing its spatial correlation. Current efforts are underway to extend these results to a larger array through the Horus project in order to quantify the extent to which the dynamic range scaling picture in the first figure below can improve with these techniques. This work resulted in a thesis.



(Top left) Interference/clutter-limited scenario for digital arrays, (bottom left) mathematical model for a DAR/Horus receiver, and (right) dynamic range scaling goal, showing several metrics when scaling a single element (faint lines) up to a large array (solid lines); without NLEQ, performance is limited by 3rd order IMD/compression.



(Top left) Measured spurious response of DAR to two-tone test, (top right) resulting spur response vs. angle, showing spatial correlation at a "blind" angle, (bottom left) measured broadside improvement in IMD using NLEQ, and (bottom right) measured improvement in IMD vs. angle, with associated boost in dynamic range.

12. CPPAR Demonstrator Calibration, Pattern Enhancements, and Planning for Larger-Scale Array Calibration

Caleb Fulton (OU ECE), and Jorge Salazar, Matt McCord, John Meier, Redmond Kelley, Lal Mohan Bhowmik, and Andrew Byrd (ARRC at OU)

Objectives

Our ultimate goal is to perform initial calibration of the Demonstrator (including pattern measurements), based on far-field testing at the OU Westheimer Airport that makes use of a number of tools that are currently under development. Also, ultimately, weather measurements remain a goal. Other goals include: continue to fix electrical and mechanical issues on the Demonstrator in order to ultimately facilitate pattern

measurements; mature and implement mutual coupling-based in-situ calibration techniques that are necessary to mitigate the remaining temperature instabilities within the electronics and cabling in the Demonstrator, finally enabling the previously-reported full-scale calibration and beamforming tests to occur; and investigate near- and far-field calibration techniques in order to continue to identify practical and fundamental measurement limitations for different calibration procedures for both the Demonstrator and larger arrays.

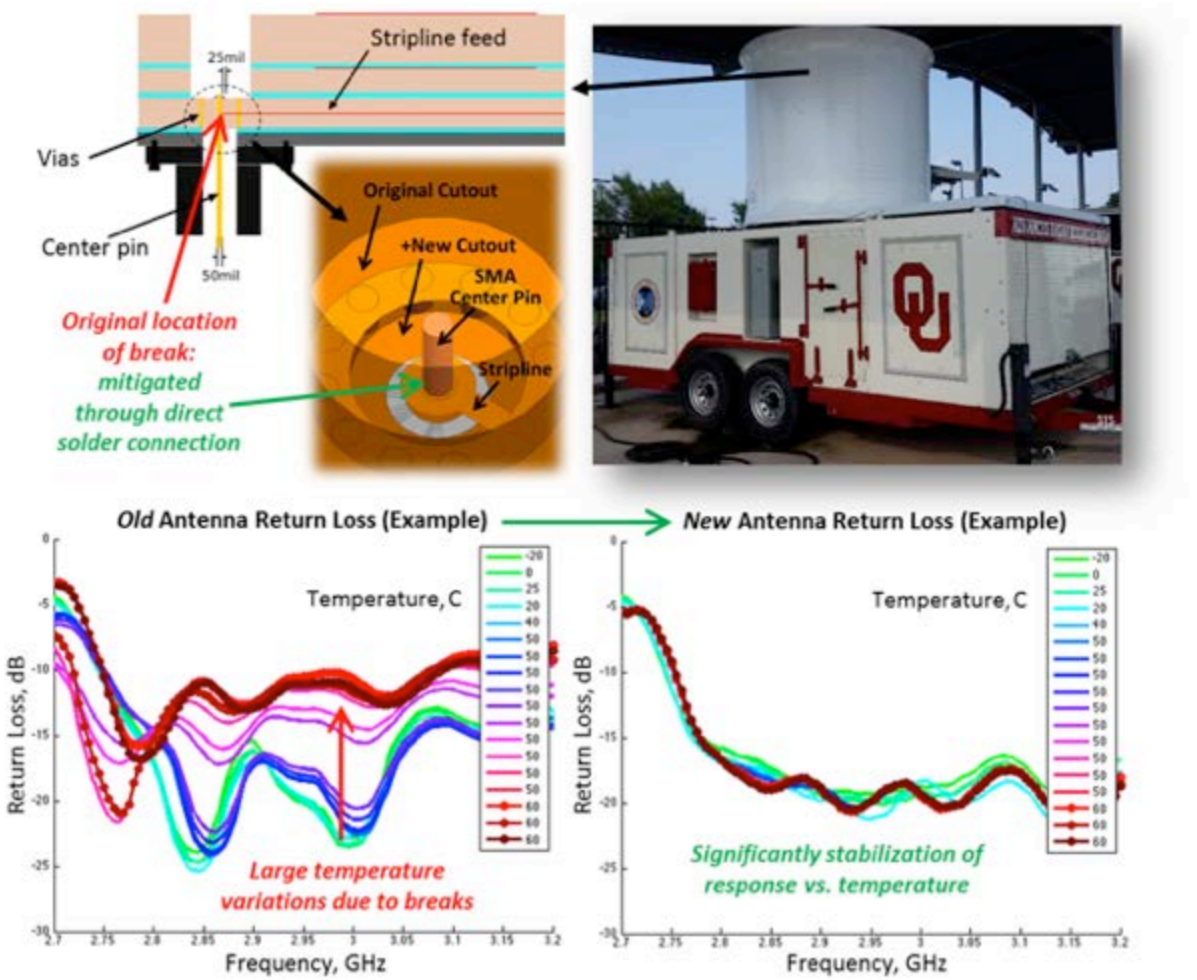
Accomplishments

Much of the last year has been spent solving fundamental problems with the CPPAR Demonstrator's electrical and mechanical components. In particular, and most importantly, it was found that the antenna feeds themselves were becoming disconnected as a function of the outside temperature, and that this problem stemmed from the way in which the multilayer PCBs were fabricated/tooled. This was causing significant changes to the antenna patterns (multiple dB and 10s of degrees), and sometimes even resulting in dangerously reflective antennas. After several extensive tests and trial solutions on the previous antennas, it was determined that the only viable path forward was to begin replacing the breaking antennas with new ones that had a re-designed feed structure. Eight such antennas have been ordered and tested, and the result is shown in the first figure below. Pending final stability tests, these will soon be replacing the worst of the old antennas. In addition, owing to aging electronics, continued use of long cables, and the constant threat of more breakage in the remaining antennas due to temperature swings, several measures have been taken to improve the air conditioning and overall airflow throughout the trailer itself. Additionally, a "shrink wrap" radome has been added, which provides a nice, airtight seal without the significant antenna pattern effects that were expected with the original Lexan concept. Despite these major improvements to the mechanical/thermal situation, previous time and temperature-related effects have taken their toll on a number of the electronic channels, ranging from cable failures to blown amplifiers. Significant work has been (and continues to be) done to work towards a goal of having all 32 dual-pol channels working, and this is expected to happen within the coming weeks. Once this happens, the Demonstrator will be in a state where the on-line, in-situ calibration routines (described next) will be able to function towards pattern measurements and, ultimately, basic radar operation.

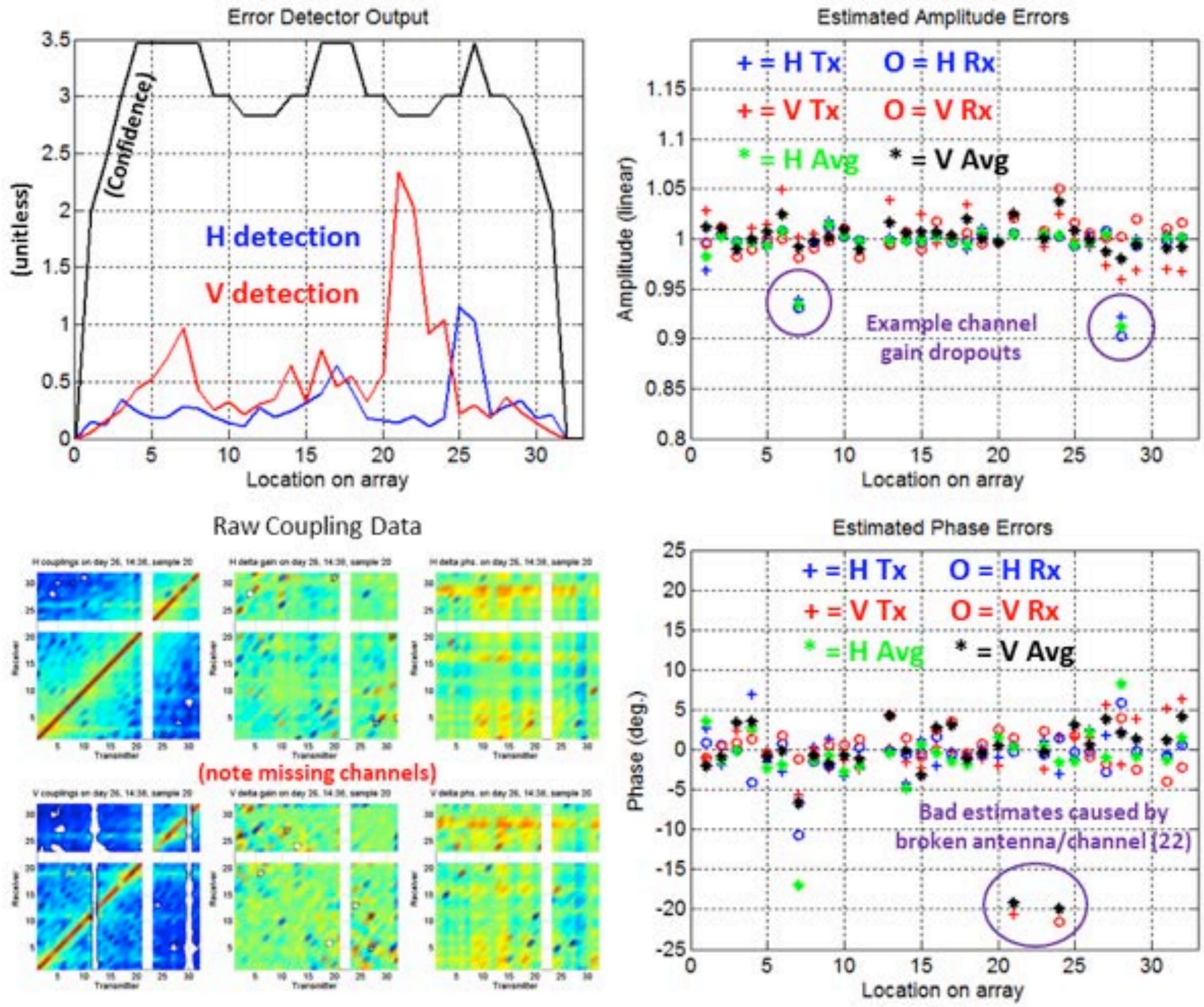
The majority of the system-level research and development performed on the Demonstrator over the last year has been in maturing, incorporating, debugging, and optimizing a set of mutual coupling-based algorithms that seek to maintain overall electronic stability over time and temperature. Specifically, the two primary goals of these algorithms are to a) estimate, track, and digitally remove the natural amplitude and phase drifts associated with changes due to temperature in each transmit and receive channel and b) to detect antenna breakage, cable disconnections, and outright failures in real-time so that the team can address these more serious issues. Both algorithms start by forming two sets of coupling data from each transmitter to each receiver, the first set being a "reference" or "golden standard" measurement made when the system has warmed up, and the second made later on. Each data set must be run

at both high and low power to calibrate the receivers and transmitters, respectively. The first algorithm builds up a large matrix equation that is solved for the amplitude and phase error estimates using the coupling changes. The second algorithm attempts to localize deviations from a physically derived model of “correctable” errors (cable stretching, LO phase changes, and natural gain drifts) to isolate mechanical problems. This is based on a modification to Dr. Fulton’s singular value decomposition algorithm from his dissertation, and it has been theoretically verified through extensive Matlab modeling. The team is using this second algorithm to identify channels and antennas that are failing, in anticipation of using the first algorithm in a closed-loop fashion with the Demonstrator in real-time in the coming weeks for pattern measurements. A summary of the types of analysis being done is shown in the second figure below. This shows outputs from both algorithms, as well as a view of the raw couplings that are being used to feed these algorithms, as viewed in matrix form. The team is now approaching the final software, hardware, and mechanical stages of readiness for far-field testing.

Finally, the CPPAR team has worked with in tandem with the OU Horus All-Digital Dual-Pol Phased Array development in investigating the use of novel near- and far-field techniques. This includes now fleshed-out plans to include a mobile ground absorber patch treatment for the outdoor far-field testing of the CPPAR antenna; this will be included in this fall’s upcoming tests, and will reduce the effect of the ground reflections to a level that will make them insignificant relative to other expected errors (misalignment, stability, etc.). The team has also been working to develop concepts for robot-assisted near-field scanning of conformal apertures. This is being developed on a small scale at first for use on the Horus project, but in principle could be scaled up (with more expense) to a full-sized array. This, in turn, could be an important technology consideration in the trade space between planar and cylindrical arrays.



(Top) Changes to the CPPAR mechanical structure to improve antenna breakage with a redesign and to maintain a more constant temperature with a "shrink-wrap" radome, as well as new air-conditioning; (bottom) measured return loss of old and new antennas vs. temperature, showing significant improvement.



Low-level engineering calibration interface to the CPPAR Demonstrator. (Top left) output of first algorithm for antenna error detection, showing problems near element 22; (right) amplitude and phase estimate outputs of second algorithm; and (bottom left) raw couplings used in algorithms, showing missing data from channels yet to be fixed.

Publications

Curtis, C., M. Yeary, and J. Lake, 2015: Adaptive beamforming to mitigate ground clutter on the National Weather Radar Testbed phased array radar. Accepted by *IEEE Transactions on Geoscience & Remote Sensing*.

Fulton, C., and A. Mirkamali, 2015: A computer-aided technique for the analysis of embedded element patterns of cylindrical arrays [EM Programmer's Notebook]. *IEEE Antennas and Propagation Magazine,* **57**, 32-138. doi:10.1109/MAP.2015.2439621.

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Karimkashi, S., and G. Zhang, 2015: Optimizing radiation patterns of a cylindrical polarimetric phased array radar (CPPAR) for multi-missions. Submitted to *IEEE Trans. On Geoscience and Remote Sensing*.

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Weather Review, **143**, 2711-2735.
Kurdzo, J. M., B. L. Cheong, R. D. Palmer, G. Zhang, and J. B. Meier, 2014: A pulse compression waveform for improved-sensitivity weather radar observations. *Journal of Atmospheric and Oceanic Technology*, **31**, 2713-2731.
Lei, L., G. Zhang, R. Doviak,, and S. Karimkashi, 2014: Comparison of theoretical biases in estimating polarimetric properties of precipitation with weather radar using parabolic reflector, planar or cylindrical arrays. Submitted to *IEEE Trans on Geoscience and Remote Sensing*.
Li, Y., G. Zhang, and R. J. Doviak, 2014: Ground clutter detection using the statistical properties of signals received with a polarimetric weather radar. *IEEE Transactions on Signal Processing,* **62**, 597-606.
Perera, S., Y. Pan, Y. Zhang, X. Yu, D. Zrnic, and R. Doviak, 2014: A fully reconfigurable polarimetric phased array antenna testbed. *International Journal of Antennas and Propagation*, Article ID 439606, 14 pp.

Awards

James Kurdzo (ARRC at OU) won the Tommy C. Craighead Award for Best Paper in Radar Meteorology – *School of Meteorology (2014-2015)*, 2nd Place Oral Presentation – *AMS Severe Local Storms Conference (2014)* – 2nd Place Oral Presentation – *AMS Conference on Environmental Information Processing Technologies (2015),* 2nd Place Oral Presentation – *AMS Conference on Research to Operations (2015).*

Caleb Fulton (ARRC and ECE at OU) is currently in the contracting stage for a DARPA Young Faculty Award to support further research into "Risk Mitigation for Large-Scale, Low-Cost, Highly Digital Phased Array Systems" for general digital beamforming systems, the proposal for which benefited substantially from work done under the support of the NSSL for this grant.

CIMMS Task III Project – Polarimetric Phased Array Radar Research in Support of MPAR Strategy

Guifu Zhang (ARRC at OU and OU School of Meteorology), Shaya Karimkashi (ARRC at OU), Richard Doviak and Dusan Zrnic (NSSL), Lesya Borowska and Said Abushamle (ARRC Post Docs), and Hadi Saeedimanesh, Mirhamed Mirmozafari, Thomas Grabow, and Mohammadhossein Golbonhaghighi (ARRC/ECE Students)

NOAA Technical Lead: Kurt Hondl (NSSL)

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

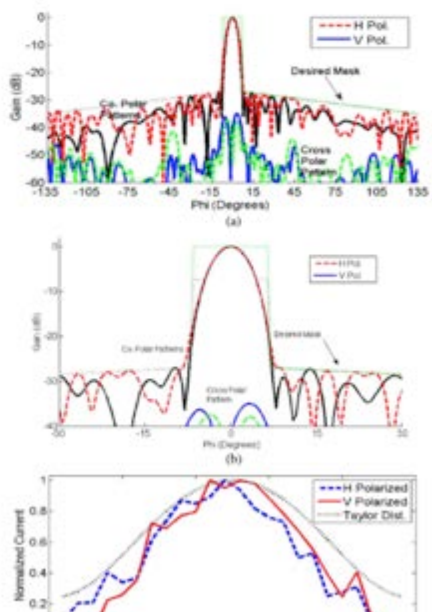
Funding Type: CIMMS Task III (NSSL; NOAA Congressional Earmark)

Objectives

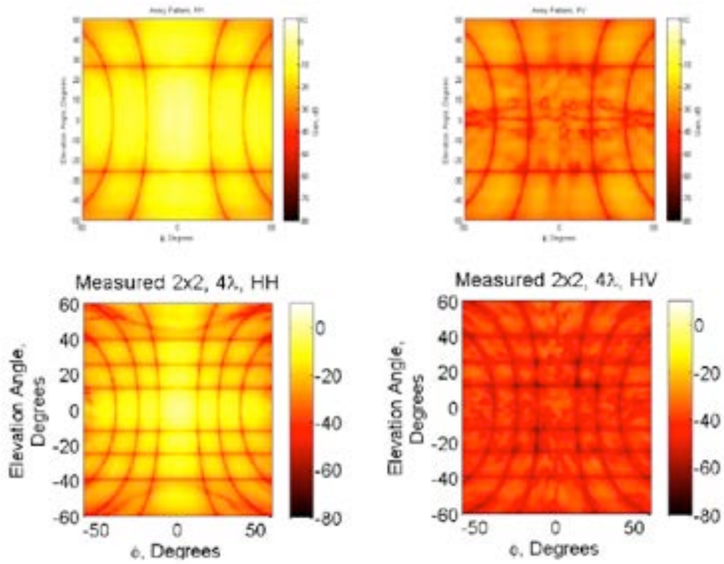
Conduct research on practical issues for designing and developing the Polarimetric Phased Array Radar (PPAR), including the Cylindrical Polarimetric Phased Array Radar (CPPAR), to better understand the scientific advantages, technical challenges & limitations and cost-performance tradeoffs, as well as to support MPAR strategy in

decision making to sustain Norman's leadership in weather radar and to expand its radar expertise for broad research and multi-mission applications.

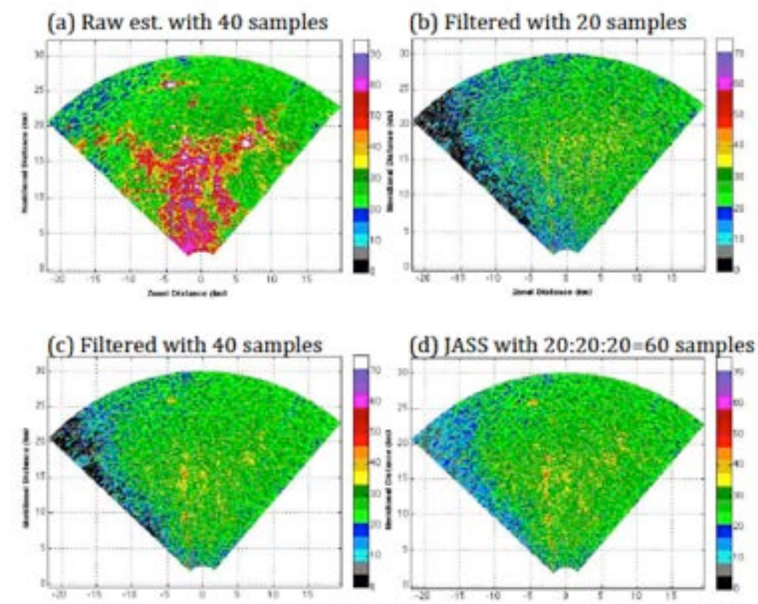
Accomplishments
To support the MPAR strategy, this team proposed PPAR research last year and has been focusing on three topics: i) CPPAR configuration, design and optimization, ii) sub-array and element design and testing, applicable to both the PPPAR and the CPPAR and iii) scan strategy and innovative signal processing. We made significant advances in our research on these topics, and our results are impressive. Corresponding to research topic i), our CPPAR patent application, filed jointly by OU and NSSL engineers, was awarded by the US patent office (#8988274). We developed a CPPAR optimization algorithm that is now ready to be used on a real system. Corresponding to research topic ii), we also introduced and studied a new cost-effective and high-performance dipole-radiating element. At the same time, we tested the existing arrays, the OU patch array and the Lockheed Martin (LMCO) slot-dipole array, with the primary results showing that the OU patch array has a higher isolation and lower level of cross-pol pattern. Corresponding to research topic iii), our proposed joint processing of PAR signals (JPARS) has been fruitful. Using NWRT data, we demonstrated that JPARS can improve weather data estimation and mitigate ground clutter contamination. An OU intellectual property disclosure has been filed for JPARS.



(a) Optimized radiation pattern of the CPPAR antenna, (b) Zoom-in view, and (c) Optimal current distribution.



Comparison of co- and cross-pol 3D radiation patterns between the LMCO slot-dipole antenna (top row) and the OU patch array antenna (bottom row) for H polarization excitations.



Comparison of radar reflectivity factors contaminated with ground clutter from different signal processing: a) raw estimates from 40 samples at each beam, b) after filtering with 20 samples, c) after filtering with 40 samples, d) JASS processing of 3-beam signals of 20:20:20=60 samples. Data were collected by NSSL engineers on 06-Feb-2014 at 12:16:00 UTC at elevation of 0.51°.

Publications

Borowska, L., G. Zhang, and D. S. Zrnic, 2015: Considerations for oversampling in azimuth on the phased array weather radar. *Journal of Atmospheric and Oceanic Technology,* **32**, 1614-1629.

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Lei, L., G. Zhang, R. Doviak, and S. Karimkashi, 2015: Comparison of theoretical biases in estimating polarimetric properties of precipitation with weather radar using parabolic reflector, or planar and cylindrical arrays, *IEEE Transactions On Geoscience and Remote Sensing*, **53**, 4313-4327.

Awards

G. Zhang (ARRC at OU), R. Palmer (ARRC at OU), and R. J. Doviak and D. Zrnic (NSSL): A Patent #8988274 of "Cylindrical Polarimetric Phased Array Radar" awarded by U.S. Patent Office, 24 March 2015.

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

Theme 2 – Stormscale and Mesoscale Modeling Research and Development

NSSL Project 3 – Numerical Modeling and Data Assimilation

NOAA Technical Leads: Adam Clark, Jack Kain, Don MacGorman, Ted Mansell, Louis Wicker, and Conrad Ziegler (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
Develop and test numerical weather prediction models, data assimilation techniques, and diagnostic, visualization, and verification methods to improve severe weather forecasts.

Accomplishments

1. Establishing Model Resolution Requirements for Warn-on-Forecast

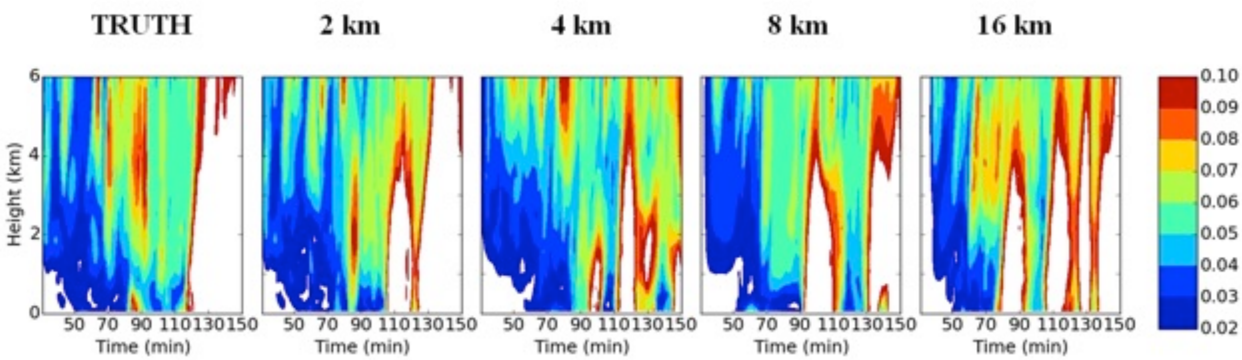
Corey Potvin (CIMMS at NSSL), and Montgomery Flora and Elisa Murillo (Research Experience for Undergraduates)

Current computational limitations prevent real-time ensemble forecasting systems from being run on convection-resolving grids. Understanding of forecast errors arising from finite model resolution is required to optimize ensemble system design tradeoffs, guide interpretation and calibration of ensemble output, and establish model resolution requirements for Warn-on-Forecast. This topic has been explored with the help of REU students Flora and Murillo.

The grid spacing sensitivity experiments with idealized supercell simulations begun last summer have been published (Potvin and Flora 2015). The results suggest that reliable prediction of rapid changes in low-level storm rotation, and therefore of tornado potential, require sub-kilometer horizontal grid spacing, and that the grid spacing dependencies of this and other model variables critical for severe weather operations are strongly sensitive to both the storm environment and the physics parameterizations used.

In new work by Potvin and Murillo, simulations with identical, 250-m or 333-m grid spacing but initialized with successively heavier low-pass filtering of the initial condition are compared to explore the sensitivity of supercell forecasts to initial condition resolution. Both idealized and full-physics simulations (downscaled from real-data analyses) are being performed. Preliminary results indicate that scales filtered from the initial condition are rapidly restored as the simulations proceed, and that forecasts of gross storm characteristics such as storm track and reflectivity structure should not be

substantially degraded if downscaled from convection-allowing (≤ 4-km) analysis grids. Low-level rotation evolution, including the onset of tornado-like vortices, is far more sensitive to the initial condition resolution; results so far suggest that ≤ 1-km data assimilation grid spacing is a necessary condition for reliable prediction of tornado potential.



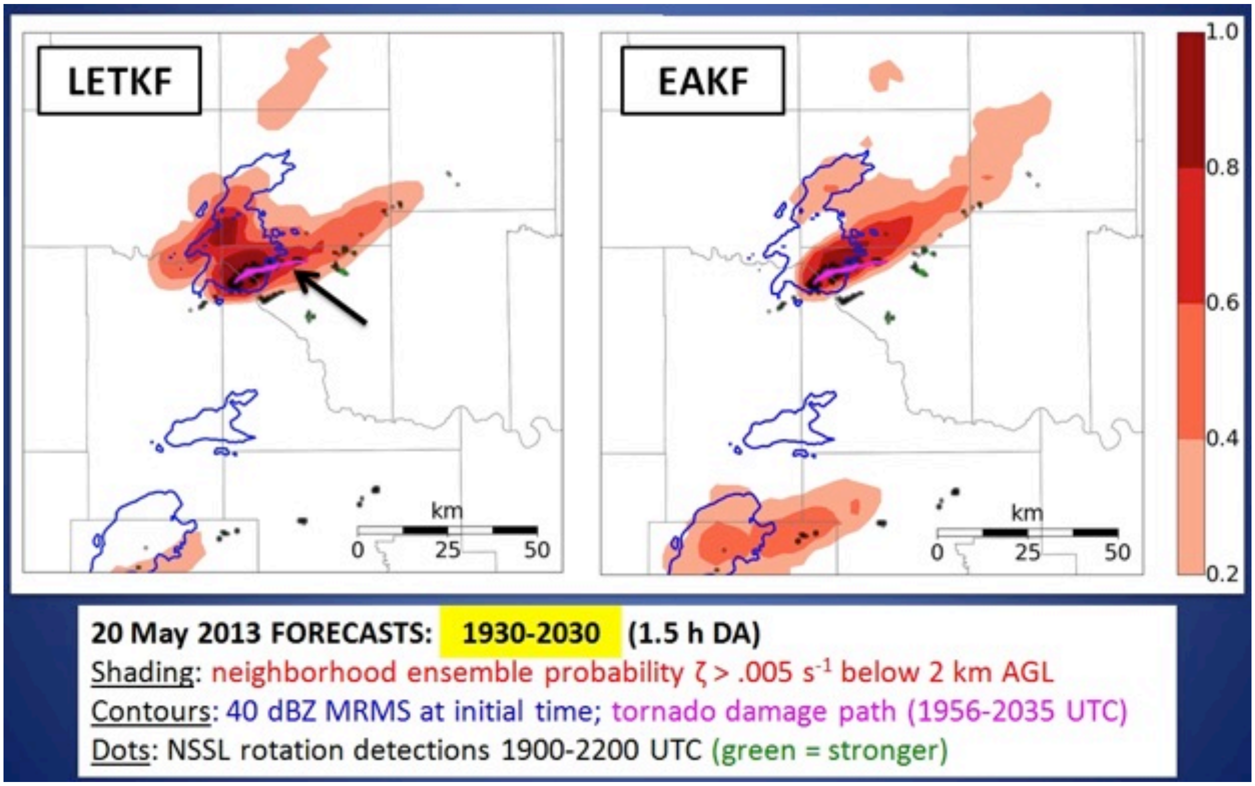
Time-height vertical vorticity composites (white indicates intense rotation) of 333-m supercell simulations. Plot headings indicate the cutoff wavelength used to filter the initial condition, which is valid 30 min into the TRUTH (control) simulation, shown in the leftmost panel.

2. Evaluating the Competitiveness of the LETKF for Warn-on-Forecast

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

Thompson's work comparing the efficacy of LETKF vs. EnSRF convective-scale data assimilation has been published (Thompson et al. 2015). Using both idealized experiments and one real data case, this work provides evidence that analyses and forecasts generated from the LETKF have comparable accuracy to those generated from serial filters.

In new work led by Potvin and Wheatley, the configuration of the WRF-LETKF developed by Thompson, Wicker and Potvin has been updated for heterogeneous, full-physics data assimilation and matched to the NSSL Experimental WoF System EnKF (NEWS-e). Currently, 3-km analyses and forecasts generated from the two ensemble systems are being compared in three retrospective case studies. Preliminary results confirm the conclusion from Thompson et al. (2015) that the LETKF is competitive with serial filters at convective scales, and that the superior computational efficiency of the LETKF should be explored for its potential to facilitate real-time operation of WoF systems.



Probabilistic forecasts of intense low-level rotation from the WRF-LETKF (left) and NEWS-e (right).

3. Impact of Phased Array Radar Data Assimilation on Warn-on-Forecast

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

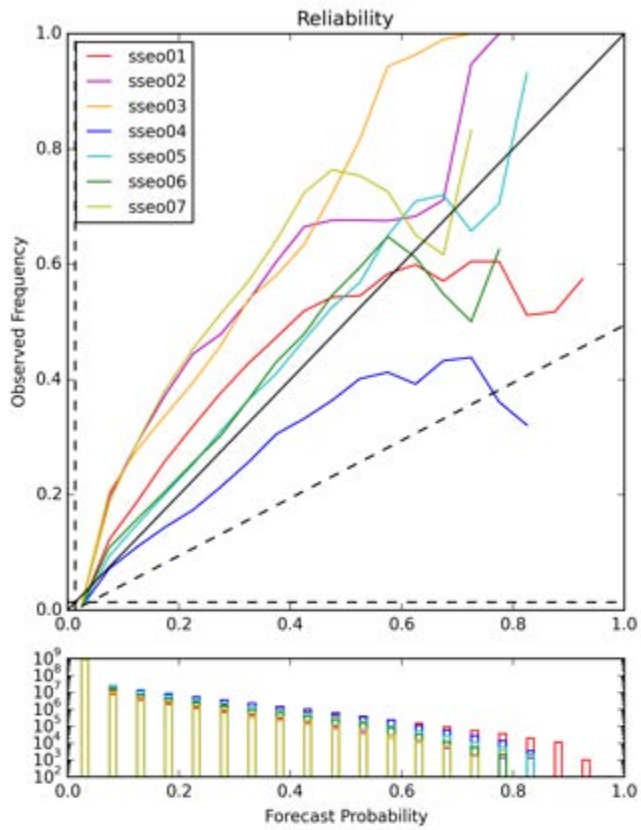
In an OSSE study by Yussouf and Stensrud (2011), assimilating simulated rapid-scan radar data using an ensemble Kalman filter (EnKF) produced better analyses and forecasts than assimilating radar data synthesized using a typical WSR-88D scan strategy. Demonstrating impacts from real PAR data, however, 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.

Wicker continues work on the 24 May 2011 case, and has begun performing experiments with the 19 May 2013 case. Results continue to indicate that assimilating PAR vs. WSR-88D data generally improves subsequent ensemble forecasts early in the assimilation period.

4. Ensemble Verification of Proxy Severe Storm Reports

James Correia, Jr. (CIMMS at SPC)

The Storm-Scale Ensemble of Opportunity (SSEO) was used to produce 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 for 9/2011-6/2014 was conducted to evaluate the proxy method and individual model reliability. Preliminary results suggest under-forecasting is prevalent with the exception of one member. Clustering of the members also suggests that model resolution is a determining factor in reliability. Analyses were conducted with the help of a NOAA Hollings Scholar and work is ongoing to evaluate an upgrade to the SSEO.

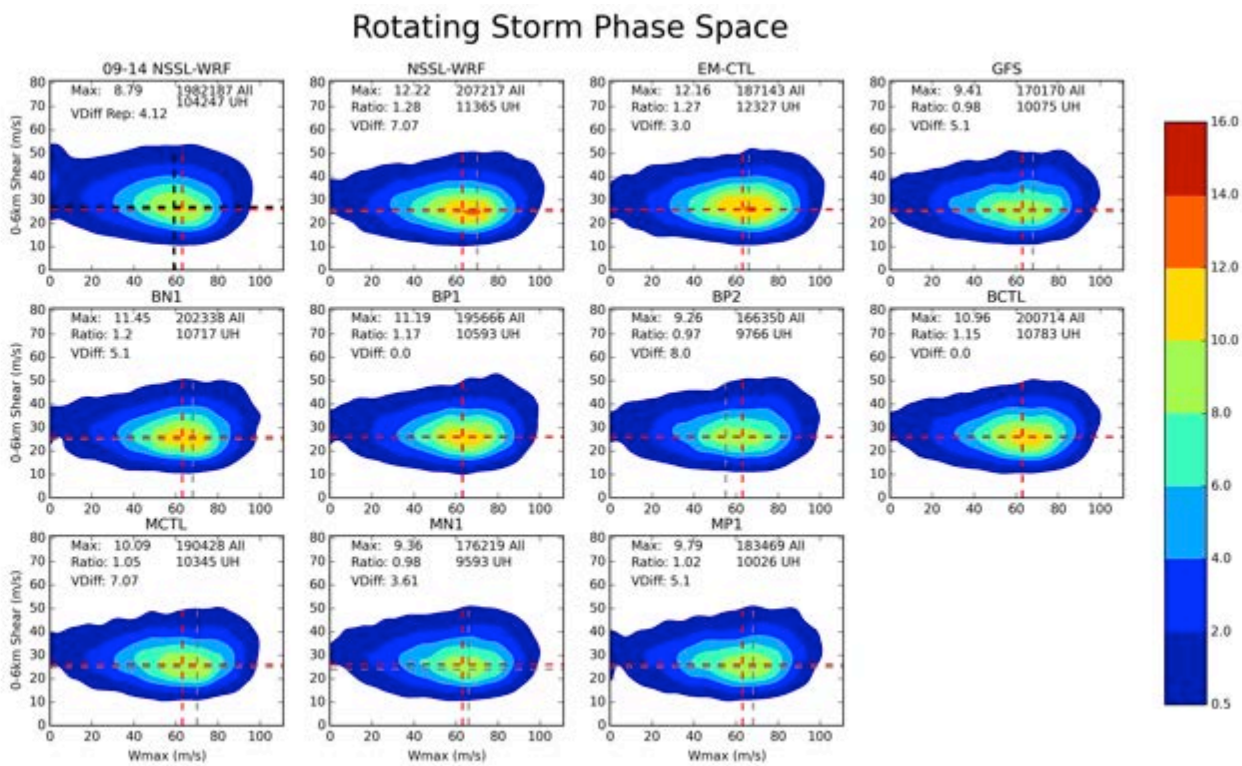


Reliability diagram depicting each member of the Storm Scale Ensemble of Opportunity. The observed frequency (y-axis) is mapped against the forecast probability (x-axis) where the solid black line is perfectly reliable, the diagonal dashed black line represents the no-skill line and the horizontal black dashed line is the climatological frequency. Sample sizes are indicated in the bottom panel. All but one model produce under-forecasts (above the perfect reliability line). The models cluster by effective resolution with more reliable models using ~4km grid spacing vs. ~5km grid spacing.

5. NSSL WRF Ensemble Severe Storm Environments

James Correia, Jr. (CIMMS at SPC)

A ~5 year (June 2009 through December 2014, 12z-12z) climatology of simulated convective storms is constructed from the experimental NSSL ARW using an object based approach. This long-term climatology is compared to that of the newly developed NSSL WRF ensemble from January through July 2015 (figure below). Comparing where simulated rotating storms occur within the CAPE and 0-6km shear parameter space in the models (gray dashed lines) and observations (black dashed line) with a reference to the long term NSSL WRF climatology (red dashed lines) show small spread but with slight differences to the frequency of storms in the centroid.



A comparison of a long term climatology vs ensemble members from the NNSL ensemble of rotating storms in the surface based CAPE (converted to maximum vertical velocity) and 0-6km bulk vertical shear parameter space. Kernel density estimates are shown throughout with maximum values, vector difference between centroids of observations (black dashed line) and the respective long-term climatology (red dashed line). This is repeated for each ensemble member during 2015 (gray dashed line), with a comparison to the long term climatology. The total number of storms and number of rotating storms (Updraft Helicity >= 25 m2s-2) are also shown since sample sizes vary.

6. Evaluating the NSSL WRF Using the Multi-Year Reanalysis Of Remotely Sensed Storms (MYRORRS)

James Correia, Jr. (CIMMS at SPC)

The need to verify the above modeling results culminated in the funding of a grant to use the MYRORRS of storm environments with radar data to directly compare with the NSSL WRF climatology. We will verify the model using a distributions oriented approach and discover the challenges and opportunities of using the radar and environment data to verify bulk storm character. The goal is to understand if the model can simulate storm character, such as rotating storms, in any way related to that observed.

7. Evaluation of Rapid Post-Processing and Information Extraction from Large Convection-Allowing Ensembles Applied to 0-3 Hour Tornado Outlooks

James Correia, Jr. (CIMMS at SPC)

The purpose of this project is to design, implement, and evaluate a new post-processing paradigm, designed for any convection-allowing modeling and ensemble system. This new paradigm will allow information extraction for severe weather forecasting, specifically tornado forecasts. This new post-processing paradigm has the benefit of being adaptable, scalable, and fast. To achieve these benefits, we propose using an object-based approach to refine gridded datasets into features of interest, a result of the data mining and information extraction, in order to achieve reduced dataset size for transmission, allow the viewing of all ensemble members, create an ability for forecasters to adapt to the problem of the day and maximize effective use of numerical guidance. Evaluation of our work will allow attribution of forecast improvements to the specific, direct cause, be that the experimental products, forecast tools, or other confounding factors.

We will be utilizing an ensemble-based, radar data assimilation system within the Hazardous Weather Testbed to generate hourly and three hourly tornado outlooks. Forecasters will use the proposed object based post-processing to derive the information they need to make these forecasts. Multiple variables and thresholds will be available for them to make full use of the guidance, rapidly prototyping and data mining to meet the problems of the day. An evaluation of how this strategy will affect forecaster workload will be conducted to further refine our post-processing strategies. This project is a necessary first step in achieving full use of rapidly updating, large convection-allowing ensemble systems and making them useful and usable to forecasters while producing consistent and reliable risk analyses in between the warning and watch time scales. This in turn, enables forecasters to provide effective decision support to help partners effectively mitigate the impacts of severe weather.

8. Expanding High Performance Computing Resources for Storm-Scale Modeling and Data Assimilation

Gerry Creager (CIMMS at NSSL)

Work was done to facilitate acquisition, installation and management of the Cray computing system, enhancing NSSL's Forecast Research and Development Division scientific computational capacity by over 20 times. Creager also consulted and supported design and installation of the upgraded Uninterruptable Power System for research computing operations for the National Weather Center, with NSSL as a key beneficiary, allowing unhindered access to computing resources and providing a high capacity (if non-redundant) power backup system. He also worked with NSSL scientists to support and improve computational techniques on the available computer resources, including Jet (NOAA/OAR/GSD), Boomer (OU HPC), and Loki (NSSL Cray). This support included work on behalf of local scientists with personnel at ESRL/GSD, NCAR/MMM, and other facilities supporting the WRF modeling system. He also evolved novel and reliable methods of acquiring and processing surface and remotely sensed data for data assimilation efforts.

9. Development of the NSSL Weather Research and Forecasting (WRF) Model

Scott Dembek (CIMMS at NSSL), Adam Clark and Jack Kain (NSSL), and Israel Jirak (SPC)

The NSSL WRF model continues to be a valuable element of the annual HWT Spring Forecasting Experiments. The model's twice-daily real-time forecasts covering the Continental United States use a 4-km grid spacing and convection-allowing dynamics, and include a unique set of storm-scale diagnostic tools developed at NSSL in collaboration with both researchers and forecasters at the SPC. These same diagnostic tools have been adopted in the latest versions of the Atmospheric Research WRF (ARW) code distributed to the meteorological community by NCAR. Similarly, researchers at the NWS NCEP Environmental Modeling Center have incorporated some of the same diagnostics codes into their operational models.

Diagnostics from the daily forecasts continue to be an extremely useful tool for SPC forecasters, who have found the NSSL WRF particularly valuable in the ability to depict convective-scale elements like supercells and bow echoes. During the forecast process many SPC forecasters look to the NSSL WRF to provide guidance on convective initiation, mode, intensity, coverage, and evolution, and it is considered one of the best convection-allowing models available in real time.

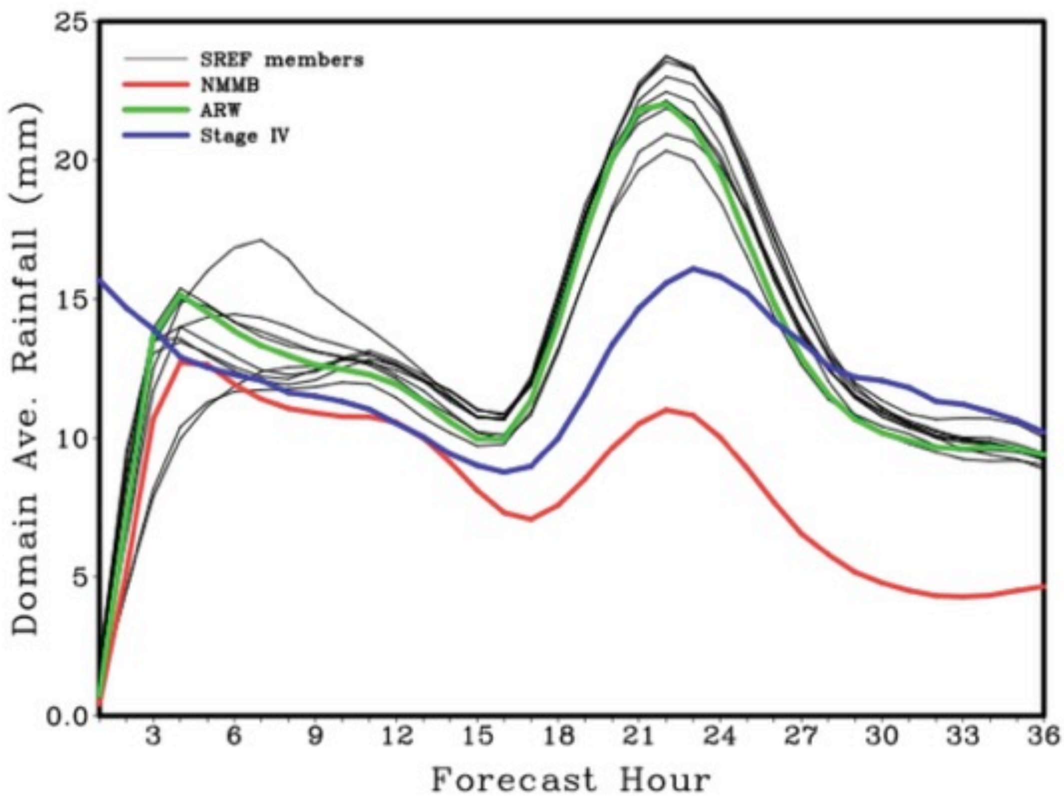
10. Implementation and Development of the NSSL NMMB

Scott Dembek (CIMMS at NSSL), Adam Clark (NSSL), Jabob Carley and Brad Ferrier (NOAA NCEP/EMC), and Laurie Carson (NOAA ESRL/GSD)

The newest addition to the suite of real-time NWP models being run at NSSL is the NOAA Environmental Modeling System (NEMS) Nonhydrostatic Multi-scale Model on the B-grid (NMMB). In early 2015 the NMMB was ported to the Jet Research and Development High Performance Computing System (RDHPCS) through collaboration with researchers at EMC and GSD. The NEMS-NMMB is being developed at NCEP and distributed by the Development Testbed Center (DTC). The architecture is a high-performance software structure based on the Earth System Modeling Framework (ESMF), and is used in operational NWP models at NCEP.

The NSSL NMMB forecast is a once-daily product that runs at 0000 UTC on a latitude-longitude grid covering the CONUS that approximates the domain of the NSSL WRF, facilitating comparison between the resulting forecasts. Many of the same storm-scale diagnostic tools developed for the NSSL WRF continue to be implemented in the NSSL NMMB, and these codes are being shared with researchers at EMC for inclusion in their operational code.

An important finding from initial comparisons between the NSSL WRF and the NSSL NMMB is a low precipitation bias and precipitation that steadily decreases with forecast length in the NSSL NMMB. Discussions with EMC researchers have begun and various strategies are being developed to diagnose the reason for this low-precipitation bias in the NSSL NMMB.



Forecast hour (x-axis) and domain averaged rainfall (y-axis, mm) from 70 forecast cases during the period April through July 2015 for the various NWP model forecasts run at NSSL, including the SREF-initialized NSSL ensemble members, the NSSL WRF (ARW), the NSSL NMMB, along with the observed rainfall from the NCEP Stage IV precipitation data set.

11. Development of the NSSL SREF Ensemble

Scott Dembek (CIMMS at NSSL), Adam Clark (NSSL), Israel Jirak (SPC), and Conrad Ziegler (NSSL)

An increase in the computing allocation on the Jet RDHPCS granted to NSSL in 2014 led to the development of an eight-member convection-allowing ensemble run once daily at 0000 UTC. The ensemble uses NCEP's Short-Range Ensemble Forecasting (SREF) members to initialize the model and as lateral boundary conditions. The NSSL SREF ensemble has been evaluated during the 2014 Spring Forecast Experiment, and is being used as a new forecasting tool at the SPC. In October 2014 some ensemble members were changed to provide greater model dispersion, and the ensemble will continue to be modified from time to time to develop an optimal ensemble configuration for storm-scale severe weather forecasting.

12. Implementation of Lightning Data Assimilation Code in the NSSL WRF

Scott Dembek and Alexandre Fierro (CIMMS at NSSL), and Adam Clark and Conrad Ziegler (NSSL)

A unique version of the NSSL WRF was used to implement code for a cloud-scale lightning data assimilation technique at convection-allowing scales (4-km grid spacing). The Earth Networks Total Lightning Network provided data for the assimilation technique over the CONUS, and data were assimilated during the first two hours of each simulation over a 67-day warm-season period.

Equitable threat scores were used as the basis for determining the skill of the resulting forecasts. Although the assimilation technique resulted in increased wet bias during the initial 3 hours of the simulations, it was found that it exhibited considerable promise for improving the forecast of high-impact weather during the short-term forecasts (0-6 hours).

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

Don MacGorman, Ted Mansell, Adam Clark, Conrad Ziegler, and Jack Kain (NSSL), and Scott Dembek and Valliappa Lakshmanan (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 (LDA) 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 implicated the development of post processing codes to derive 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 fiscal year’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. Forecasts produced by the LDA had a noticeable, statistically significant improvement over those by the control run up to 6 h into the forecast with an aggregate (bias corrected) ETS score differences often

exceeding 0.4. This improvement was seen independently of the accumulated rainfall threshold (ranging from 2.5 to 50 mm) and the neighborhood radius (ranging from 0 to 40 km) selected. Past 6 h of the forecast, the accumulated rainfall fields from the LDA progressively converged to that of the control run probably due to the longer-term evolution being bounded by the large-scale model environment.

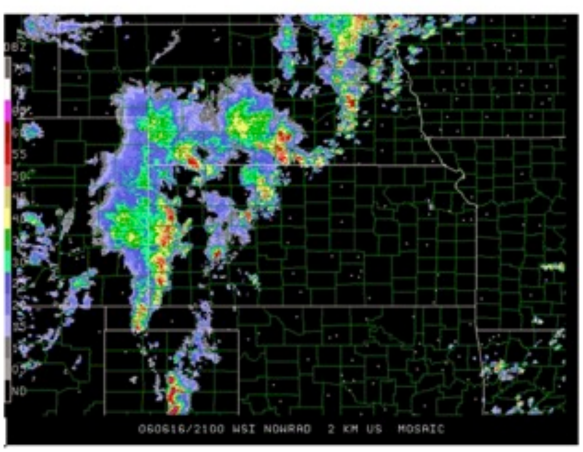
During the course of FY14, the results from the aforementioned study have been formally accepted for publication to Monthly Weather Review – completing the project.

Follow-on work will attempt to incorporate the LDA philosophy of Fierro et al. (2012, 2014) and evaluated in Fierro et al. (2015a) in the NSSL/ARPS 3DVAR system - which has recently been ported to the WRF model. Preliminary/embryonic results for the 29 June 2012 ‘super-derecho’ case using water vapor as a proxy for lightning flash rate densities in the 3DVAR forward operator showed similar encouraging results than for the nudging/direct insertion method of Fierro et al. 2012. Future experiments will evaluate additional lightning operators based on intrinsic relationships between lightning and storm properties derived from a high resolution, 350 m simulation of the electrification within a tropical cyclone.

14. The Assimilation of Hyperspectral Sounder Observations into Mesoscale Models

Thomas Jones (CIMMS at NSSL), Steven Koch (NSSL), and Heather Reeves and Nusrat Yussouf (CIMMS at NSSL)

This project is to assess the viability and value of assimilating hyperspectral sounder observations into mesoscale models for the prediction of convective weather. This description covers H. Reeves’ contributions, which ended in February 2015. For this part of the project, a nature run and associated synthetic observations were created. These were compared against observations and show good agreement.



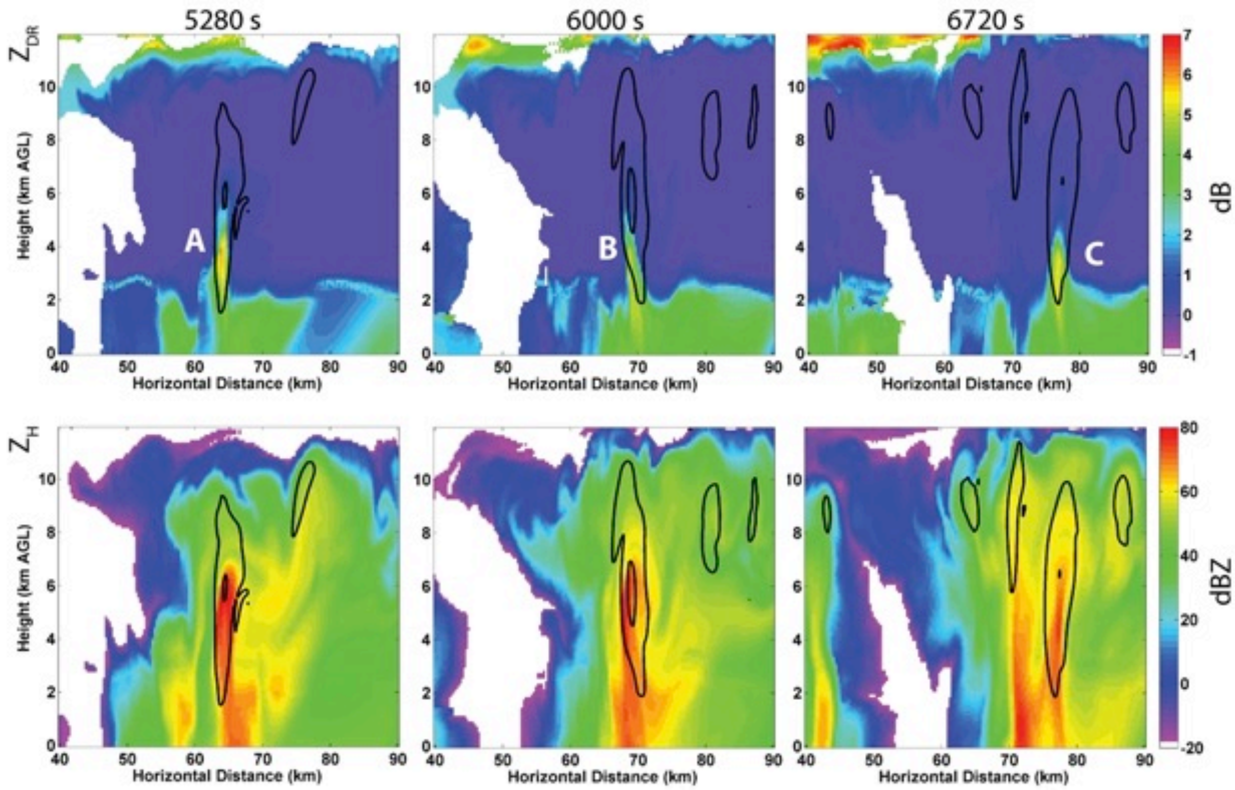
Observed (left) and synthetic (right) composite reflectivity valid 1800 UTC 16 June 2006.

15. Advancing a Sophisticated Polarimetric Radar Forward Operator

Jeffrey Snyder and Alexander Ryzhkov (CIMMS at NSSL)

The development of an advanced forward operator allows for numerical model output to be represented by commonly used polarimetric weather radar quantities. This forward operator has a wide range of potential applications, including for use in storm-scale data assimilation, for evaluating microphysical schemes, and for examining relationships between radar signatures and the underlying microphysical processes and dynamic and kinematic structures responsible for the simulated radar signatures.

Since March 2015, Snyder modified the FORTRAN-based forward operator code to incorporate sophisticated two-layer T-matrix scattering calculations. To increase the efficiency of the code, he added the capability to calculate and write to file the forward and backward complex scattering amplitudes as a function of size, temperature, and volume water fraction. These precomputed values can be read by a numerical model (such as the Hebrew University Cloud Model); the use of lookup tables significantly speeds up the calculation of the radar quantities. Specific attenuation, specific differential attenuation, and circular depolarization ratio were added as new radar parameters.

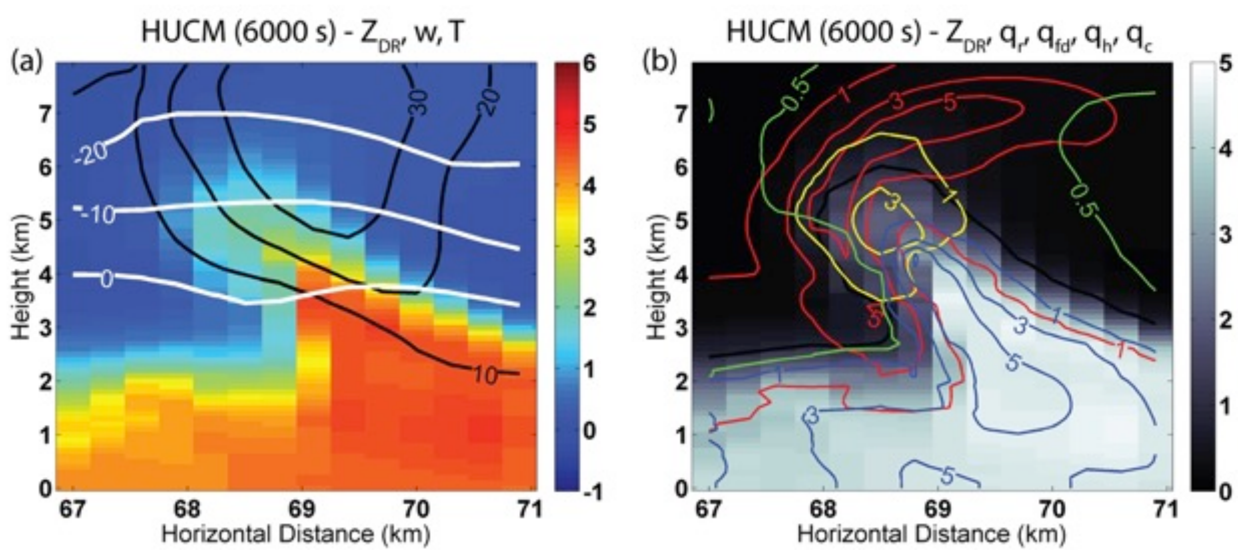


(Top row) Z_{DR} and (bottom row) Z_H from the HUCM simulation at three different times between 5280 s and 6720 s every 360 s. Upward vertical velocities are contoured in black at 10 m s^{-1} and 30 m s^{-1}. White letters in the top panel mark three different Z_{DR} columns that occur during the time period represented in this figure.

16. Simulating Polarimetric Signatures Using High-resolution Numerical Simulations

Jeffrey Snyder and Alexander Ryzhkov (CIMMS at NSSL)

Assessing the intensity and evolution of convective storm updrafts can be an important skill for operational meteorologists responsible for providing severe weather warnings to the public. Unfortunately, conventional, single-polarization weather radar data can provide only very limited information about the location, structure, and intensity of updrafts. Dual-polarization weather radars, however, can provide information on the dominant hydrometeors in a radar resolution volume owing to the distinctly different scattering behaviors of various scatterers. To this end, Snyder continued to examine the relationship between the intensity of convective storm updrafts and the polarimetric structure of the simulated storms using a three moment, bulk microphysics scheme in the Advanced Regional Prediction System (ARPS). In addition, he used the Hebrew University Cloud Model with complex spectral bin microphysics and an advanced forward operator to examine the positive relationship between the intensity of simulated convective storms and quasi-vertical volumes of enhanced differential reflectivity (Z_{DR}). Using the results from these simulations has led to the development of a Z_{DR} column algorithm that can be used, at least when they are well sampled, for operational and research applications.



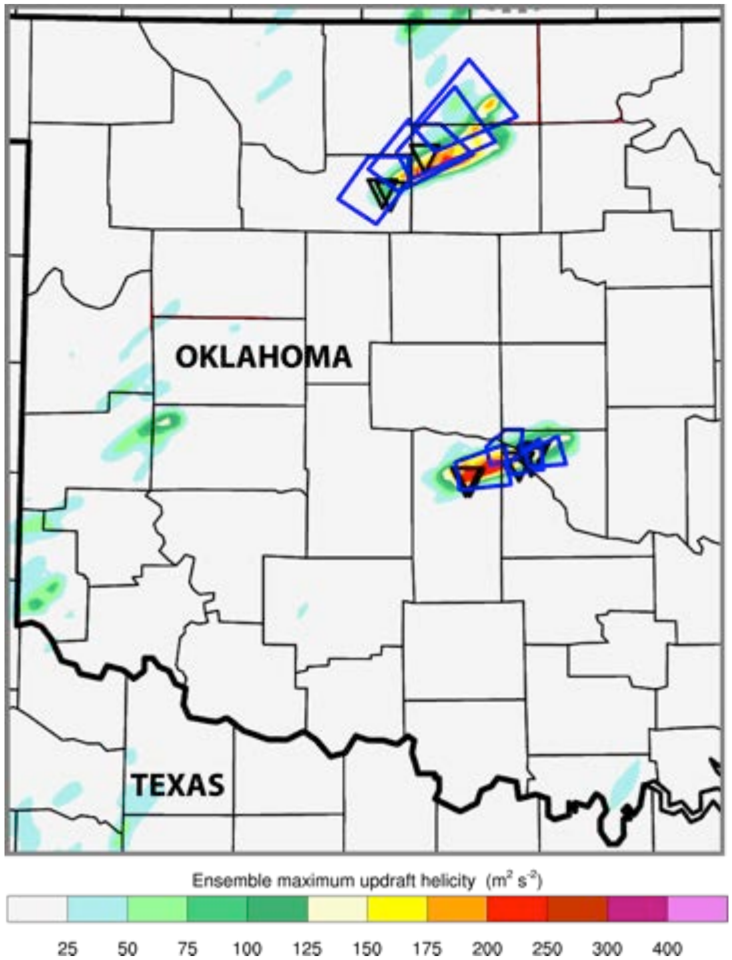
(a) Z_{DR} (colored; dB), w (contoured in black every 10 m s^{-1} starting at 10 m s^{-1}), and air temperature (contoured in white at 0 ºC, -10 ºC, and -20 ºC) shows the general relationship between the Z_{DR} column and the updraft. (b) The general microphysical mass composition of the Z_{DR} column (grayscale color; dB) for rain (blue contours), freezing drops (yellow contours), and hail (red contours) every 2 g cm^{-3} starting at 1 g cm^{-3}. The 0.5 g cm^{-3} cloud water contour is shown in green.

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

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

The Warn-on-Forecast program is working toward the development of very short-range (0-1 h) probabilistic forecasts that accurately predict convective hazards such as tornadoes, high winds, and flash flooding. Preliminary work with a WRF-based ensemble data assimilation system has begun on regional convection-allowing grids. This system—the NSSL Experimental Warn-on-Forecast System for ensembles (or NEWS-e)—was run quasi-real-time during the 2015 Spring Experiment. This ensemble could serve as the background for nested very-high-resolution, event-dependent grids (a component considered essential for a Warn-on-Forecast system). Earlier development and testing of this system has produced one paper that has been conditionally accepted to Weather and Forecasting.

Storm-scale ensemble analyses and forecasts of severe weather events from spring 2015 were produced on a 3-km event-dependent grid. This storm-scale ensemble is nested within a 15-km continental United States ensemble constructed from initial and boundary conditions provided by members of the Global Ensemble Forecast System (GEFS) forecast cycle starting at 1800 UTC the previous day. Around the time of convective initiation, radar and satellite (cloud water retrievals) data were assimilated every 15 min using the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). Two 90-min ensemble forecasts were initialized from the resultant storm-scale analyses each hour of the storm event.



90-min forecast of ensemble maximum updraft helicity (a measure of thunderstorm rotation), valid at 2300 UTC 6 May 2015. Darker reds are indicative of more intense thunderstorm rotation. Blue polygons show tornado warnings issued by the National Weather Service during the 90-min forecast period. Black triangles show the locations of preliminary tornado reports.

18. Application of the Warn-on-Forecast Concept to Severe Mesoscale Convective Systems

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

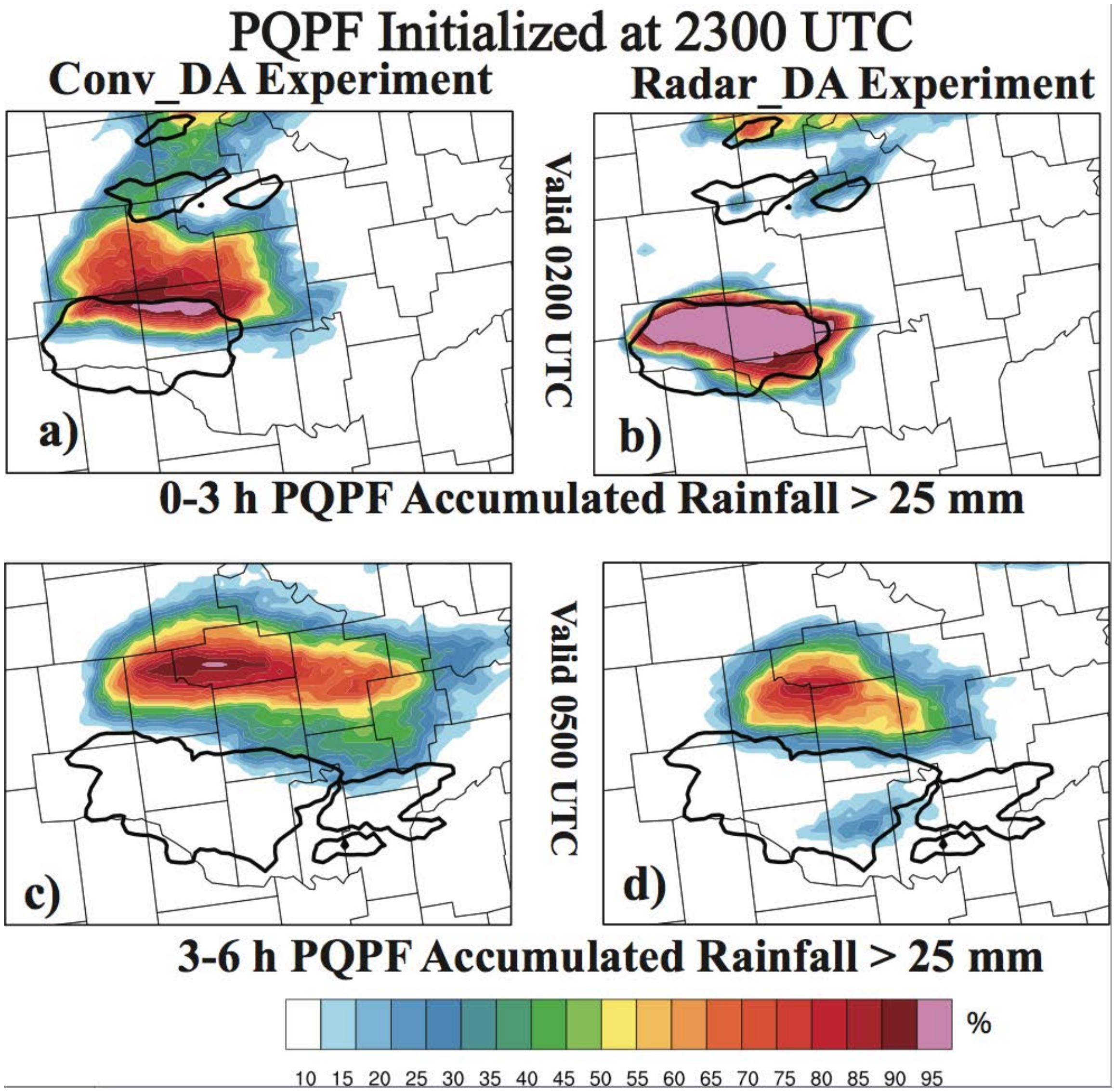
A WRF-based ensemble data assimilation system is used to produce storm-scale analyses and forecasts of the 4-5 July 2003 severe mesoscale convective system (MCS) over Indiana and Ohio, which produced numerous high wind reports across the two states. Single-Doppler observations are assimilated into a 36-member, storm-scale ensemble during the developing stage of the MCS with the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). Three EnKF simulations were performed using the NSSL 1- and 2-moment and Thompson

microphysical schemes, to examine the impact on (convective) system evolution when using these different choices of microphysical schemes. This work seeks to expand upon previous work with a convective-scale EnKF, which have focused more on the individual convective element, by evaluating simulations of meso-convective organization. The findings have been published in *Monthly Weather Review*.

19. Short-term Probabilistic Forecasts of the 31 May 2013 Oklahoma Tornado and Flash Flood Event Using Continuous Update Cycle Storm-scale Ensemble System

Nusrat Yussouf (CIMMS at NSSL)

NSSL is developing a continuous update storm-scale ensemble data assimilation (DA) and prediction system using the WRF-ARW model and the Data Assimilation Research Testbed software as part of Warn-On-Forecast project. In addition to tornadic thunderstorm events, the ensemble system can be utilized for short-term probabilistic forecasts of other hazardous convective weather like heavy rainfall, floods and flash floods. Therefore to evaluate the capability of system in forecasting severe weather related hazards, retrospective 0-6 h ensemble probabilistic forecasts of the 31 May 2013 tornado and flash flood event over central Oklahoma are chosen. Results indicate that the predicted probabilities of strong low-level mesocyclones of the El-Reno, Oklahoma tornadic supercell correspond well with the observed tornado rotation tracks from the continuous 5-min radar DA system. The ensemble mean QPF and ensemble PQPFs from the radar DA experiments matches reasonably well with the stage-IV analyses in terms of location and amount of rainfall particularly during the first 0-3 h forecast period. The conventional observation assimilation experiment generates noticeably less rainfalls and location errors. The statistical skill scores of FSSs, AUC and the reliability diagram also indicate that the radar DA experiment generates more skillful and reliable rainfall forecasts out to 3-h period. The skill and accuracy of the ensemble decrease during the later 3-6 h forecast period indicating that the impact of radar DA is the greatest during early forecast hours. Overall results demonstrate the potential of a frequently updated, high-resolution ensemble system to extend probabilistic flash flood forecast lead-time and improve accuracy of convective precipitation nowcasting.



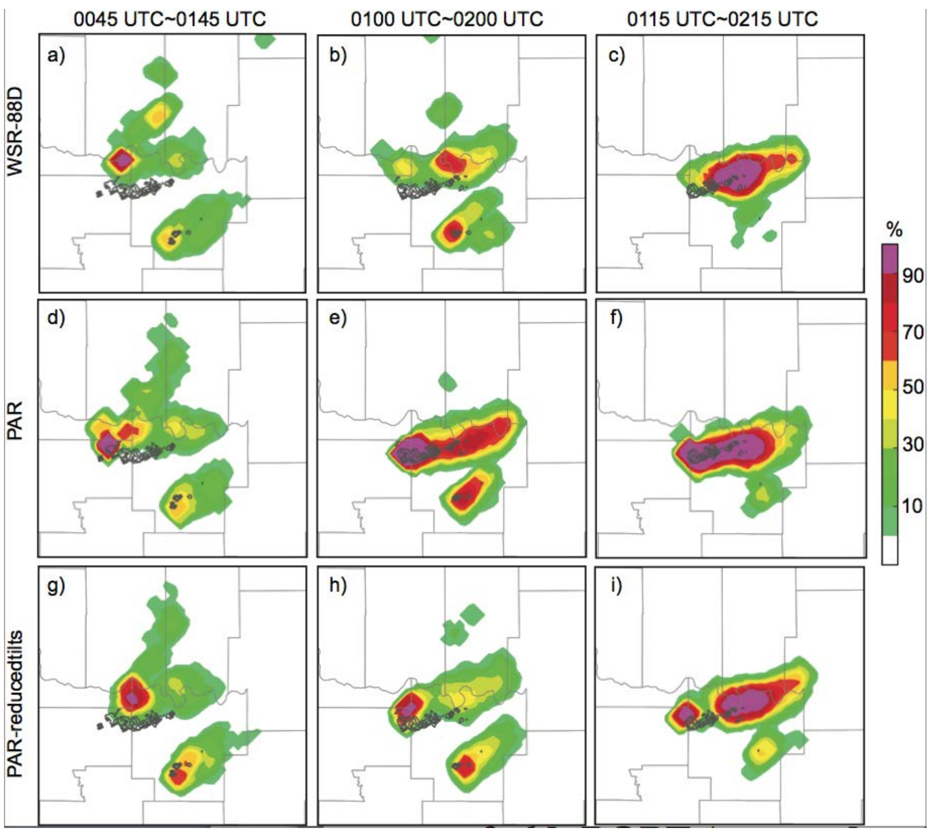
The ensemble probability of rainfall greater than 25 mm (colors, 5% increment) from 0-3 h and 3-6 h accumulated precipitation forecasts initialized at 2300 UTC. The thick black contour is the stage-IV 25 mm precipitation contour. The portion of the domain shown here is over central Oklahoma.

20. Comparison of the Analyses and Forecasts of a Tornadic Supercell Storm from Assimilating Phased Array Radar and WSR-88D Observations

Jing Cheng and Nusrat Yussouf (CIMMS at NSSL), and Youngsun Jung (CAPS)

One unique feature of phased array radar is its rapid scanning capability, which is at least 4-5 times faster than the scanning rate of WSR-88D. To explore the impact of such high-temporal-resolution PAR observations compared to the traditional WSR-88D in severe weather forecasting, several storm-scale data assimilation and forecast experiments are conducted. Reflectivity and radial velocity observations from the 22

May 2011 Ada, Oklahoma tornadic supercell storm are assimilated into the model over a 45-min period using observations from the experimental PAR located in Norman, Oklahoma and the operational WSR-88D (KTLX) within a heterogeneous mesoscale environment and 1-h ensemble forecasts are generated from every 15-min analyses. Results indicate that with only a shorter 30-min assimilation window, the PAR experiment is able to analyze and forecast more realistic storm structure, higher skill scores and higher probabilities of low-level vorticity of the tornadic supercell that align well with the locations of radar-derived rotation compared to the WSR-88D experiment. Continuous assimilation of PAR observations for a longer 45-min time period generates slightly better forecasts compared to the WSR-88D observations indicating the advantage of rapid scan PAR is more advantageous over a shorter 30-min assimilation period. The improved accuracy of the PAR experiment over a shorter assimilation window is mainly due to its high-temporal-frequency sampling capability. These results highlight the benefit of PAR rapid-scan capability in storm-scale modeling that could potentially be used to extend severe weather warning lead times.

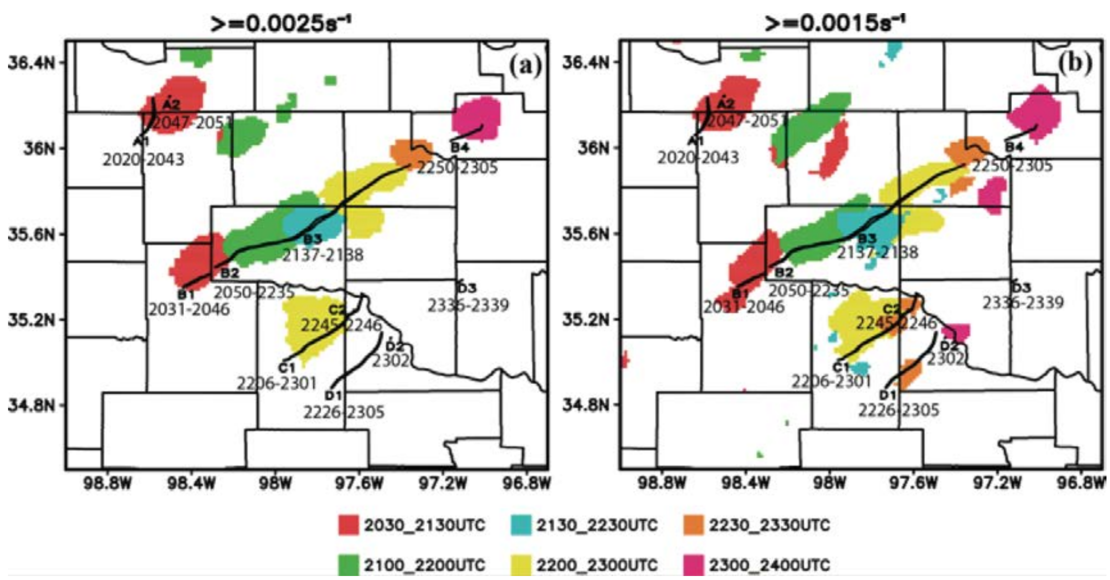


1-hr forecast neighborhood ensemble probability of vertical vorticity exceeding a threshold of 0.002 s^{-1} at the first model level above ground from WSR-88D (top row), PAR (middle row) and PAR-reduced tilts (bottom row) experiments initialized after 15-min (valid 0045 UTC, left column), 30-min (valid 0100 UTC, middle column) and 45-min (valid 0115 UTC, right column) of data assimilation. The gray contours overlaid are the WDSS-II generated KTLX low-level mesocyclone rotation exceeding 0.01 s^{-1} vorticity during the 0-1 h forecast periods.

21. Analyses and Forecasts of the 24 May 2011 Oklahoma Tornadic Supercell Storms using Ensemble of 3DVAR System

Zhaorong Zhuang and Nusrat Yussouf (CIMMS at NSSL), and Jidong Gao (NSSL)

As part of the Warn-On-Forecast initiative, a convective-scale data assimilation and prediction system is developed using the WRF-ARW model and ARPS 3DVAR data assimilation technique and is evaluated using retrospective short-range ensemble analyses and probabilistic forecasts of the 24 May 2011 Oklahoma tornadic supercell outbreak event. A 36-member multi-physics ensemble system provides the initial and boundary conditions for a 3-km convective-scale ensemble system. Radial velocity and reflectivity observations from four WSR-88Ds are assimilated into the ensemble using the ARPS 3DVAR technique. Five data assimilation and forecasts experiments are conducted to evaluate the sensitivity of the system to data assimilation frequencies, in-cloud temperature adjustment schemes, and fixed- and mixed-microphysics ensemble. Results indicate that the experiment with 5-min assimilation frequency quickly builds up the storm and produces more accurate analysis and forecast compared to the 10-min assimilation frequency experiment. The predicted vertical vorticity from the moist-adiabatic in-cloud temperature adjustment scheme is larger in magnitude than that from the latent heat scheme. Cycled data assimilation yields good forecasts where ensemble probability of high vertical vorticity matches reasonably well with the observed tornado damage path. The overall results suggest that the 3DVAR analysis and forecast system can provide reasonable forecasts of tornadic supercell storms.

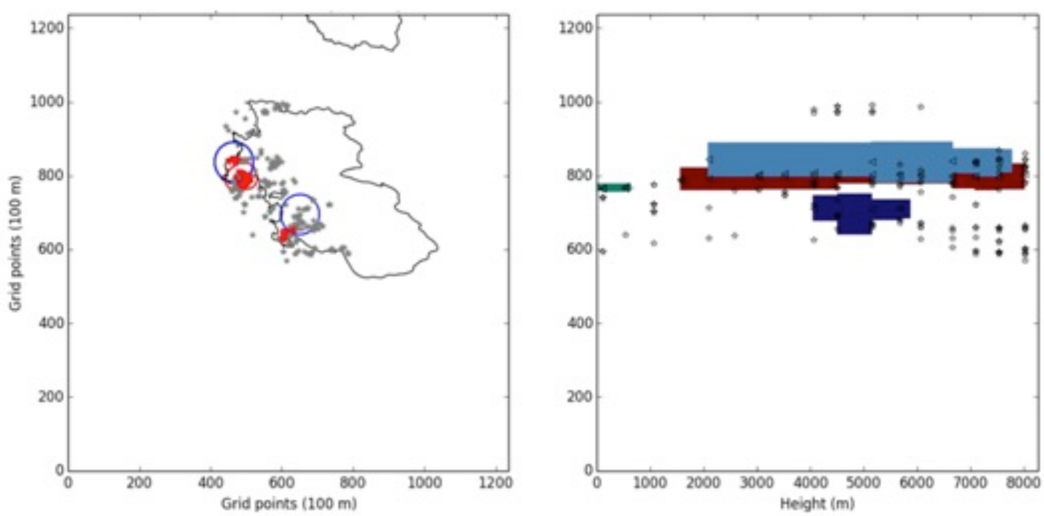


1 hr neighborhood ensemble probability forecasts of vorticity between 0-5 km MSL exceeding 90% for thresholds of (a) 0.0025 s^{-1} within a radius of 9 km and (b) 0.0015 s^{-1} within a radius of 6 km from the MultiExp experiments at every 30-min analyses interval. Overlaid in each panel is the NWS surveyed tornado damage track (black outline) and the start and end times of violent observed tornado tracks.

22. Using Spatiotemporal Relational Data Mining Techniques to Improve Understanding of Tornadogenesis

Amy McGovern (OU School of Computer Science), Corey Potvin (CIMMS at NSSL), and Rodger Brown (NSSL)

Data mining techniques provide a powerful, automated way to analyze numerous analyses or simulations of supercells to discover storm processes and features that are important for tornadogenesis. In particular, spatiotemporal relational techniques allow for automatic discovery of relationships between supercell objects (e.g., mesocyclones) and/or fields (e.g., low-level vorticity) that presage tornado formation. McGovern recently developed one such technique and applied it to various weather phenomena. The technique is currently being adapted for application to a large and growing set of 100-m supercell simulations (>100 storms so far). Preliminary results have validated the methodology and further refinements are being made. The results could be useful for developing new automated tornado detection and prediction techniques for use on Warn-on-Forecast ensemble output.



Mesocyclone and tornado objects automatically extracted from a supercell simulation; these and many other objects are input to the data mining technique. Left: composite 40 dBZ reflectivity (contour), cyclonic mesocyclone (red circle), and anticyclonic mesocyclones (blue circles). Right: zonal composite of tornado (green) and mesocyclones (other colors).

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

Corey Potvin (CIMMS at NSSL), Daniel Betten and Gordon Carrie (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.

The variational dual-Doppler retrieval code developed by Potvin and Shapiro continues to be improved and shared with the research community. Ph.D. student Betten has added new features that better accommodate real mobile radar datasets, and Gordon Carrie has further improved the code structure and resilience. Betten continues to use the technique to analyze thunderstorm datasets collected during the Deep Convective Clouds and Chemistry (DC3) field campaign. The software is also being used by Michael French (Stony Brook University) to analyze a four-radar dataset from the 19 May 2013 Norman-Shawnee tornadic supercell, and by a researcher at the Shanghai Central Meteorological Observatory to investigate damaging wind production in mesoscale convective systems.

24. Investigating Forcing Mechanisms of Internal Rear-Flank Downdraft Momentum Surges in a Supercell

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

Skinner's work retrieving and interpreting perturbation pressure gradients from EnKF analyses of the 18 May 2010 Dumas, TX supercell has been accepted for publication (Skinner et al. 2015). Skinner used the analyzed pressure gradients along with backwards trajectory analyses to illuminate the forcing mechanisms for rear-flank downdraft surges observed in the storm.

25. Improving Trajectory Analyses Using Advection Correction

Stefan Rahimi and Alan Shapiro (OU School of Meteorology), Corey Potvin (CIMMS at NSSL), and Leigh Orf (Central Michigan University)

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. Rahimi's work using Gal-Chen (1982) advection correction to improve trajectory calculations in supercells has been accepted for publication (Shapiro et al. 2015). The technique has been demonstrated using a 50-m simulation of the 24 May 2011 El Reno, OK, tornadic supercell.

26. Variational Multiple-Doppler Vertical Wind Retrievals Within Convective Clouds Observed During (MC3E)

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

Ph.D. student Kirk North performed variational dual-Doppler wind retrievals of Midlatitude Continental Convective Clouds Experiment (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. In addition, collocated vertical profiler observations of vertical wind provided a rare opportunity to evaluate the variational dual-Doppler retrieval technique relative to traditional approaches.

Publications

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Awards

Corey Potvin (CIMMS at NSSL) was nominated for 2015 Presidential Early Career Award for Scientists and Engineers (PECASE)

NSSL Project 4 – Hydrologic Modeling Research

NOAA Technical Lead: Jonathan Gourley (NSSL)

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

Funding Type: CIMMS Task II

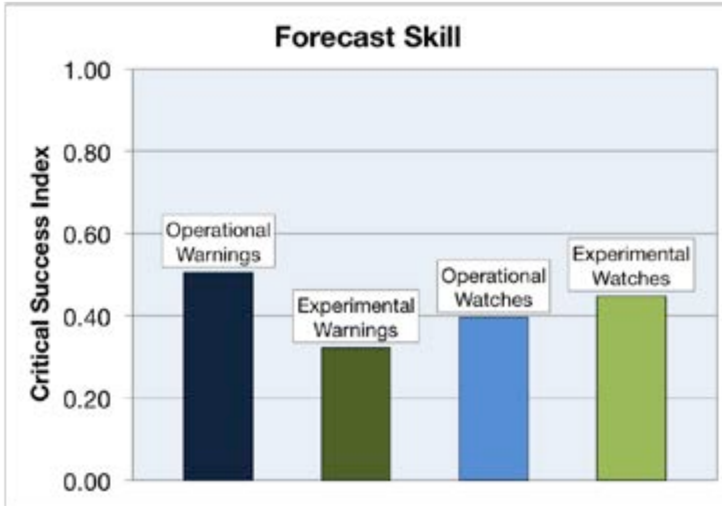
Accomplishments

1. Demonstrate Real-Time Flash Flood Predictions Across the Conterminous U.S.

Jonathan Gourley (NSSL), and Humberto Vergara-Arrieta, Robert Clark III, Zachary Flamig, Elizabeth Argyle, and Steven Martinaitis (CIMMS at NSSL)

The research team was awarded funds for a MRMS hydrologic experiment within the framework of the Hazardous Weather Testbed in order to evaluate the suite of products comprising the Flooded Locations and Simulated Hydrographs (FLASH) project. Throughout the month of July 2014 a total of 17 NWS forecasters travelled to the HWT in Norman, OK and issued experimental flash flood watches and warnings based on the developmental flash flood products. These activities were coordinated with the Weather Prediction Center's Flash Flood and Intense Rainfall Experiment.

Results from the experiment indicated that forecasters had increased confidence in the issuance of their products given that there were multiple sources of information provided about the possibility of imminent flash flooding rather than just one. An objective evaluation of forecaster skill indicated that the experimentally issued flash flood watches were slightly more skillful than those the operational counterparts, while the flash flood warnings were less skillful (figure below). The latter result is an expected one because the forecasters were competing with products that were issued by offices with local knowledge of flood-prone regions. Nonetheless, the new information that was provided to the forecasters yielded improvements to the forecast products. Moreover, the forecasters provided valuable feedback to the development team, and the experiment produced training for the forecasts so that they will be prepared to use the FLASH products when they are transitioned to operations in the near future.



Experimental flash flood watches and warnings that were issued during the testbed experiment in comparison to their operational counterparts.

2. Compare Skill of FLASH Model Outputs to Operational Flash Flood Guidance System

Jonathan Gourley (NSSL), and Humberto Vergara-Arrieta, Zachary Flamig, Galateia Terti, and Ke Zhang (CIMMS at NSSL)

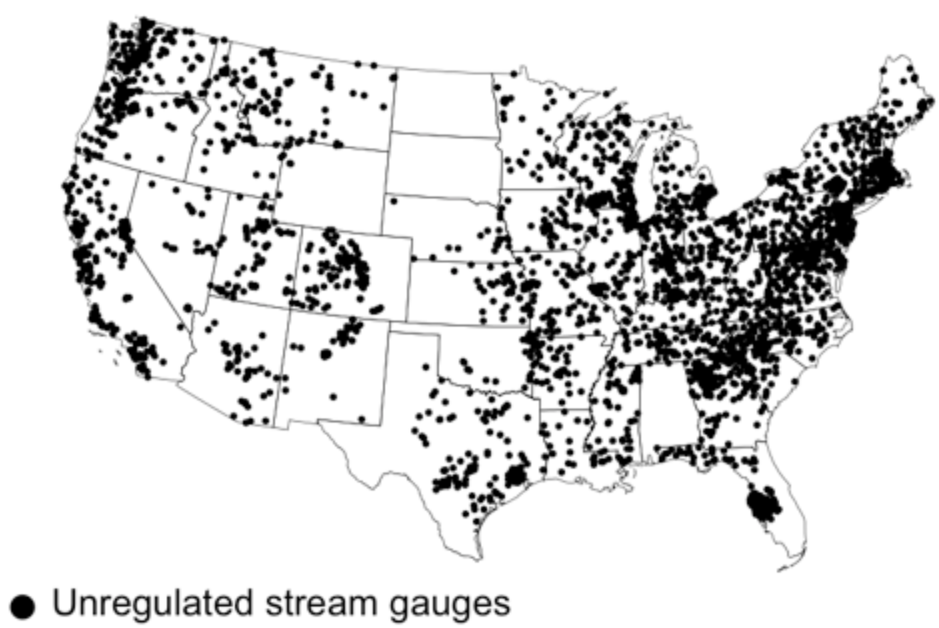
The evaluation previously performed on 18 basins across the Conterminous United States in a pilot study has been extended to a larger set of locations where the United States' Geological Survey (USGS) stream gauge observations are available. Stream gauges on unregulated catchments under 1000 km^2 were selected for the purpose of the evaluation. This amounts to a total of 2,680 catchments over CONUS (see first figure below). The Coupled Routing and Excess Storage (CREST) distributed hydrologic model embedded in FLASH was employed to generate simulations of streamflow for the period of January 2002 to December 2011 to assess the skill of FLASH's simulations of peak flow. MRMS data from the re-analysis effort by NSSL and the National Climatic Data Center were used as forcing of the hydrologic model. A total of 75,496 events were identified from the 10-year period, which are used for the simulation diagnostic analysis.

Streamflow errors were studied at the event scale with particular focus on the peak flow magnitude and timing. The second figure below presents a summary of the peak flow simulation skill for all catchments and all events. It can be observed that the peak timing is remarkably skillful (panel b). The peak magnitude, on the other hand, tends to be underestimated (panel a). The spatial distribution of the peak magnitude errors (panel c) points to topography as an important factor on the skill of simulated peak flow.

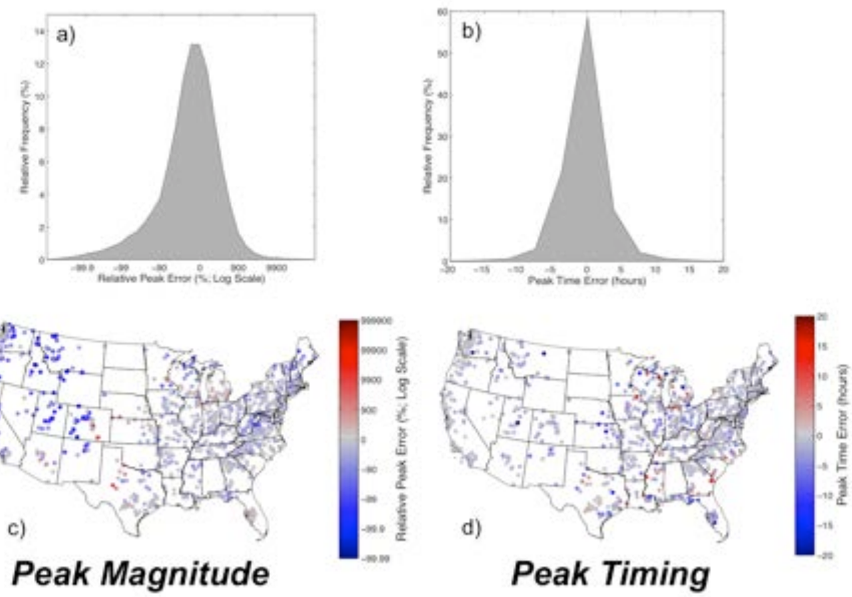
Associations between streamflow errors and factors such as hydro-climatology, radar coverage, basin geomorphometry, pedology, and land cover/use were explored. It was

found that radar coverage and significant snowmelt processes could explain the significant underestimation of peak flow in regions of complex terrain. Furthermore, the statistical multi-dimensional modeling of peak flow errors shows that other geophysical factors could also provide explanatory information. The third figure below shows a comparison between simulated and observed peak flows. Panel a) of the figure shows the comparison using peak flow simulations from the original run. Panel b) shows a conditional bias correction based on the statistical multi-dimensional modeling of peak flow errors. Furthermore, panel c) presents the prediction of the peak flow error median for CONUS, which shows consistent patterns of peak flow underestimation over complex terrain. Additionally, it shows patterns of peak flow overestimation, which was related to the impervious surface ratio (panel d).

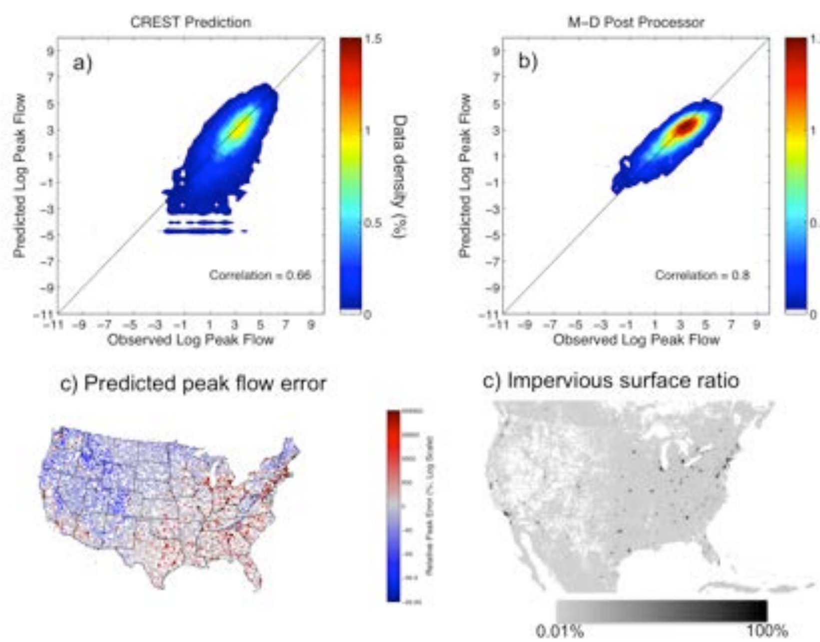
Results from this evaluation highlight the need for incorporation of snowmelt processes representation and revision of some model parameters. Likewise, the need for quality control mechanisms on the forcing is evidenced. Ongoing efforts focus on the implementation of the SNOW17 model component to improve the skill of the hydrologic model in snow dominated basins.



USGS stream gauge stations of unregulated catchments over CONUS utilized in the error evaluation.



Summary of peak flow simulation for the selected catchments: a) histogram of relative peak error; b) histogram of peak time error; c) spatial distribution of median relative peak error over CONUS; and d) spatial distribution of peak time error over CONUS.



Peak flow comparison and modeling: a) scatter density plot of simulated vs. observed peak flows; b) scatter density plot of simulated vs. observed peak flows after bias correction; c) predicted median peak flow error over CONUS; and d) raster grid of the imperviousness ratio model parameter.

Publications

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

NOAA Technical Leads: Don MacGorman, Ted Mansell, and Conrad Ziegler (NSSL), and Mark DeMaria (NOAA NHC)

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

Funding Type: CIMMS Task II

Objectives

Continue to maintain, improve, and optimize the new explicit WRF lightning model (E-WRF). An auxiliary goal was to subsequently evaluate and document the performance of the new model for one sub-kilometer simulation of a retrospective tropical cyclone case (TC) making landfall in the US. This work is one of the chief milestones of Year 1 of a 3-year GEOS-R3 proposal in collaboration with the National Hurricane Center to improve intensity forecasts of TCs. Another goal was to simultaneously convert E-WRF into a user-friendly version for official release in WRF 3.7.x bundle and dissemination to interested groups worldwide.

Accomplishments

1. Improve and Optimize E-WRF for Sub-Kilometer Resolution Simulations of Tropical Cyclones

Alexandre Fierro (CIMMS at NSSL), Don MacGorman, Ted Mansell, and Conrad Ziegler (NSSL), Mark DeMaria (NOAA NHC), and Andrea Schumacher (CIRA-Colorado State University)

During the course of FY14, a more realistic three-dimensional discharge code initially developed at NSSL was successfully implemented into E-WRF and optimized for the

targeted sub-kilometer (250-500-m) scales simulations forming the building block of the GEOS-R3 proposal. The line of proposed research builds upon recent TC modeling research and upon the previous development involving several collaborating researchers at the National Severe Storms Laboratory (NSSL) to implement explicit electrification physics and lightning within the WRF-ARW model.

Last fiscal year, it was proposed to investigate lightning in numerical simulations of TCs and to use the relationships tested in these simulations and verified by comparison with TC observations to develop total lightning predictors that can be used to assimilate total lightning observations directly into NHC's statistical prediction model (SHIPS). Total lightning is emphasized because it is much better correlated to convective strength than cloud-to-ground lightning is. Lightning information is particularly critical in regions where radar data are scarce, such as over oceans where all TCs develop and eventually intensify. Focus will first be placed on archived US landfalling TCs. The simulated lightning will be evaluated against total lightning observations from the EarthNetworks® Total Lightning Network (ENTLN).

The targeted simulations were successfully completed on the HP resources hosted at the Texas Advanced Computing Center (TACC), which access was obtained through a full Research Allocation Proposal submitted to the Extreme Science and Engineering Discovery Environment (XSEDE). The proposal was awarded for a 1 yr period starting in July 2014. During the course of this FY, several simulations were conducted with the results from one realization thoroughly analyzed and documented in a manuscript that was recently published in the Journal of Atmospheric Sciences.

Future plans in this topic include two separate visits at NHC and CIRA (with formal seminars) to discuss the implementation on the key results of this work into SHIPS and/or how to improve/complete (convolve) the results based on (with) parallel observational statistical work conducted at CIRA.

This fiscal year, we submitted a user-friendly version of E-WRF (Fierro et al. 2013, 2015) to the WRF developers for official release into the 3.7.1 or 3.7.2 bundle. The package and necessary libraries are made publicly available on the Sourceforge.org repository. Since its implementation in 2013, the code has been disseminated to various interested groups worldwide (the last being in South Korea). I have received formal invitations (i.e., expenses covered) to visit a group in China and Brazil in that regard – but was inclined to decline the invitations owing to time constraints.

Publications

Fierro A. O., 2014: Relationships between California rainfall variability and large-scale climate drivers. *International Journal of Climatology*, **34**, 3626-3640. doi:10.1002/joc.4112.

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2. Physical Process Studies

Chris Karstens (CIMMS at NSSL)

Expanding upon efforts from 2008 and 2014, the 2015 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted in the Experimental Warning Program (EWP) during the weeks of 4-8 May, 19-23 May, and 1-5 June. In addition, a simultaneous experiment with emergency managers (3 per week) was conducted to gain an understanding of how end-users interpret and use the probabilistic information for (simulated) decision-making. Two forecasters participated each week by issuing probabilistic forecasts for severe convective phenomena, including any-severe (tornado, wind, hail) and specifically for tornado, in the 0-2 hour timeframe using a prototype web tool. Automated, object-based guidance was provided to the forecasters in real-time for each of the aforementioned probabilistic forecast types. The primary objective of this experiment was to develop an understanding how forecasters use the PHI system with the automated guidance by varying the forecasters' level of interactivity with the guidance information.

To achieve the objective of this experiment, three experiment strategies were developed and tested with forecasters: the loop, out of the loop, and in the loop. First, "the loop" strategy involved removing the automated, object-based guidance from the forecasters. Thus, the forecasters had to rely purely on their intuition for judgments under uncertainty. The second "out of the loop" strategy is the opposite of the first, in that forecasters are completely removed from the decision-making process. Thus, all forecasts were being generated by the automated system. The third "in the loop" strategy represents a mixture of the first two strategies, by giving the forecasters full access to the automated guidance for assistance in decision making. In each strategy, 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.

Each strategy produced interesting preliminary results. Results from the first "the loop" strategy reinforced findings from the 2014 HWT PHI experiment. The so called "on-the-fence" decision to warn or not warn is effectively removed from the forecaster because

of the ability to issue information for storms based on their current and projected likelihood of producing severe weather. However, this liberating effect introduced a paradoxical increase in workload. Forecasters felt taxed when having to manage in excess of 4-5 hazard areas simultaneously. To speed up the pace of work, forecasters resorted to workload simplifiers, such as simple object geometries (analogous to WarnGEN-like warning polygons) and a general dearth of communication.

Results from the second “out of the loop” strategy revealed that forecasters quickly became frustrated with the inability to intervene with the automated system. Forecasters want to be part of the forecast process. In addition, with the only means of communication being routed through NWSChat, the emergency managers were forced to interrogate the storms themselves, relying on what training and intuition they had received or developed about radar meteorology. In effect, this strategy puts end-users in the position equal to that of a forecaster (i.e., warning decision makers). This may work for savvy end-users, but most Emergency Managers felt uncomfortable in this position.

Results from the third “in the loop” strategy showed that, early on, forecasters had difficulty interacting with the automated guidance. In many instances, forecasters would issue a PHI object for a storm or hazard at approximately the same time as the automated system, thus resulting in two, often similar, forecasts for the same storm or hazard. After a few instances of these types of events, forecasters would frequently raise the thresholds of the automated system to block such guidance from entering the forecast process. In essence, forecasters gravitated back toward the first “the loop” strategy, thus reintroducing the aforementioned workload complications.

After observing and taking recognition of this effect, the facilitators developed a fourth strategy, a hybrid of the third “in the loop” strategy. This new strategy required the forecasters to allow the automated system to generate PHI objects, for any-severe, within forecaster-defined severity thresholds. Forecasters could optionally override specific object attributes, including the object speed, direction, duration, discussion, and probability trend, in addition to allowing or blocking PHI objects completely. For tornado, the first “the loop” strategy was employed, as the automated guidance, still premature, had far too much false detection, and there are often fewer tornado hazards to manage simultaneously than any-severe.

Results from the fourth hybrid “in the loop” strategy suggest that this was the optimal strategy, for both forecasters and emergency managers. Forecasters could leverage the rapid mechanical abilities of object generation from the automated system, thus prioritizing their decision making on a storm’s or hazard’s severity likelihood, movement, and longevity. These decisions were expressed in the PHI object attributes directly and in the object discussion (i.e., communication), thus working toward messaging consistency. The emergency managers appreciated the rapid flow information and updates enabled by this hybrid strategy. However, in at least one instance, a hazard was not collocated with the automated system’s object (surging winds ahead of a convective line). Forecasters communicated this observation, along with an estimation

of the hazard intensity, via the object discussion, and emergency managers found this information to be effective.

The preliminary results of this experiment have highlighted areas needing further research and development. First, the communication from the forecaster to end-users via the prototype PHI tool is currently unstructured, given as a blank text box open for interpretation. It became clear that some forms of communication were found to be effective, while others were not. Therefore, we plan to use the information and data collected from the experiment to develop a set of communication protocols for various hazard situations, and implement tools that allow forecasters to quickly leverage such protocols in the next HWT experiment. Second, we plan to make improvements in the automated guidance, such as including more sources, improvements in these sources (understanding and reliability), presentation within the tool, and refinements of forecaster interactivity. Third, the notion of lead-time and its meaning will be of primary focus during the follow-up emergency manager experiment, along with testing the receipt of the newly developed communication protocols.

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 4-June 5). Forecasters working on the NSSL desk 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. On the SPC desk, forecasters issued 4-hour probabilistic outlooks for individual hazards (tornado, wind, and hail) from 18-22 UTC and 22-02 UTC and within 25 miles of a point. At both desks, updates to the morning forecasts were conducted in the afternoon. Forecasters were given the ability to create their own probabilistic forecasts, with tool functionality similar to that of NMAP (GEMPAK software), by examining experimental guidance from convection-allowing models and ensembles. 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.

Publications

Karstens, C. D., G. Stumpf, C. Ling, L. Hua, D. Kingfield, T. M. Smith, J. Correia, Jr., K. M. Calhoun, K. L. Ortega, C. J. Melick, and L. P. Rothfusz, 2015: Evaluation of a probabilistic forecasting methodology for severe convective weather in the 2014 Hazardous Weather Testbed. *Weather and Forecasting,* in press.

3. Forecast and Model Evaluation during the 2015 HWT Spring Forecast Experiment

Kent Knopfmeier (CIMMS at NSSL), and James Correia, Jr. and Chris Melick (CIMMS at SPC)

Objectives

The Experimental Forecast Program (EFP) of the NOAA HWT conducts a collaborative

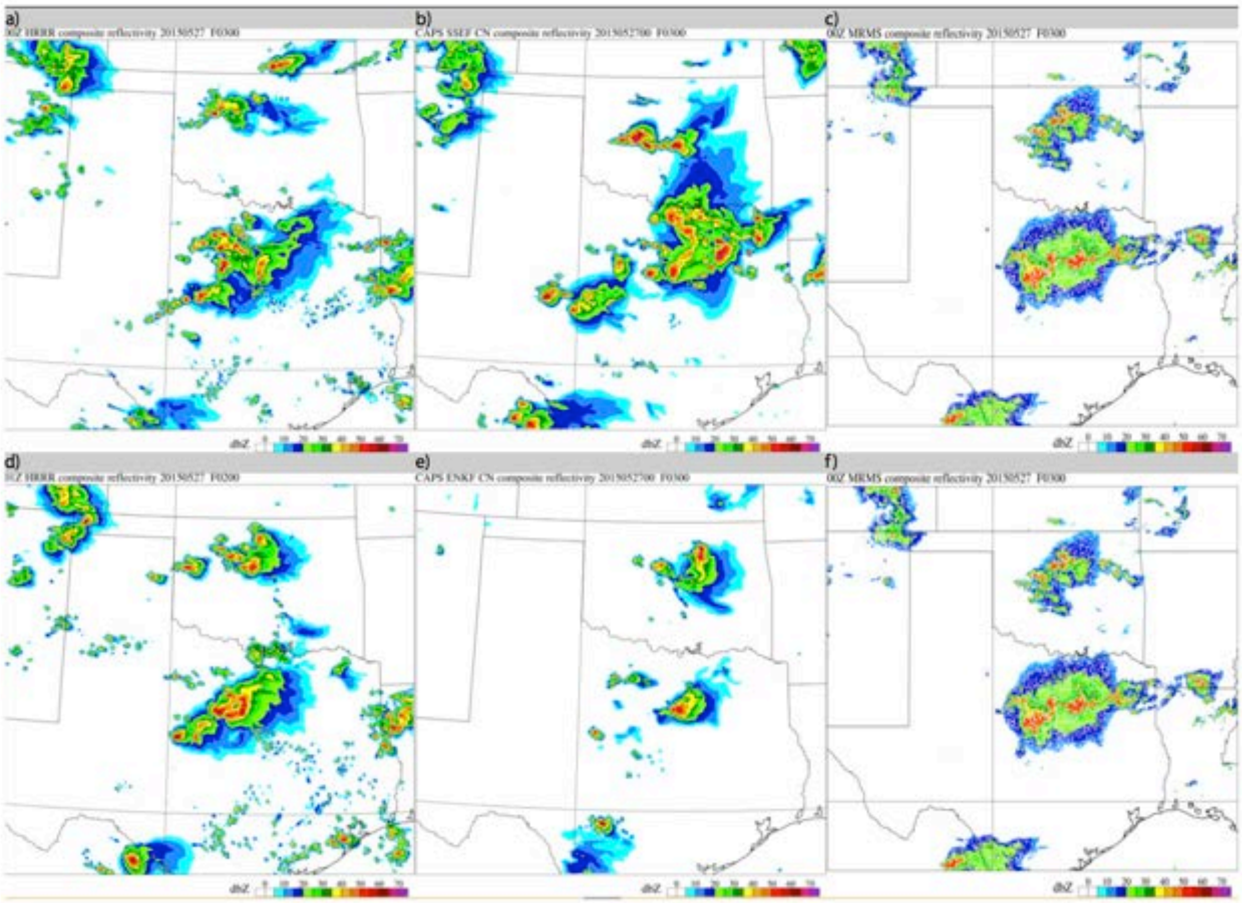
experiment each spring to test emerging concepts and technologies designed to improve hazardous convective weather prediction. Accelerating the transfer of new tools from research to operations, inspiring new ideas for operationally relevant research, and to identify and document sensitivities and the performance of convection allowing models (CAMs; 1-4 km grid spacing) are the primary goals of the EFP.

Accomplishments

Forecasts generated manually by participants and automatically from numerical models were evaluated each day using both subjective and objective methods. Participants compared forecasts subjectively to observed radar reflectivity, severe weather reports, NWS warnings, and radar-estimated hail sized and rotation tracks over the forecast time periods to determine the relative skill of the both the model and human forecasts. Objective measures such as the Critical Success Index (CSI) and Fractions Skill Score (FSS) were also computed for the forecasts, and participants' subjective impressions of skill were compared to them as a means to explore the utility of verification metrics in assessing forecast skill for long and short periods.

As noted in the objectives, evaluation of new numerical modeling systems is a key component of the SFE. Ensemble forecasting systems at convection-allowing grid spacings that employ predominantly an ensemble Kalman filter (EnKF)-based data assimilation procedure are becoming more prevalent owing to increasing computer speed and resources. In addition to evaluating ensembles (i.e. CAPS SSEF/EnKF, AFWA, SSEO, and NCAR) for their efficacy during the Day 1 (i.e., 12 to 36 hour lead time) forecast period, their performance during the first 6-h is also a topic of interest. To that end the CAPS SSEF (3DVAR-based) and EnKF were evaluated on how each depicted storms and their subsequent evolution during the first 6-h of the forecast. Probabilistic forecasts of simulated reflectivity and other convection-related fields were compared to diagnose differences in forecast skill and ensemble dispersion.

The collaboration with the UK Meteorological Office continued during the 2015 SFE with evaluations of the UK Met Office 2- and 1-km grid spacing deterministic numerical models. Simulated reflectivity from both of these models was compared to the NSSL-WRF 4-km model over the Day 1 and Day 2 forecast periods. Additionally, environmental soundings generated from the UK Met Office models were compared to those from the NSSL-WRF in pre-convective regions near observed atmospheric sounding locations across the US. In past experiments, the UK Met Office models were much more accurate in depicting the sharp gradients in temperature and moisture at the boundary layer/elevated mixed layer interface when compared to the NSSL-WRF.



Simulated composite reflectivity (dBZ; see label bar) valid at 0300 UTC 27 May 2015 from the a) 0000 UTC initialization of the operational High Resolution Rapid Refresh (HRRR) model, the b) CAPS SSEF (3DVAR-based) "control" ensemble member, the d) 01000 UTC initialization of the operational HRRR model, and the e) CAPS EnKF-based "control" ensemble member. c) and f) are the Multi-Radar Multi-Sensor (MRMS) observed composite reflectivity valid at 0300 UTC 27 May 2015.

4. 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.

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

Kristin Calhoun and Darrel Kingfield (CIMMS at NSSL), and Donald MacGorman (NSSL)

NOAA Technical Lead: Dan Lindsay (NOAA/NESDIS)

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

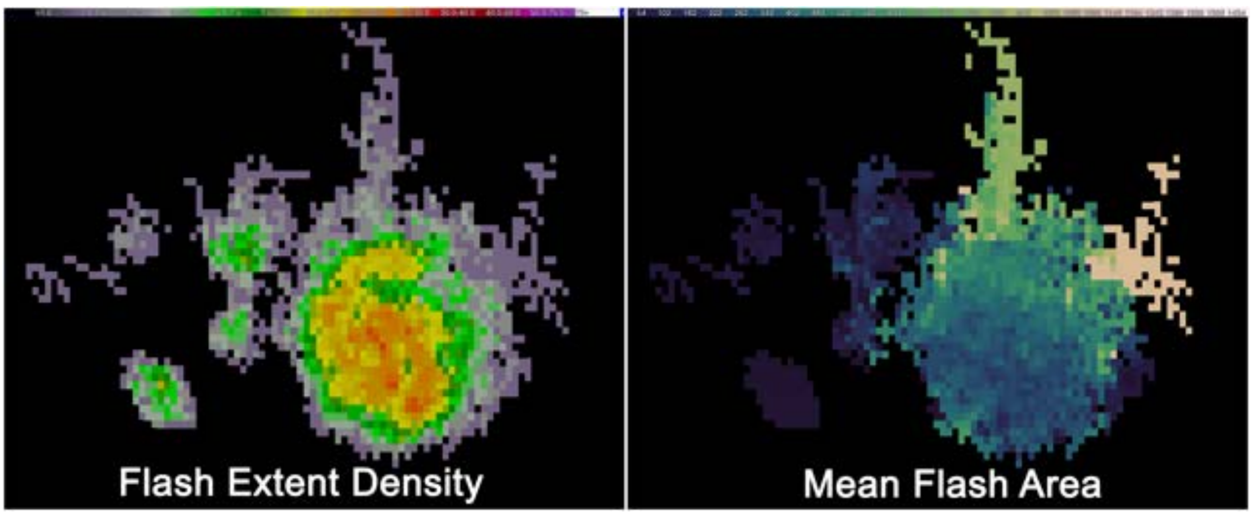
The GOES-R Geosynchronous Lightning Mapper (GLM) will provide information about convective storms across large territories, including typically data sparse regions such as oceans and mountainous terrain. Additionally, lightning data will be available with a higher temporal resolution than that of the radar network once the GLM 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 could be relevant to operational forecasters. These data can be analyzed to determine what criteria for lightning data are most indicative of convective development and severe weather potential across a multitude of storm types.

The team worked with Dr. Eric Bruning at Texas Tech University alongside forecasters from the NWS Forecast Office in Lubbock, Texas, to generate and integrate real-time 1km lightning products into the Advanced Weather Interactive Processing System-2 (AWIPS-2). AWIPS-2 is the weather forecasting, display and analysis package currently being used by the NWS and the integration of the lightning data into operations provides a preview of how lightning data from the GLM could be relevant to operations.

Two of these products – Flash Extent Density and Flash Initiation Density – are gridded visualizations of total lightning data from Lightning Mapping Arrays (LMA) and have been previously evaluated in the Hazardous Weather Testbed through the GOES-R proving ground during multiple experiments (left half of figure below). These products are created using algorithms developed within the Warning Decision Support System – Integrated Information (WDSS-II). WDSSII identifies a group of VHF sources as a flash

by using thresholds for the time and distance between sequential mapped points; these WDSSII algorithms were updated this year to clarify possible errors in time integration and spatial weighting. A third new product was developed within WDSSII and integrated into AWIPS-2 during spring of 2015, the experimental Flash Area (right half of figure below) originally conceived by Drs. Bruning and MacGorman.

Research using LMA data has shown that small, compact flashes are mostly associated with robust or developing convection and updrafts. As thunderstorms mature and reach the subsequent dissipation stage, the flash area starts to increase. The new flash area product could tell forecasters more about storm development and intensity. The transfer of these products to operations will provide developers, researchers and forecasters with the opportunity to learn more about how total lightning products can be utilized in the forecast and warning decision process. This work benefits operational forecasters, highlights research to operations transitions, and supports NOAA’s work to evolve the NWS.



An example of the lightning products created for NWS using WDSSII and AWIPS2. This is a comparison of the 2000 UTC 1 min flash extent density (left) and mean flash area (right) for a supercell over Kingfisher County, Oklahoma on 16 May 2010. This storm produced a wide swath of giant hail (>2″ in diameter), causing severe damage to buildings and vehicles in its path.

CIMMS Task III Project – Lightning Mapper Array Operations in Oklahoma and the Texas Gulf Coast Region to Aid Preparation for the GOES-R GLM

Don MacGorman (NSSL), Stephanie Weiss, Dennis Nealson, and Sean Waugh (CIMMS at NSSL), Ben Trabing, Rachel Miller, and Michael Biggerstaff (OU School of Meteorology), Martin Uman, Doug Jordan, and John Pilkey (University of Florida and International Center for Lightning Research and Testing), and Douglas Kennedy and Sherman Fredrickson (NSSL)

NOAA Technical Lead: Steve Goodman (NOAA/NESDIS)

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

Funding Type: CIMMS Task III

Objectives

This project had three primary objectives: (1) maintain and continue operating the Oklahoma Lightning Mapping Array; (2) acquire electric field and microphysics data via balloon soundings in collaboration with Dr. Biggerstaff (mobile polarimetric radar) and with the International Center for Lightning Research and Testing at Camp Blanding, Florida (triggered lightning facility); and (3) subcontract to Richard Orville at Texas A&M to provide partial funding for their continued operation of the South Texas Lightning Mapping Array, which covers a region around Houston, Texas.

Accomplishments

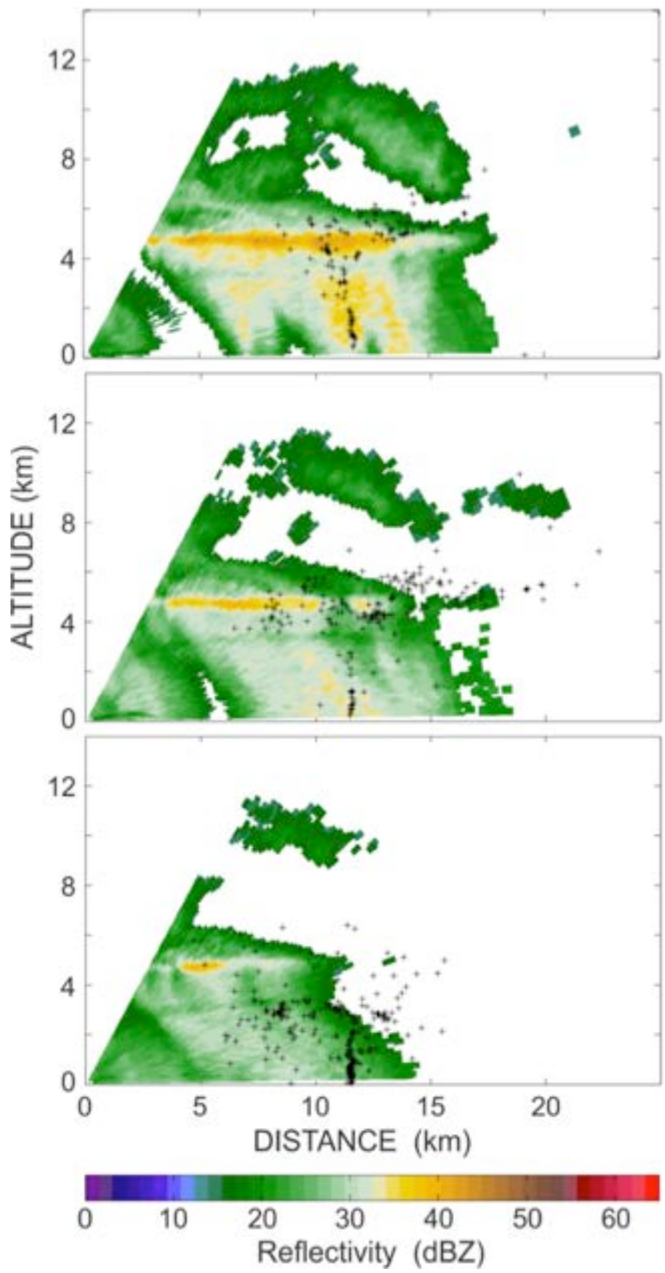
CIMMS continued maintaining and operating the Oklahoma Lightning Mapping Array in collaboration with NSSL. Dr. Orville continued operating the South Texas Lightning Mapping Array. Data from both Lightning Mapping Arrays were provided to those developing and testing algorithms for the GOES-R Geosynchronous Lightning Mapper (GLM) and to the NSSL Hazardous Weather Testbed and GOES-R Proving Ground, in which real-time applications of an LMA proxy for GLM data are being investigated.

Stephanie Weiss continued investigating how to compensate for range-dependent bias in data from Lightning Mapping Arrays (LMAs), which provide proxy GLM data for present use and after the launch of GOES-R will be used to provide verification for GLM data. She investigated several techniques. The two that she has identified as performing well and producing similar results are (1) statistically applying signal amplitude filters to maintain the signal strength spectrum of the farthest analyzed range in the data used in any study of the VHF sources mapped by LMAs and (2) grouping VHF sources into flashes and then using only the flash data in determining variations in the data with range. Because each flash typically produces VHF sources with a spectrum of signal amplitudes, the two filters have a similar effect in removing range bias in the data. She has prepared a draft manuscript describing these results, intended for eventual publication in a refereed journal.

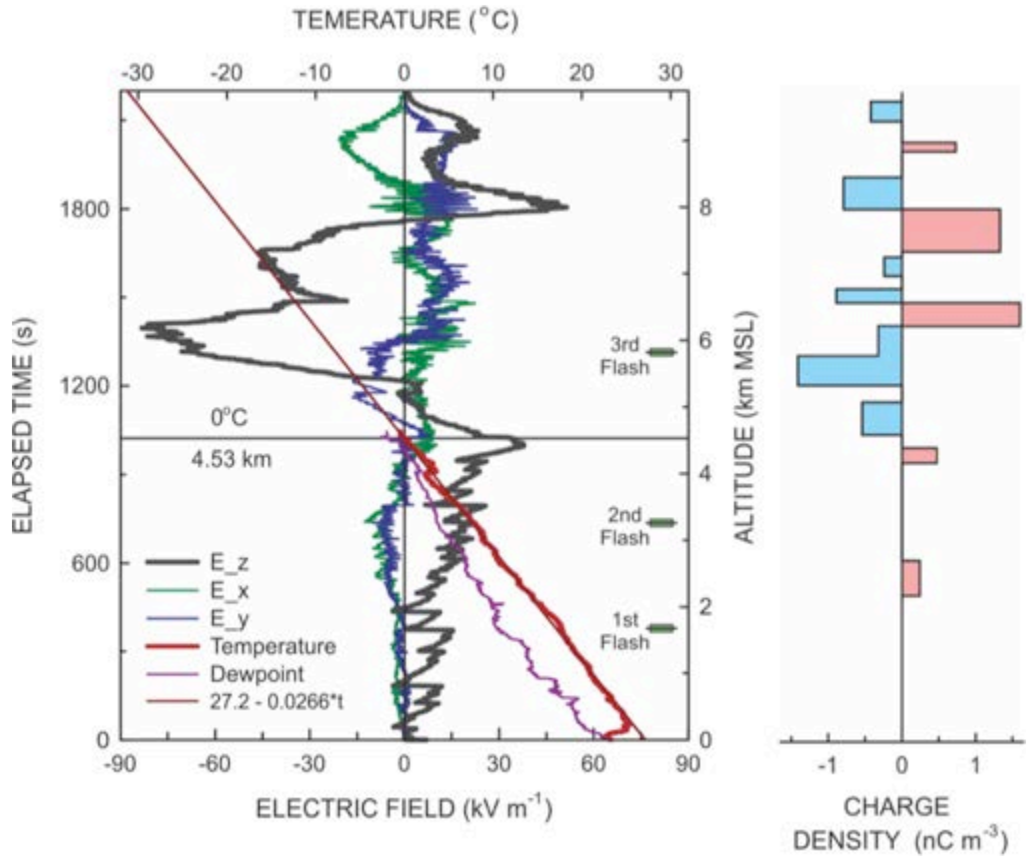
This was the second and final year in which grants funded mobile ballooning near the International Center for Lightning Research and Testing in Camp Blanding Florida, to better understand the meteorology and characteristics of the lightning to be mapped by the GOES-R GLM. The project had three objectives: (1) determine why the channels of triggered lightning flashes in Florida propagated vertically into storms and then turned horizontal near the melting level; (2) begin investigating the vertical distribution of electric fields and charge in storms in the southeastern United States; and (3) acquire microphysics data that can be used to interpret polarimetric radar data and to verify hydrometeor classification schemes used with polarimetric radar data.

Electric field profiles from the first year in Florida were analyzed and have been published (MacGorman et al. 2015). In one case, lightning flashes were triggered near the sounding location during the balloon flight. The sounding showed that the transition from vertical channel structure entering the cloud to horizontal channel structure near the melting level occurred because the lightning was propagating through a layer of negative charge that was near the melting level (first two figures below). Three dissipating storms observed on different days all had negative charge near the melting level, but a growing mature storm had positive charge there (second two figures below).

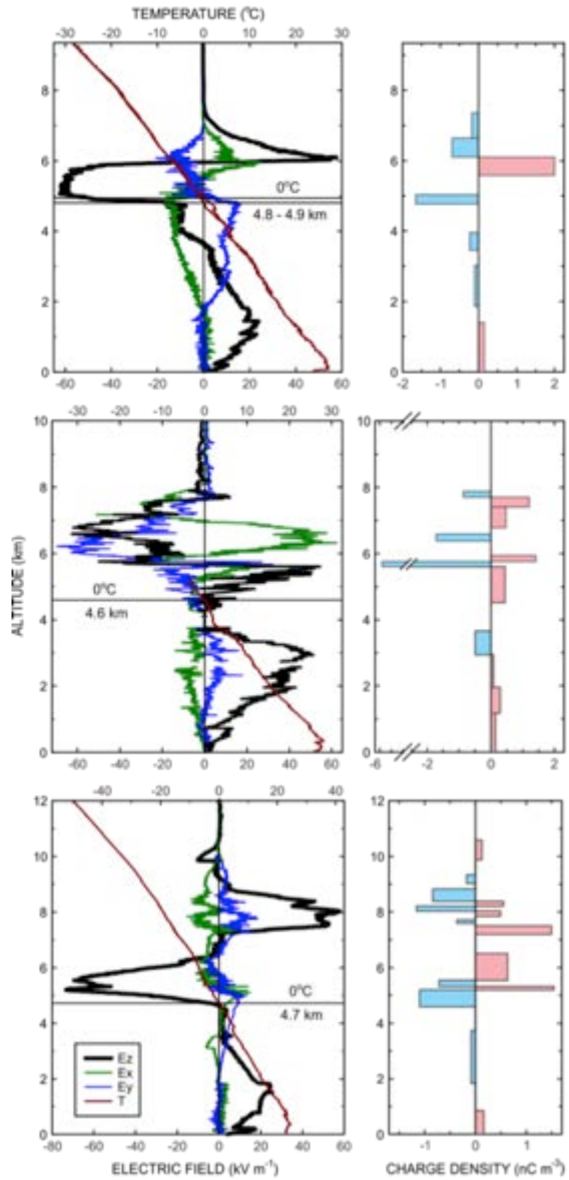
Microphysics data were also collected from several soundings. The new balloon-borne instrument employed a high-definition video camera to provide images of precipitation particles from which size spectra could be obtained for rain and to identify the various habits and concentrations of frozen precipitation. The intake to the imaging area also had a modified Parsivel laser disdrometer to provide independent estimates of particle size and number and also to provide data for some particles too small to be seen in imagery. The instrument, calibration tests, and an automated analysis package are described in Waugh et al. (2015). Data from Florida are still being analyzed and will be incorporated in Sean Waugh's dissertation, with completion expected in calendar 2016. In collaboration with Dr. Biggerstaff, these data also are being compared with polarimetric radar signatures from storms in Florida, in part to identify what is causing an unusual signature he observed in stratiform precipitation regions.



Locations of VHF sources for the three triggered flashes on 1 August 2013 relative to reflectivity from the 5-cm wavelength SMART-R radar [Biggerstaff et al. 2005]. The vertical projection is along the 9.6° azimuth from the radar through the lightning strike at the ICLRT. Note the bright band (yellow shading) near 4 km MSL, which indicates melting particles. Values of ρ_{hv} (not shown) indicate mixed-phase particles consistent with melting in roughly the same region. Triggered flash at (top) 1919 UTC, (middle) 1925 UTC, and (bottom) 1934 UTC. In contrast with the first two flashes, the third triggered flash had only an initial stage and did not reach the melting level or have any return strokes. Data were available from six stations, but noise caused many mapped VHF source locations to use data from only five.



Electric field as a function of height and elapsed time from the sounding launched at approximately 1912 UTC on 1 August 2013. Radiosonde data were lost a short distance above the 0°C isotherm, but the electric field meter continued operating. Heights and temperatures at later times were extrapolated by using a linear fit to the rate of change with time at lower altitudes. The approximate height of the balloon at the time of each flash is indicated by a green dash. Abrupt changes in the electric field magnitude are due to lightning flashes. Charge density estimates (right panel) were obtained by applying a one-dimensional approximation of Gauss's Law to a piecewise linear fit to the E_z profile and involved a somewhat subjective choice of endpoints. Although this affected the charge density magnitudes and heights to some degree, the gross structure inferred from the larger changes in E_z is robust.



Electric field soundings on (top) 10 August, (middle) 12 August, and (bottom) 15 August in 2013. Altitude is relative to mean sea level. The sounding on 12 August had some data gaps. Note that E_z in both the top and bottom panels, as in Figure 2, has a large negative slope just above the 0°C isotherm, due to the balloon passing through a layer of substantial negative charge density in these dissipating storms. E_z at lower altitudes has smaller slopes and smaller maximum magnitudes indicating less charge there. The vertical profile of E_z in the middle panel is much different, with larger changes at altitude below the 0°C isotherm and a substantial region of positive charge, instead of negative charge, just above the melting layer. Charge density estimates (right panels) were obtained by applying a one-dimensional approximation of Gauss's Law to a piecewise linear fit to the E_z profile and involved a somewhat subjective choice of endpoints. Although this affected the charge density magnitudes and heights to some degree, the gross structure inferred from the larger changes in E_z is robust.

Publications

MacGorman, D. R., M. I. Biggerstaff, S. Waugh, J. T. Pilkey, M. A. Uman , D. M. Jordan, T. Ngin, W. R. Gamerota, G. Carrie, and P. Hyland, 2015: Coordinated lightning, balloon-borne electric field, and radar observations of a triggered lightning flash in North Florida. *Geophysical Research Letters*, **42**, 5635–5643, doi:10.1002/2015GL064203.

Waugh, S., C. L. Ziegler, D. R. MacGorman, S. E. Fredrickson, D. W. Kennedy, and W. D. Rust, 2015: A balloon-borne particle size, imaging and velocity probe for in situ microphysical measurements. *Journal of Atmospheric and Oceanic Technology*, **32**, 1462-1580, doi: 10.1175/JTECH-D-14-00216.1.

CIMMS Task III Project – Using Total Lightning Data from GLM/GOES-R to Improve Real-Time Tropical Cyclone Genesis and Intensity Forecasts

Alexandre Fierro (CIMMS at NSSL), Ted Mansell, Conrad Ziegler, and Don MacGorman (NSSL), and Andrea Schumacher and Renate Brummer (CIRA-Colorado State University)

NOAA Technical Lead: Mark DeMaria (NOAA/NCEP)

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

Funding Type: CIMMS Task III

Objectives

Conduct and subsequently use the output from very high–resolution numerical simulations (< 500 m) of the small-scale electrification processes within tropical cyclones (TCs) to derive functional relationships between various lightning metrics and the microphysics/kinematics of TCs. Whenever possible, these relationships will be verified against observations to ultimately develop total lightning predictors that could be used to assimilate total lightning observations directly into NHC's statistical prediction model (SHIPS). Total lightning is emphasized because it is much better correlated to convective strength than cloud-to-ground lightning is. Lightning information is particularly critical in regions where radar data are scarce, such as over oceans where all TCs develop and eventually intensify.

Accomplishments

We successfully simulated several sub-kilometer scale (350-m) explicit simulations of the electrification and lightning processes within an Atlantic hurricane (> 4000 cores). These were made possible through a successful auxiliary proposal for allocations on the TACC high performance machines (which allocations have now been used). We also compared results with available total lightning observations from ENTLN for this storm, and derived relationships between simulated storm microphysical/kinematical variables and simulated 2D and 3D lightning metrics.

Publications

Fierro, A. O., E. R. Mansell, D. R. MacGorman, and C. Ziegler, 2015: Explicitly simulated electrification and lightning within a tropical cyclone based on the environment of Hurricane Isaac (2012). *Journal of the Atmospheric Sciences*. in press.

Fierro, A. O., A. J. Clark, E. R. Mansell, D. R. MacGorman, S. Dembek and C. Ziegler, 2015: Impact of storm-scale lightning data assimilation on WRF-ARW precipitation forecasts during the 2013 warm season over the contiguous United States. *Monthly Weather Review,* **143***,* 757-777.

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

NOAA Technical Lead: Steve Goodman (NOAA/NESDIS)

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

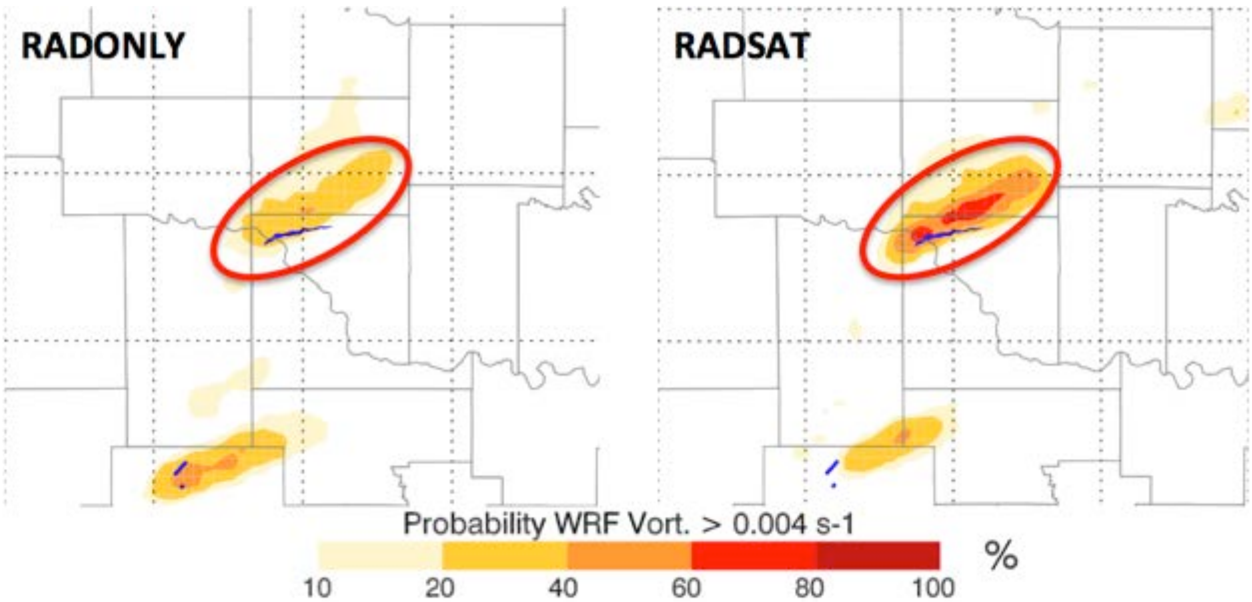
Thomas Jones (CIMMS at NSSL), Dave Stensrud (Penn State University), Louis Wicker (NSSL), Steve Goodman (NOAA NESDIS), and Patrick Minnis (NASA Langley Research Center)

Research is ongoing towards assessing the impacts of assimilating GOES cloud water path (CWP) retrievals into convection permitting models. Additional research was undertaken to determine the best methods to simultaneously assimilate both CWP and radar observations. Experiments were conducted on several severe weather events from the 2013 – 2014 seasons using a preliminary version of the NSSL experimental WoF System for ensembles (NEWS-e). Assimilating LWP and IWP observations generally resulted in improved thermodynamic conditions over the storm-scale domain through better analysis of cloud coverage compared to radar-only experiments. These improvements often corresponded to an improved analysis of supercell storms leading to better forecasts of low-level vorticity. This positive impact was most evident for events where convection is not ongoing at the beginning of the radar and satellite data assimilation period.

For example, the 0-2 km probability of vorticity greater than 0.004 s^{-1} for radar only (RADONLY) and radar + satellite (RADSAT) experiments for a 1 hour forecast period

beginning at 1915 UTC on 19 May 2013 shows that the RADSAT experiments generate higher probability swaths associated with the central OK storm nearby the actual tornado track with began at ~2000 UTC.

For more complex cases containing significant amounts of ongoing convection, assimilating LWP and IWP in place of clear-air reflectivity generated spurious regions of light precipitation compared to the radar only experiments. The analyzed tornadic storms in these experiments are sometimes too weak and quickly diminished in intensity in the forecasts. The lessons learned, as part of these experiments, should lead to improved iterations of the NEWS-e system building on the modestly successful results described here.



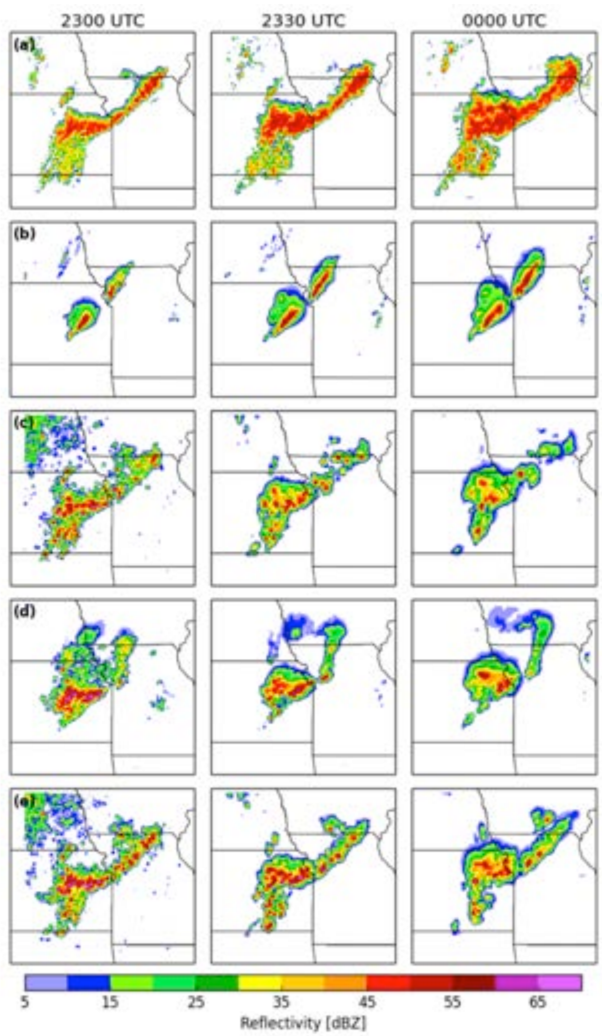
Probability of 0-1 hour forecast 0-2 km vertical vorticity greater than 0.004 s^{-1} for forecasts initiated at 1915 UTC for RADONLY and RADSAT experiments. Blue lines indicate tornado tracks.

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

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

This project leads the NSSL contribution to the larger Observing System Simulation Experiment (OSSE) 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. Simulated GOES-R ABI radiances and WSR-88D reflectivity and radial velocity observations were generated from a high-resolution nature run. These observations were then assimilated back into a ensemble data assimilation system to determine their combined effectiveness at improvement the storm-scale analysis.

The figure below shows the ensemble mean composite reflectivity analysis at 2300 UTC and 30 min and 1 hour forecasts thereafter for the nature run (truth), no-assimilation, satellite only, radar only and radar+satellite experiments. Note that the radar-only run fails to generate the convection in southern Kansas, which is present in the nature run. The satellite-only experiment does generate this convection and the combined radar+satellite experiments generally produce convection that is most similar to that generated by the nature run. Thus, assimilating both satellite water vapor radiance and radar observations provides benefits over only assimilating one or the other. These results will be used to design experiments using real data that assimilations ABI radiances and radar data to determine if the expectations seen in the OSSE translates to a real-world environment.



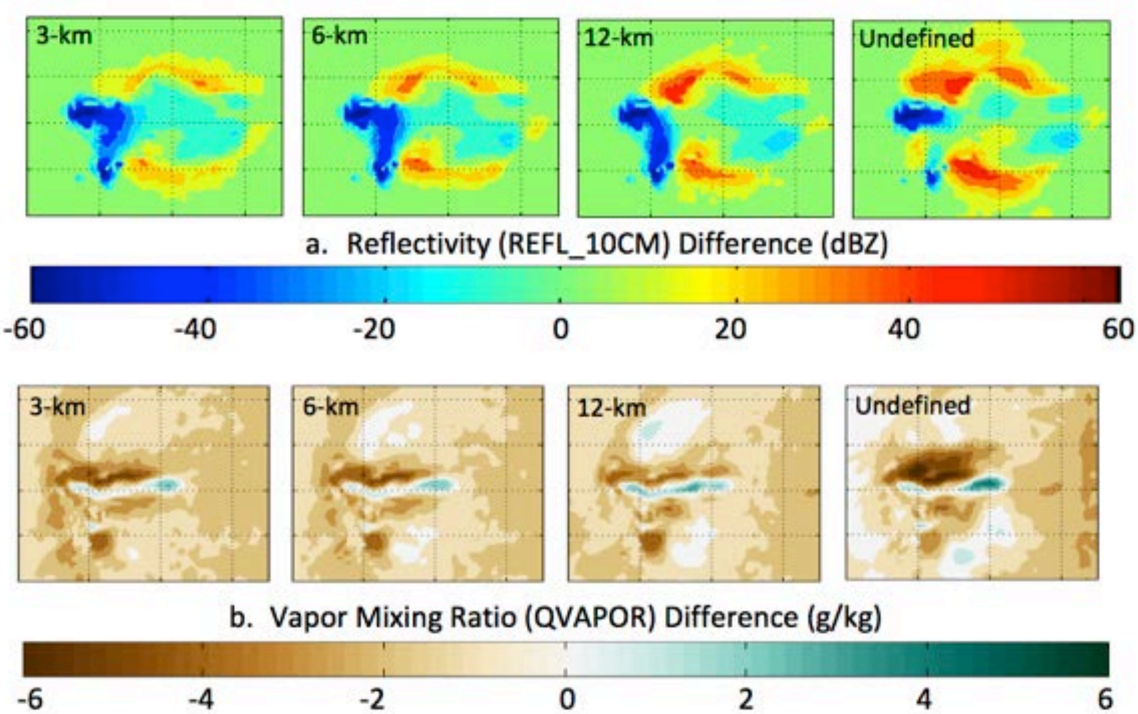
Ensemble-mean composite reflectivity for the final 1-hour forecast at 2300, 2330, and 0000 UTC – (a) truth, (b) no assimilation, (c) satellite only, (d) radar only, and (e) satellite + radar.

3. Honors Student Mentorship

Thomas Jones (CIMMS at NSSL) and Jessica Tomaszewski (OU School of Meteorology Honors Undergraduate Student)

Ms. Tomaszewski conducted research into the importance of vertical localization radius to assimilating CWP data into an ensemble modeling system for an idealized supercell event. Large sensitivities were observed 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} (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.



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, 2014: Forecast evaluation of an Observing System Simulation Experiment assimilating both radar and satellite data. *Monthly Weather Review,* **142**, 107-124.

Jones, T. A., D. Stensrud, L. Wicker, P. Minnis, and R. Palikonda, 2015: Simultaneous radar and satellite data storm-scale assimilation using an ensemble Kalman filter approach for 24 May 2011. *Monthly Weather Review*, **143**, 165-194.

Jones, T. A., and D. J. Stensrud, 2015: Assimilating cloud water path as a function of model cloud microphysics in an idealized simulation. *Monthly Weather Review*, **143**, 2052-2081.

CIMMS Task III Project – Hybrid Data Assimilation for Convective-Scale "Warn-on Forecast"

Xuguang Wang and Yongming Wang (OU School of Meteorology)

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

Objectives

One key component of this project is to provide sufficiently accurate initial conditions through assimilation of radar data to initialize the convective-scale NWP model. The GSI-based Hybrid data assimilation system was further developed to include convective-scale radar data assimilation capability. Various options of hydrometeor-related control variables in GSI hybrid were derived, developed and explored. The impacts of these options were also explored in an 8 May 2003, Oklahoma City, tornadic supercell storm. Detailed diagnostics were also performed to understand the reasons that the newly developed reflectivity control variable was able to produce the best analysis and forecast for the tornadic supercell.

Accomplishments

Owing to the high spatial and temporal resolution capable of sampling the structure of the convective storms (Sun 2005), the Doppler velocity and reflectivity are the most commonly used observations for the storm-scale numerical weather prediction (NWP) (Dowell et al. 2011). Numerous studies (Daley 1991; Sun and Crook 1997, 1998; Snyder and Zhang 2003; Dowell et al. 2004; Tong and Xue 2005; Caya et al. 2005; Xiao et al. 2005; Gao and Xue 2008; Xu et al. 2008; Jung et al. 2008; Dowell and Wicker 2009; Aksoy et al. 2009; Yussouf and Stensrud 2010; Lu and Xu 2009; Xue et al. 2009; Zhang et al. 2009; Dowell et al. 2011; Gao and Stensrud 2012) investigated the impacts of radar data assimilation and indicated the benefits from assimilating these data for convective storms. However, challenges for the assimilation of radar data still remain, especially for reflectivity data (Dowell et al. 2011; Gao and Stensrud 2012).

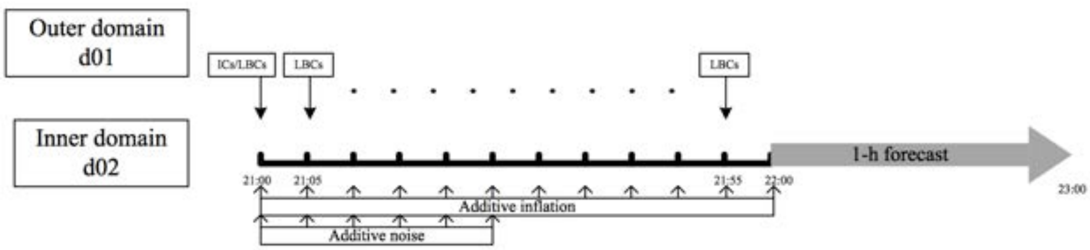
For producing detailed analyses of convective storms and initializing the NWP models,

various techniques were developed over the past few decades to assimilate radar reflectivity directly or the derived quantities (e.g., rain-water mixing ratio) into the high-resolution numerical models (Sun 2005). Because the radar reflectivity is an indirect model variable, early studies retrieved the essential variables for initializing a convective scale numerical model from that (Lin 1983; Albers et al. 1996; Zhang et al. 1998). A few studies implemented the successive correction (Bergthorsson and Doos 1955) or Newtonian nudging (Hoke and Anthes 1977) for assimilation of the derived variables, such as the rain-water content derived from radar reflectivity using a cloud analysis (Albers et al. 1996; Zhang et al. 1998; Souto et al. 2003; Ducrocq et al. 2000, 2002; Xu et al. 2004) and the latent heating resulting from the rain-water difference as an extra source term adding to the thermodynamic equation (Liu et al. 2002). Some studies used three-dimensional variational (3DVar) techniques to assimilate radar reflectivity directly with the total liquid water used as the control variables (Xiao et al. 2004) or a new forward operator based on a background temperature field for automatic hydrometeor classification (Gao and Stensrud 2012). Sun and Crook (1997) compared assimilating rainwater mixing ratio obtained from the reflectivity data with directly assimilating the reflectivity in a four dimensional variational (4DVar) techniques, which also was applied to an observed supercell storm (Sun 2005) and real-time in several field programs (Sun and Crook 2001; Crook and Sun 2002). Recently, studies have started to use the ensemble Kalman Filter (EnKF) to assimilate the reflectivity directly (Dowell et al. 2004; Tong and Xue 2005; Lei et al. 2009; Dowell et al. 2011; Yussouf et al. 2013; Johnson et al. 2015). In such studies, the reflectivity observation operators in the model control variables that are the original values of hydrometeor with the reflectivity observations.

One of the greatest difficulties of directly assimilating reflectivity data is the uncertainty in the observation operators because of the complexity of the microphysical parameterizations (Gao and Stensrud 2012). In other words, the uncertainties are due to errors in predicting the hydrometeor fields and diagnosing the reflectivity from the hydrometeor fields (Dowell et al. 2011). The first one results from the inadequate numerical microphysical schemes. For the latter one, a series of studies were proposed to improve it. Sun and Crook (1997) calculated the simulated reflectivity using the model output rainwater mixing ratio only, as the ice-related hydrometeors are neglected. The observation operator from Tong and Xue (2005) and Dowell et al. (2011) is obtained from three hydrometeor mixing ratios – rain, snow, and hail-graupel. Additionally, to avoid the possibility of obtaining a nonzero snow/graupel mixing ratio at very warm levels, Gao and Stensrud (2012) developed a new operator that uses a background temperature field to classify the hydrometeor types. As introduced in these studies above, the observation operators for reflectivity are nonlinear and because of that the error distribution of the reflectivity is likely non-Gaussian. And the gradient of the cost function with respect to the low values of hydrometeor can be dominantly large (Sun 2005), such that the minimization has difficulty converging and the numerous gradient could cause an imbalance of the gradient among different control variables.

GSI-based hybrid DA system has been successfully implemented for GFS and HWRF for general global forecast and convection allowing hurricane forecasts (Wang et al.

2013; Lu et al. 2015). The research and development of this system for convective scale radar data assimilation are still very limited. Since hybrid DA adopts the variational framework (Wang 2010), the ill behavior of assimilating reflectivity as described by Sun (2005) exists in such system. In this study, two methods are proposed, implemented and compared to solve this issue. We first applied the logarithm to these hydrometeor mixing ratio control variables, and then a newly developed reflectivity control variable was derived and compared with other options.



Schematics of the data assimilation configuration. The inner domain radar DA adopts the 5 minute cycling, driven by the outer domain analyses and forecast cycles. One-hour forecasts are then initialized by the analysis at 2200 UTC. See text for details of additive inflation and additive noise.

Publications

Johnson, A., X. Wang, J. R. Carley, L. J. Wicker, and C. Karstens, 2015: A comparison of multiscale GSI-based EnKF and 3DVar data assimilation using radar and conventional observations for midlatitude convective-scale precipitation forecasts. *Monthly Weather Review*, **143**, 3087-3108.

Thompson, T. E., L. J. Wicker, X. Wang, and C. Potvin, 2015: A comparison between the Local Ensemble Transform Kalman Filter and the Ensemble Square Root Filter for the assimilation of radar data in convective-scale models. *Quarterly Journal of the Royal Meteorological Society*, **141**, 1163-1176.

CIMMS Task III Project – Objective Probabilistic Guidance for Severe Weather Outbreaks

Michael Richman (OU School of Meteorology)

NOAA Technical Lead: John Cortinas (NOAA/OWAQ)

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

Funding Type: CIMMS Task III

Objectives

Application of the areal-coverage (AC) technique to convection-permitting models to depict days with more significant severe weather; develop an objective method to verify the AC forecasts; and develop a training dataset using the NSSL-WRF forecasts of past events.

Accomplishments

Preliminary findings have indicated that the areal-coverage (AC) technique applied to convection permitting models depicts days with more significant severe weather reasonably well. The AC technique identifies the regions with significant severe weather, but also identifies broad regions adjacent to, but not collocated, with severe report clusters. The training models developed were not particularly beneficial in developing helpful guidance unless modifications to the technique were implemented.

Two such modifications were created. In the first, the intersection of "surrogate severe" regions with areas featuring favorably large AC magnitudes reduced the false alarm problem considerably. This results in contiguous regions closely tied to observed severe weather. Though this technique is not identical to that used in the development of the training model (which uses the observed reports themselves to identify the outbreak region), subjective inspection of this intersection technique suggests much improved utility in the AC technique and the NARR-derived training model in a real-time setting. Moreover, this intersection technique more accurately identifies separate severe weather clusters than using AC magnitudes alone, which may combine regions inappropriately, owing to the false-alarm problem. The second modification is the preferred option, but currently not feasible until more cases are tested. A training model using the NSSL-WRF model simulations themselves on past cases will eliminate the discrepancies between the identification of the outbreak region in the training data versus the real-time simulations. However, a large dataset is required for such implementation, likely necessitating a significant investment in computer time in order to build a large data set of simulations.

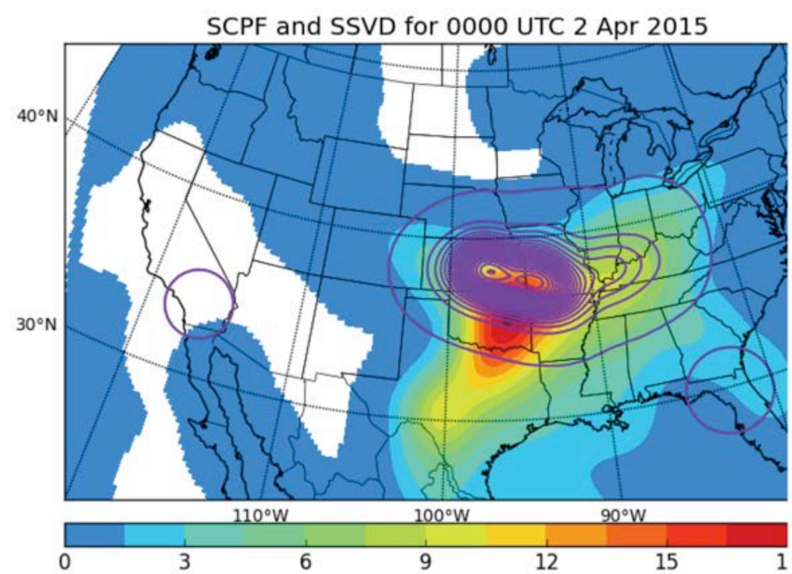


Illustration of the intersection method. SCP (filled contours) and surrogate severe PDF values (purple contours). The intersection of the two, which looks at the product of the two values is the diagnostic variable magnitude at a given grid point and the PDF value is useful for identification of potential severe weather regions.

Theme 3 – Forecast and Warning Improvements Research and Development

NSSL Project 5 – Hazardous Weather Testbed

NOAA Technical Leads: Lans Rothfusz and Jack Kain (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 include:

- 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 include:

- 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)

Dr. Correia's work on this project is reported under **SPC Project 11**.

2. Experimental Warning Program

Kristin Calhoun, Darrel Kingfield, Chris Karstens, Tiffany Meyer, and Travis Smith (CIMMS at NSSL), William Line (CIMMS at SPC), Michael Bowlan (CIMMS at WDTD), Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), and Gabriel Garfield (CIMMS at OUN)

a. Probabilistic Hazard Information (PHI) Experiment

Forecasters were provided real-time, automated, statistical guidance for the occurrence of any severe (tornadoes, wind, and hail) via NOAA/CIMSS ProbSevere and for tornadoes via early algorithm development occurring at CIMMS/NSSL. Forecasters

were presented with several options to utilize, manipulate, override, ignore, block, or allow these guidance sources, while generating probabilistic forecasting for severe convective events. By creating/issuing PHI with these guidance sources, forecasters found themselves needing to worry less about drawing a box around the hazard, as is done in the current warning paradigm, and rather, focusing or shifting their attention more on communication. This natural progression was a consistently observed throughout each of the three weeks. In addition, the forecasters didn't immediately embrace the automated guidance that was provided to them, but as the week went along and forecasters experienced various scenarios/strategies using the automated guidance, a human-machine mix was identified that appeared to produce the best results in terms of balancing the increased workload that comes with frequent updates for lots of severe storms, where wind and hail are the primary hazards, while maintaining correspondence geographically. On the other hand, tornado hazards were primarily handled by the forecasters alone, which seemed to produce the best results given there were generally far fewer tornado hazards to monitor and update, and the tornado hazards were easier for the forecasters to maintain geographic correspondence (using a circle or ellipse), as opposed to severe hazards. A full evaluation of the experiment results in currently underway.

b. GOES-R Convective Applications

The GOES-R Proving Ground at the HWT provided a pre-operational demonstration of recently developed products and capabilities associated with the next generation GOES-R series of geostationary satellites, subject to the constraints of existing data sources to emulate the satellite sensors. This early exposure allowed forecasters to become familiar with future GOES-R capabilities and products prior to launch, helping to ensure day-1 readiness for the receipt of data. Additionally, feedback received from participants will be utilized in the continued development of GOES-R algorithms. The first of the GOES-R series of satellites is scheduled to launch in March 2016.

c. Earth Networks Total Lightning Network

Earth Networks' total lightning and total lightning derived products were evaluated in real-time as part of the 2015 HWT Experimental Warning Program. This experiment built upon the initial evaluation in 2014, including enhancements derived from forecaster feedback. The ENI-derived products that were evaluated included storm-based flash rates tracks, and time-series, as well as three levels of thunderstorm alerts. The 2015 evaluation tested the feasibility of use and performance under the stress of real-time warning operations.

d. Lightning Jump Algorithm

In severe storms, rapid increases in lightning flash rate, or "lightning jumps," are coincident with pulses in the storm updraft and typically precede severe weather, such as tornadoes, hail, and straight-line winds, at the surface by tens of minutes. The GOES-R Geostationary Lightning Mapper (GLM) provides a general path to operations

for the use of continuous total lightning observations and the lightning jump concept over a hemispheric domain. The 2015 Spring Experiment evaluated a gridded sigma-level based lightning jump product on a CONUS scale in real time using total lightning data to prepare for possible operational implementation in 2016 following the launch of GOES-R.

e. Evaluation of Experimental Forecast Program Probabilistic Severe Weather Outlooks

Experimental Outlooks generated in the Experimental Forecast Program were evaluated for utility as guidance for experimental warning operations.

Publications

Karstens, C. D., G. Stumpf, C. Ling, L. Hua, D. Kingfield, T. M. Smith, J. Correia, Jr., K. M. Calhoun, K. L. Ortega, C. J. Melick, and L. P. Rothfusz, 2015: Evaluation of a probabilistic forecasting methodology for severe convective weather in the 2014 Hazardous Weather Testbed. *Weather and Forecasting,* in press.

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; and (3) conduct enhanced verification of severe weather events.

Accomplishments

1. Warn-on-Forecast

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 models within the Warn-on-Forecast project.

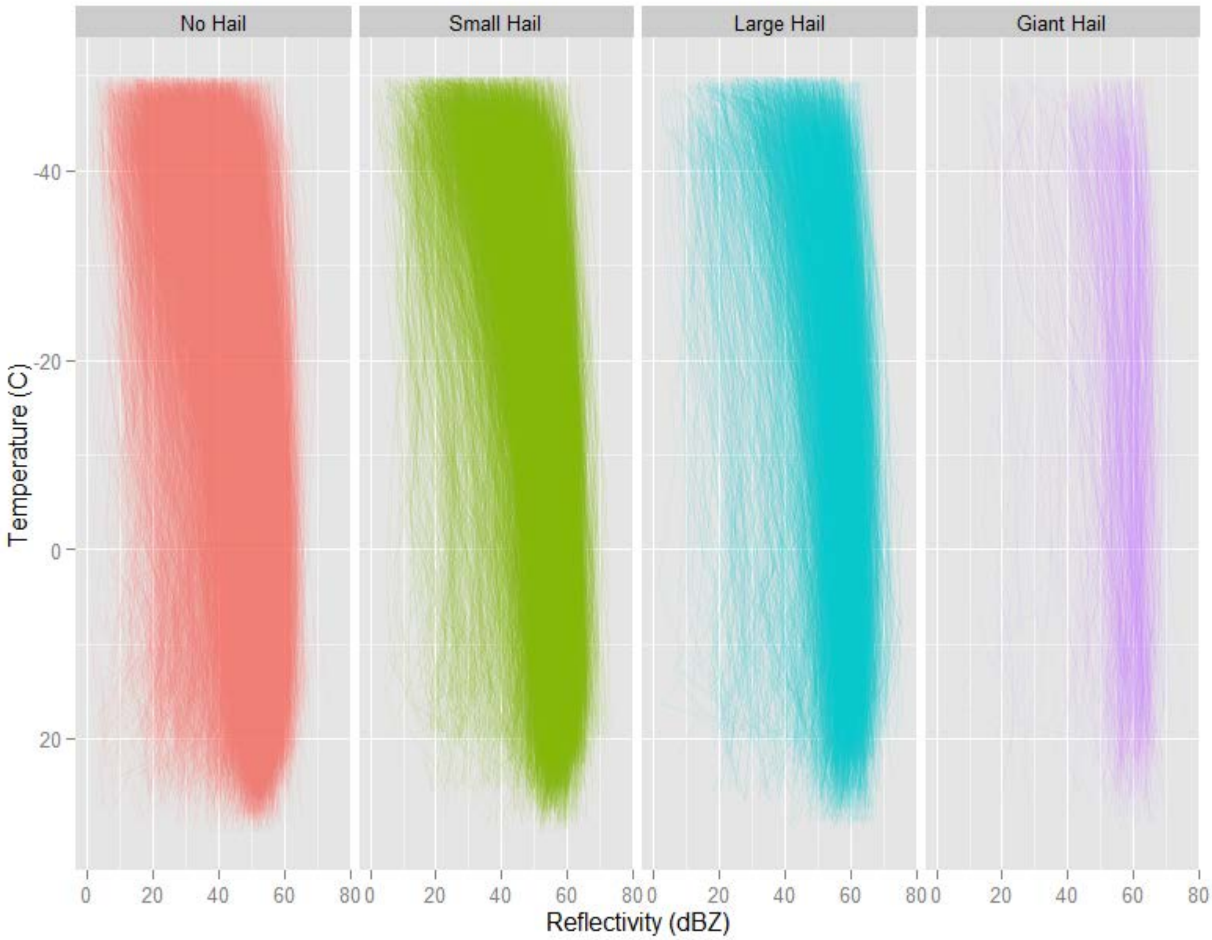
Additionally, initial code development was conducted for infusing probabilistic forecast guidance from a real-time Warn-on-Forecast system running during the 2015 Spring Experiment into a prototype web tool allowing forecasters to issue probabilistic forecasts for severe convective weather hazards (tornado, 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.

2. Severe Hazards Analysis and Verification Experiment (SHAVE)

Kiel Ortega (CIMMS at NSSL)

The Severe Hazards Analysis and Verification Experiment (SHAVE) is a unique project that blends high-resolution radar data with geographic information. The primary objective of this experiment is to collect high temporal and spatial resolution data that describe the distribution of hail sizes, wind damage, and flash flooding produced by severe thunderstorms. It's data has enabled several goals, including: (1) provide high-resolution verification data for the NWRT phased array radar; (2) use the high-resolution verification data in the development of techniques for probabilistic warnings of severe thunderstorms; (3) evaluate the performance of multi-sensor, multi-radar severe weather algorithms; (4) associate changes in hail size and wind damage distributions with storm evolution; and (5) enhance climatological information about severe storm threats in the United States.

SHAVE (http://www.nssl.noaa.gov/projects/shave/) concluded its 10th and most likely final year of operations. The project, in total, made 255,489 phone calls collecting 73,885 reports. Of those reports, 54,307 were hail reports; 6,435 were related to wind damage; 10,967 reports were related to flash flooding; and 2,176 were reports of wintertime precipitation. SHAVE data has been used in Hazardous Weather Testbed operations, especially during the testing of experimental flash flood products. SHAVE hail reports are currently being used to evaluate a range of hail detection techniques, from non-polarimetric to polarimetric to Multi-Radar, Multi-Sensor (MRMS) techniques. SHAVE reports still continue to support research related to the GOES-R lightning jump algorithm.



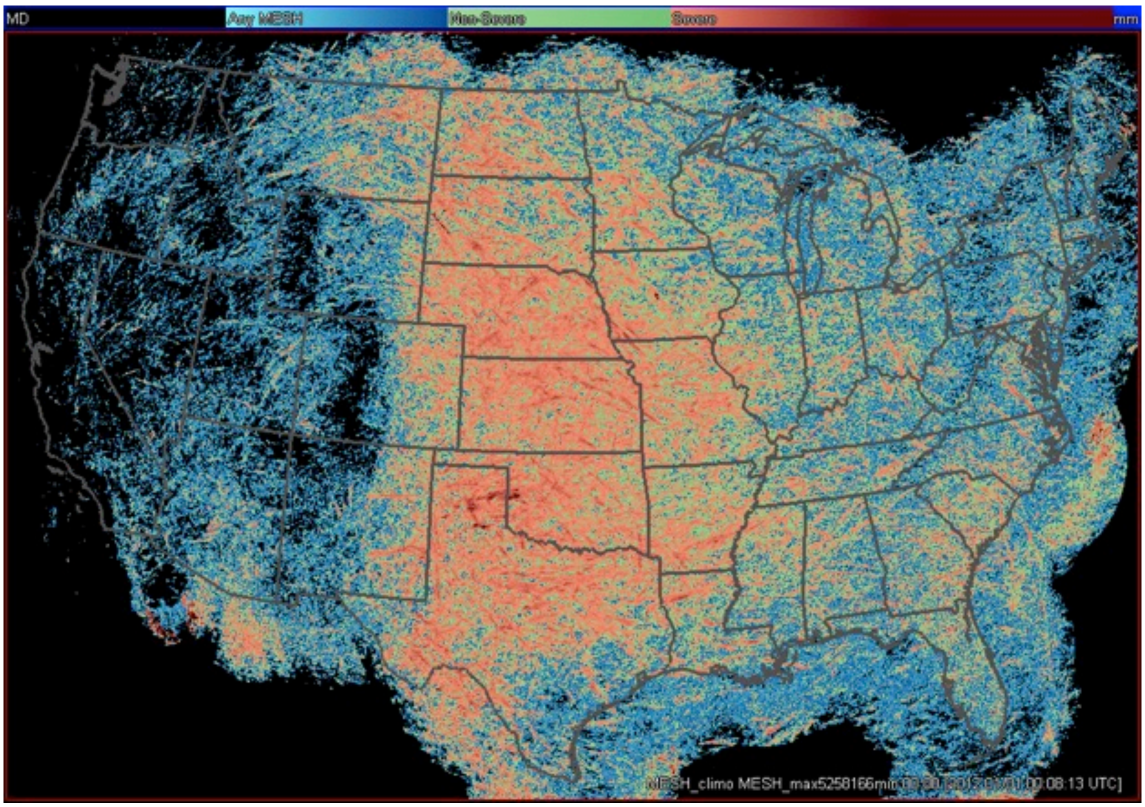
Vertical reflectivity profiles from the multi-radar, multi-sensor (MRMS) system for hail reports from SHAVE. There are 486 giant (diameter greater than 2 inches), 3,648 large (diameter between 1 and 2 inches), 9,896 small (diameter less than 1 inch), and 7,130 "no" hail reports. The data illustrate the large amount of overlap between the hail size classes, and thus, difficulty in hail size estimation.

3. Multi-Year Analysis of Remotely Sensed Storms (MYRORSS)

Kiel Ortega and Travis Smith (CIMMS at NSSL)

An intensive quality control effort has been ongoing at NSSL for the completed years (2000-2011). Five years of the 12 completed years have been thoroughly quality controlled. Data transfer between NCEI and NSSL is nearly complete, with only 1.5 years of raw level-II radar data and 1 year of MYRORSS data remaining at NCEI. Recent (2013+) radar and environmental analyses data has been archived at NSSL and is available for future production processing. Applications of MYRORSS data have been investigated; the database has been used in projects exploring radar-based hail climatology, reflectivity climatology, and investigating storms that produce severe wind gusts.

A paper was published summarizing an analysis performed by a Research Experience for Undergraduates (REU) during the summer of 2013 for determining which polarimetric variables are important for weather/no-weather discrimination. Additionally, High-resolution from SHAVE are being used to help calibrate MRMS hail size estimates.



The maximum hail size for 5 years (2001,2003,2008,2010,2011) of data processed through the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS). The blues highlight areas where weak convection was present, the greens where storms most likely did not produce severe hail, and the reds where severe hail most likely fell. All production data for 2001 through 2011 has been completed and an intensive quality control effort is underway for the remaining 7 years not included within this image.

Publications

Johnson, A., X. Wang, J. Carley, L. Wicker, and C. D. Karstens, 2015: A comparison of multi-scale GSI-based EnKF and 3DVar data assimilation using radar and conventional observations for mid-latitude convective-scale precipitation forecasts. *Monthly Weather Review,* **143,** 3087-3108.

Lakshmanan, V., C. D. Karstens, K. Elmore, S. Berkseth, and J. Krause, 2015: Which polarimetric variables are important for weather/no-weather discrimination? *Journal of Atmospheric and Oceanic Technology,* **32,** 1209-1223.

Awards

CIMMS scientists were key contributors to winning the NOAA 2015 Silver Medal for the “successful transition of the Multi-Radar, Multi-Sensor system into operations to provide critical radar-based products to forecast weather hazards.”

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 Technical Lead: Maj. David McDonald (ROC)

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

Funding Type: CIMMS Task II

1. Dual-Polarization Precipitation Identification

Stephen Castleberry (CIMMS at ROC), Daniel Berkowitz and Richard Murnan (ROC), and Hoyt Burcham and John Krause (CIMMS at NSSL)

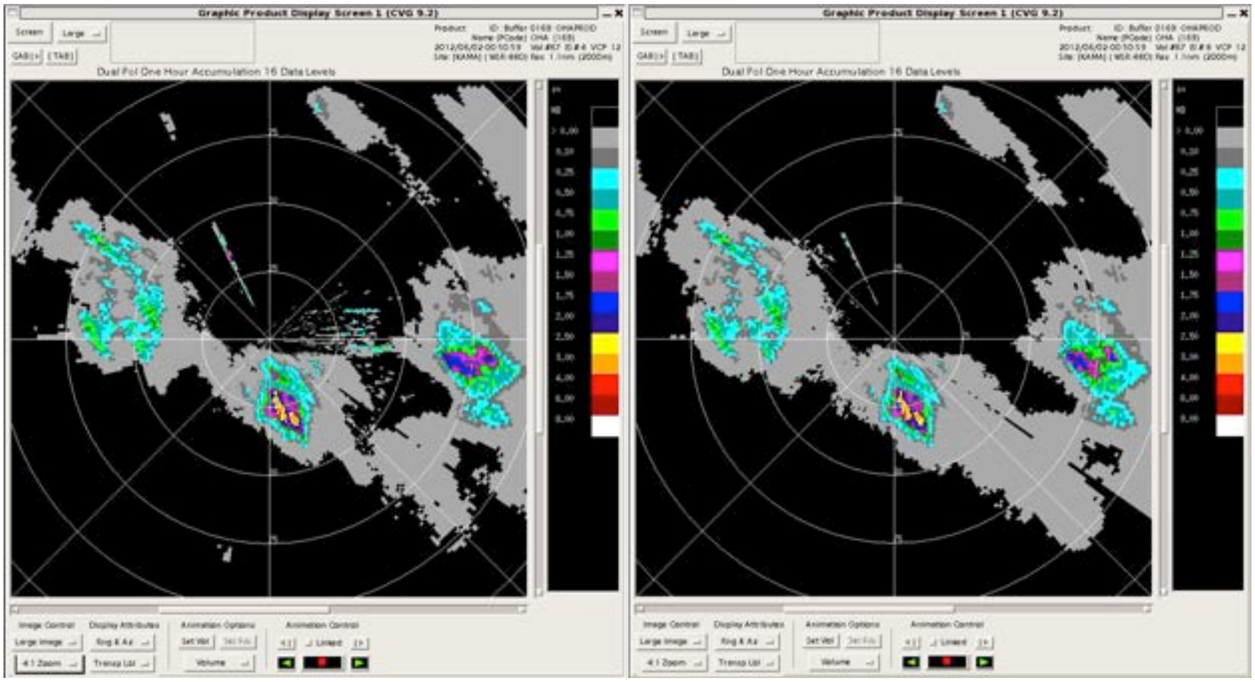
Objectives

Integrate, implement, and test software for the Met Signal algorithm, code that was previously developed for the ROC by NSSL scientists that identifies and filters non-meteorological targets from derived precipitation estimation radar products such as specific differential phase (K_{DP}) and digital precipitation rate (DPR). This ensures that 1) the code is properly integrated into the current Radar Product Generator (RPG) software build as per guidelines and results provided by NSSL, and 2) the algorithms perform as expected.

Accomplishments

A significant problem exists in processing and analyzing radar data to study precipitation and convective weather systems in that non-meteorological targets (wind turbines, birds, insects, vehicle traffic, etc.) can “contaminate” the data and cause incorrect values to be reported in various radar products, especially those related to precipitation estimation and derived dual-pol products. The Met Signal algorithm developed by NSSL scientists for the ROC is designed to identify and filter this contamination, thus improving the quality of derived dual-pol products and precipitation estimation products. After the code was completed by NSSL and delivered to the ROC, we integrated it into our existing RPG software, performed an integration test to ensure our results matched those from NSSL, and now continue to do further implementation and optimization testing to evaluate how the algorithm performs in different situations (various weather / contamination conditions: convective storms mixed with ground clutter, precipitation contaminated with biological scatter targets, etc.). Thus far, the results have been promising and have shown that the Met Signal algorithm does improve the quality of the derived radar products. Testing and analysis continues on optimizing the way to configure the algorithm (which adaptable parameter inputs to select) under different contamination / precipitation conditions. For example, cases of lighter precipitation / weaker clutter returns require a lower, less-aggressive filtering threshold than that for a case of strong clutter / heavy precipitation. The future goal of this research is once the performance and reliability of the algorithm has been

demonstrated using the derived radar products, the technique could then be used to actually filter contamination out of the operational base radar products (such as reflectivity and velocity).



Comparison between One Hour Accumulation (OHA) precipitation products in units of inches using no Met Signal processing (left), and with Met Signal processing (right). The radar data used were from KAMA (Amarillo, TX) on 2 June 2012 at around 0050 UTC. The algorithm removed much of the clutter contamination just to the E-NE of the radar site (center of the PPI).

2. Quantitative Precipitation Estimation Analyses using MRMS and WDSS-II Tools

Stephen Castleberry (CIMMS at ROC), Heather Grams (CIMMS at NSSL), and Daniel Berkowitz and Richard Murnan (ROC)

Objectives

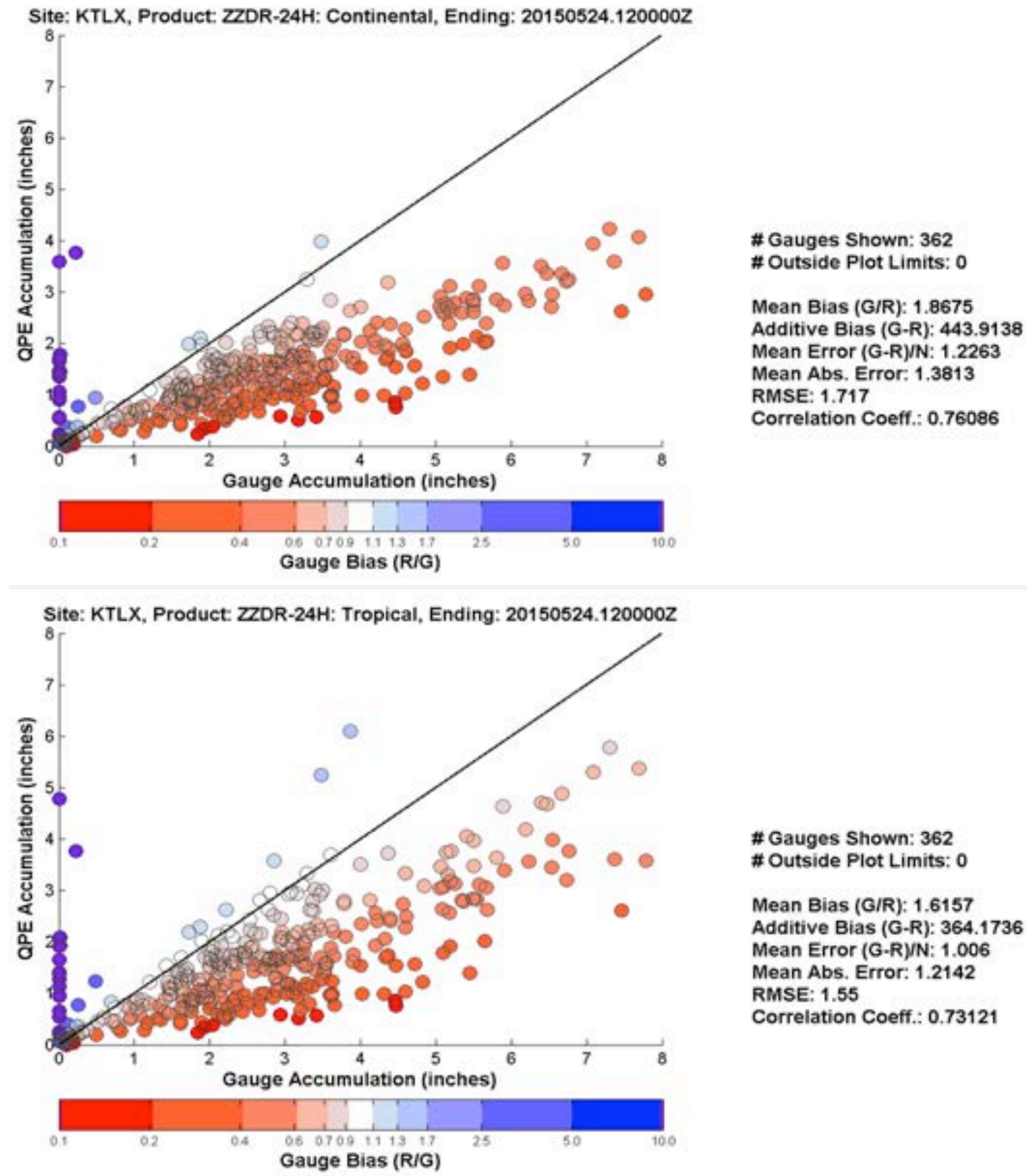
Analyze QPE techniques using MRMS and WDSS-II software. Evaluate and compare QPE results obtained using a continental rain rate ($R(Z, Z_{DR})$) scheme versus those obtained using a tropical $R(Z, Z_{DR})$ scheme, as they compare with corresponding rain gauge data, to determine which scheme (under various circumstances) yields radar estimated precipitation accumulations closest to the rain gauge values.

Accomplishments

In doing QPE analyses using dual-pol radar data, the rainfall accumulations estimated by the radar over a given time interval are very sensitive to the rainfall rate calculated for that time period. The rainfall rate R is calculated as $R \equiv R(Z, Z_{DR}) = A * (Z)^B * (Z_{DR})^C$ with units of mm hr^{-1}. Where Z is reflectivity in linear units and Z_{DR} is differential

reflectivity in linear units. The coefficient A, and the exponents B and C are selected based on which precipitation type, continental or tropical, is to be used for the given time interval. Accordingly, the selection of these parameters can have significant impacts on the final estimated rainfall accumulation amounts over a period of time. A calculated rainfall rate that is too low would yield lower than actual accumulations, while one that is too high would overestimate the accumulations.

By using the MRMS and WDSS-II software provided by NSSL, along with MATLAB post-analysis scripts to compare QPE products obtained using both continental and tropical rainfall rate parameters with rain gauge data, we are able to evaluate which set of parameters to best choose for different cases to get the QPE values closest to the rain gauge values. For the data cases we examined, it is clear that the current way of estimating rainfall accumulations using radar data (with either set of $R(Z, Z_{DR})$ parameters) has some issues to be resolved in that it exhibits a strong tendency to underestimate the rainfall accumulations relative to the rain gauge data. However, the tropical estimates tended to yield overall slightly better statistical results as compared to the continental estimates.



Comparison of scatter plots of rain gauge accumulations versus radar-derived QPE accumulations (inches) over a 24-hour accumulation period. The radar data used were from KTLX (Oklahoma City, OK) between 1200 UTC on 23 May 2015 and 1200 UTC on 24 May 2015. The upper plot uses the continental R(Z, Z_{DR}) scheme and the lower plot uses the tropical scheme. Throughout this figure, "R" is used to represent the radar-QPE accumulations and "G" is used to represent the rain gauge accumulations. The gauge bias colors of the scatter points are a reflection of the points' positions on the graph; warm colors indicate radar underestimates and cool colors indicate radar overestimates. Ideally, all points would be neutral (white) and fall along the center reference line, indicating an R/G value of 1 and equivalent QPE and gauge accumulations.

3. 3D Modeling of Clouds to Aid in Development of a Cloud Detection Algorithm

Stephen Castleberry (CIMMS at ROC), Valery Melnikov (CIMMS at NSSL), and David McDonald and Richard Murnan (ROC)

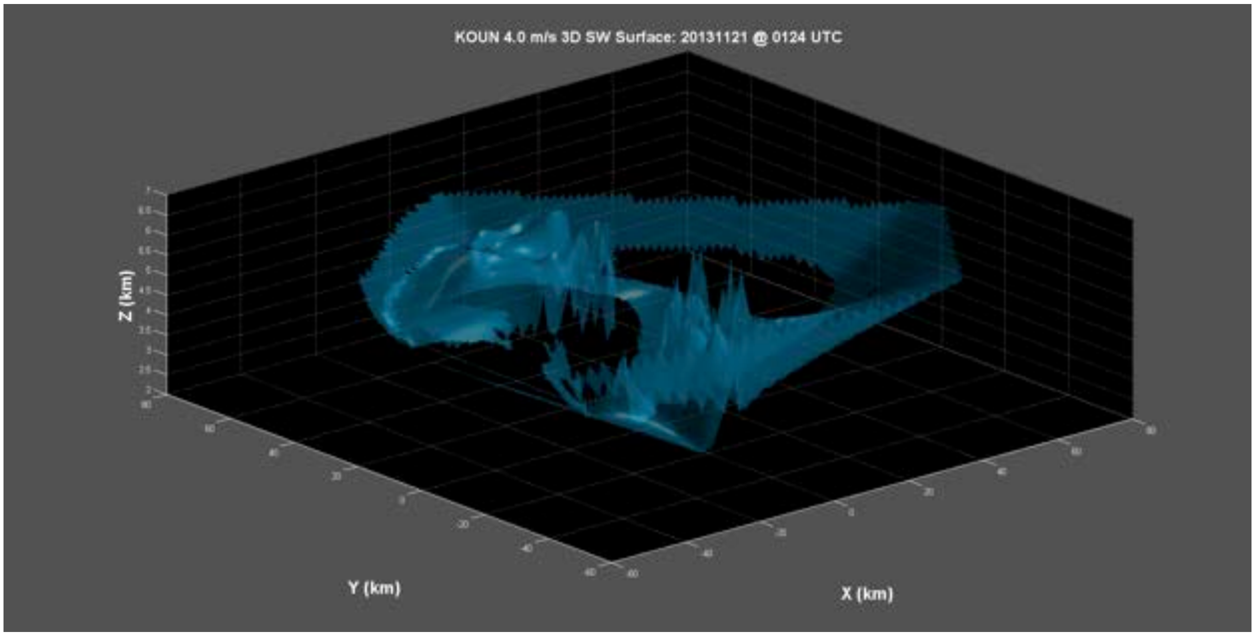
Objectives

Develop techniques to visualize cloud structures in 3D using radar data. Using the 3D models and visualizations of the clouds, work to develop an algorithm that can use operational radar data to detect cloud structures in real-time to assist forecasting, research, and aviation.

Accomplishments

Until recently, radar data has been analyzed and visualized primarily using 2D methods such as plan position indicator (PPI) plots and range-height indicator (RHI) plots, and used primarily to study precipitation and convective weather systems. We aim to take these methods a step further and explore techniques to analyze and visualize radar data in 3D to get a better idea as to what is occurring throughout the depth of the atmosphere visible to the radar. Also, we evaluate the effectiveness of using radar data to visualize cloud layers (non-precipitating) and examine the structure within the clouds. The features we are most interested in are the cloud bases and tops, the thickness of the cloud layers, if there are multiple cloud layers present, the size and shape of the droplets / particles within the clouds, and the flow patterns within the clouds – especially those that indicate the presence of turbulence.

To perform these cloud analyses and 3D modeling using radar data, we have been using the Gibson Ridge GR2 Analyst and MATLAB software packages, and comparing the results and evaluating the limitations and advantages of each. We have been primarily examining the radar variables of reflectivity (Z) to get an overall idea of the bases and tops of cloud layers as well as whether or not multiple layers are present, differential reflectivity (Z_{DR}) to examine the size and shape of the droplets within the clouds (gives an idea of their optical nature), and spectrum width to locate areas of severe turbulence. Using the 3D model images of the aforementioned variables, we are determining how to best design an algorithm that uses certain thresholds / gradients in the radar data to automatically detect the presence of thick / multiple cloud layers, very optically thick clouds, and areas of severe turbulence within cloud layers. The overall aim is to use these 3D models and algorithm to assist research scientists in studying clouds, and aviation weather forecasters in advising pilots of areas of thick cloud cover, cloud cover with poor visibility, and areas of severe turbulence to avoid. Furthermore, to supplement this research, we have also been examining the use of radar data taken from satellites to study cloud structures.



3D isosurface plot (generated in Matlab) of spectrum width showing the 4.0 m/s contour, with the radar site at the center of the plot (X, Y = 0.0 km). The radar data used were from KOUN (Norman, OK) on 21 November 2013 at 0124 UTC. This particular contour of spectrum width was examined since that value is considered to be the lower threshold for severe turbulence. Spectrum width values equal to or greater than 4.0 m/s indicate turbulence that can be very hazardous to aircraft passing through those areas, especially during takeoff and landing.

4. ROC Applications Branch Undergraduate Student Projects

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

Objectives
CIMMS undergraduate 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, it needs tools that can take raw data as input and quickly generate various statistics and graphics.

Accomplishments
The Applications Branch is using two approaches to improving the QPE algorithm output, including the upstream algorithms whose output serves as input to QPE. The first obvious approach is to make changes to the algorithms themselves. The second approach examines the data going into the algorithms to ensure high quality. The two students have provided valuable contributions to QPE improvement using both of these approaches.

Mr. Biggs finished a prototype ASP Sifter version and provided a capability to run the program overnight on a set schedule. One of the items added to the ASP Sifter program was the ability to display time series graphics of performance parameters recorded in the radar log files. As part of this effort, a user's guide was also developed. He also designed a new MATLAB Graphic User Interface (GUI) to easily access the new ZDR calibration evaluation tools that include programs previously used to examine base moment radar data. The result was a Toolbox for MATLAB applications generate.

Mr. Cooper helped modify the prototype ASP Sifter to increase performance and make it easier to maintain in the future. This production version takes only 5 hours to process all 156 WSR-88D radars log files for an entire month, which is considerably less than the 24 hours required by the prototype ASP Sifter. The ASP Sifter prototype user's guide was also modified along with the addition of a programmer's guide for future programming reference. He also provided team support for modifications to the GUI described above. Both students worked together to include animation software as a GUI option that allows users to develop animations of graphics directly from the GUI.

5. ROC Engineering Branch Undergraduate Student Projects

NOAA Technical Leads: Russ Cook and Christina Horvat (ROC)

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 engineering project management tools for planning, track and reporting on modifications and upgrades. It needs tools to quickly determine the progress of proposed system modifications and to generate various statistics and graphs for engineering management. It also needs tools to improve calibration of the WSR-88D fleet for better overall precipitation estimation. Calibration methodology needs to be thoroughly understood and improvements well documented.

Accomplishments

Undergraduate students Anthony Custable and Brandon Taylor helped enhance NEXRAD critical radar project planning and calibration test methodology. Mr. Custable completed 16 complex engineering project plans and assisted in producing a NEXRAD master project plan. The significance of this effort was the successful completion of NEXRAD Program Management Committee presentations in a timely manner. Mr. Taylor developed documentation and provided presentations on the core methods used by the ROC to calibrate the Differential Reflectivity of the WSR- 88D fleet. Mr. Taylor studied Radial-by-Radial noise estimates that replaced the derived Signal to Noise Ratio (SNR) estimates from reflectivity within the algorithm. He researched the introduction of unwanted weak sun spike instances, which were invariant in elevation, as compared with results the previous reflectivity method yielded. He studied how the algorithm was corrected, and the extra data pared. Mr. Taylor presented briefings on a proxy for SNR. This proxy was the ratio of the peak sun spike noise to the legacy Blue-

Sky noise, which was used as the global noise value before Radial-by-Radial Noise was introduced. This significance of his work is a better understanding for other ROC Hardware Engineers that this ratio is representative of SNR, and it can be used to filter the data. This ratio is referred to as SPNR (Sunspike Noise Ratio or Spike Noise Ratio).

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

NOAA Technical Leads: Russell Schneider and Steven Weiss (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, 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) and collaboration and sharing of information with the Experimental Warning Program (EWP). This involves performing research into application of new tools and applying verification techniques to convection allowing models/ensembles and experimental forecasts in near real-time within the HWT; and transferring of those activities found to be promising and of value from the HWT into daily operations at SPC. In addition, basic research is conducted to improve understanding of severe, fire, and winter weather topics that are of interest to SPC but are not related to any formal activities within the HWT. Finally, SPC partners are engaged to improve communication with the public to better mitigate the impacts of severe weather.

Accomplishments

1. Hazardous Weather Testbed

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

Melick performed objective evaluation in near real-time for the fourth consecutive year during the 2015 HWT Spring EFP. The participants once again investigated forecast verification metrics during the five-week period of the EFP to document their importance in the daily evaluations of convection allowing model performance. Following the initial findings from the 2012 EFP, computations of Fractions Skill Score (FSS) for neighborhood probabilistic guidance of simulated reflectivity continued to be a valuable

measure of skill from convection allowing ensembles but had now expanded to examining six different ensemble systems. In addition, experimental probabilistic forecasts of tornado, wind, and hail were evaluated similarly as in 2014 EFP by using local storm reports (LSRs) as the verification. For this purpose, CSI was calculated at a couple of fixed probability thresholds used in SPC operational outlooks and FSS was determined by directly comparing the probabilistic areas in the forecast to the observations. For the first time, however, a separate set of skill scores were generated using supplemental observations for hail. Specifically, a multi-hourly, radar-derived field of maximum expected size of hail (MESH) from the MRMS system was developed to run in parallel to gauge the feasibility of alternative sources for verification. A quality control measure was applied to the hourly MESH grids using CG lightning flashes. Further, only spatially filtered grids were considered to ensure the presence of contiguous swaths in the high-resolution MESH tracks (Melick et al. 2014). Similar to LSRs, "Practically Perfect" hindcasts were created from the MESH to provide valuable baselines to measure the skill of the probabilistic severe hail forecasts during the 2015 EFP.

Correia planned and supported various activities within the 2015 EFP including:

- Generating forecast soundings for UKMET (including SPC operations) and MPAS modeling systems,
- Creating ensemble forecasts of severe weather using updraft helicity objects for 4 systems (NCAR, SSEO, NSSL, CAPS),
- Performing exploratory visualization of CAPE-shear phase space for rotating storms using the NSSL ensemble,
- Conducting briefings to EWP participants to highlight EFP forecasts,
- Planning and supporting EWP-Probabilistic Hazard Information (PHI), and PHI-Emergency Manager projects to explore the use of PHI and its communication with emergency managers. Tailored briefings were provided for real-time cases while some graphics were provided for case study briefings. Also served as note taker and interviewer for various parts of the project, and
- Planning, writing, and ultimately being funded as Co-PI on the grant: Data Mining of High-resolution Storm-Scale Datasets

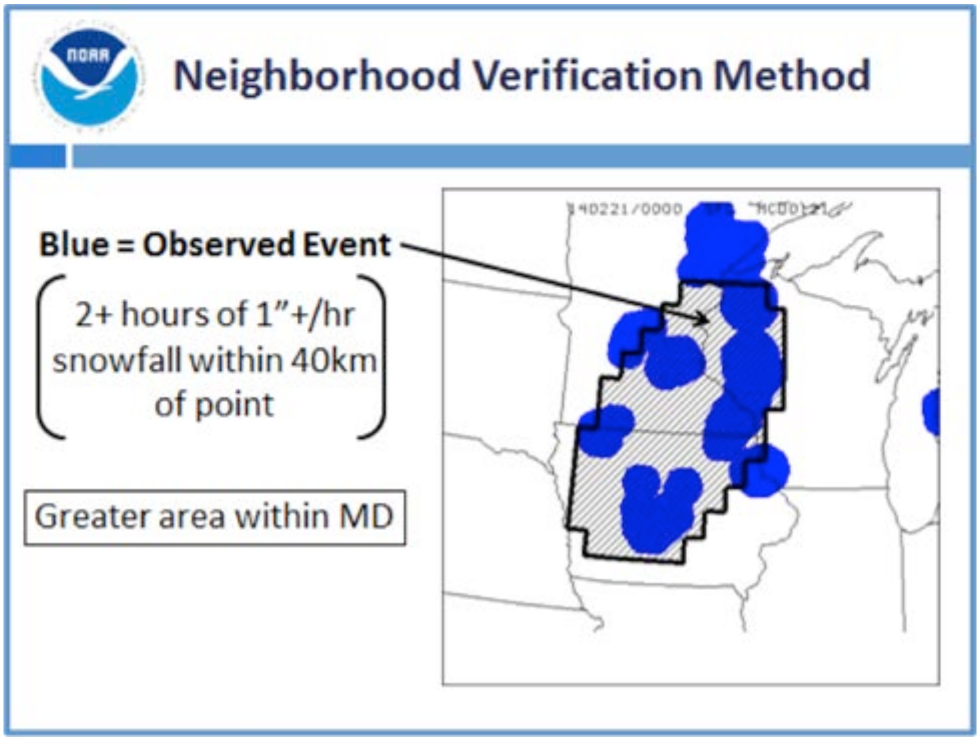
The need to verify the above modeling results culminated in the funding of a grant to use the MYRORSS of storm environments with radar data to directly compare with the NSSL WRF climatology. The model will be verified using a distributions-oriented approach to discover the challenges and opportunities of using the radar and environment data to verify bulk storm character. The goal is to understand if the model can simulate storm character, such as rotating storms, in any way related to that observed.

2. Verification of SPC Winter Weather Mesoscale Discussions

Chris Melick (CIMMS at SPC)

The SPC has issued winter weather mesoscale discussions (MDs) since 1997 to alert meteorologists at NWS Weather Forecast Offices and other partners of the near-term potential for heavy snowfall or freezing rain rates, winter mixed precipitation events, and for the initiation of mesoscale blizzard conditions. To date, SPC has had no means of objectively verifying these discussions. An evaluation of mesoscale discussions from January 2007 to April 2014 was performed to determine the spatial and temporal characteristics of the various types of MDs issued (McCray et al. 2015). To aid in enhancing SPC winter weather operations, a verification method was developed using gridded surface station precipitation type observations, local storm reports (LSRs), and QPE data. From the surface observations and LSRs, a gridded dominant precipitation type product was generated and used alongside gauge-corrected National Mosaic & Multi-Sensor QPE (NMQ) and snow-to-liquid ratio climatology to calculate estimated hourly snowfall accumulations. Similar methods utilizing these datasets were developed for verifying blizzard, freezing rain, and mixed precipitation MDs.

A heavy snow event in February 2014 (figure below) over the upper Midwest illustrated the best means to validate an MD forecast was through a neighborhood approach with a radius of influence of 40-km, similar to that used in the verification of SPC convective forecasts. The case study also demonstrated the benefit of incorporating multiple datasets to more effectively analyze dominant precipitation type in winter weather situations. While not explored exclusively yet, the prototype design would allow for development of other post-processed product for practical forecasting applications, such as the probability of snow or freezing rain and associated rates of precipitation based off of some estimate of QPE and snow-to-liquid ratios. Thus, this type of comprehensive gridded precipitation type system could be incorporated into operational systems and is also flexible, allowing for the implementation of new methods and datasets as they become available.



Prototype display showing application of a method to objectively verify an SPC winter weather mesoscale discussion (MD) by placing both the forecast and observational datasets on the same type of grid for comparison. In this instance, a scheme was devised and tested to evaluate a heavy snow MD (#121; bold black contour line) that was issued for parts of Iowa, Minnesota, and Wisconsin on 21 February 2014. The first step to confirm occurrence required determining the dominant precipitation type at each grid point from nearby surface stations and local storm reports (LSRs). In order to qualify completely, the observed precipitation must be mostly snow, snowfall rates [calculated from QPE and climatological snow-to-liquid ratios] had to be greater than or equal to an inch per hour for at least two hours. If all of these conditions were met, then the grid point was classified to have an observed heavy snowfall event. By incorporating some realistic spatial uncertainty as well, the blue, highlighted areas in the plot represent those locations that verify within a 40-km radius of influence of the grid point. As a result, the neighborhood approach was advantageous as a larger area of the winter weather MD was confirmed.

3. Lightning Characteristics and Relationship to Preliminary Local Storm Reports

Chris Melick (CIMMS at SPC)

Observational datasets serve a prominent role at the SPC in situational awareness and verification. For example, preliminary local storm reports (LSRs) issued by the NWS forecast offices are decoded in an automated fashion at SPC as a means to provide information about previous or ongoing weather events. Although severe (tornado, wind, and hail) LSRs have traditionally been the focus for evaluating forecast products, the

SPC LSR database has expanded recently to include winter weather reports of snow, heavy snow, blizzard, freezing rain, ice storm, and sleet to support the mesoscale discussions (MDs) created for short-term, high-impact winter weather episodes. In addition, data from Vaisala's National Lightning Detection Network and Earth Networks Total Lightning Network are available to forecasters in operations given the importance of monitoring electrical activity from both intra-cloud (IC) and cloud-to-ground (CG) lightning flashes in near-real time.

The relationship between preliminary LSRs and total (IC plus CG) lightning were explored by developing a time-matched high-resolution gridded climatology for 2014. The purpose of this work is to provide some initial statistical characteristics of the lightning data when stratified by geographic region, time of year, time of day, and type of flash (IC or CG) associated with severe and winter LSRs (Melick et al. 2015). A neighborhood approach was also applied to accommodate known spatial and temporal discontinuities between different observational datasets. The designed system will support inclusion of additional years of data to explore variability on the inter-annual scale, as well as case studies and other more detailed analyses focusing on specific topics.

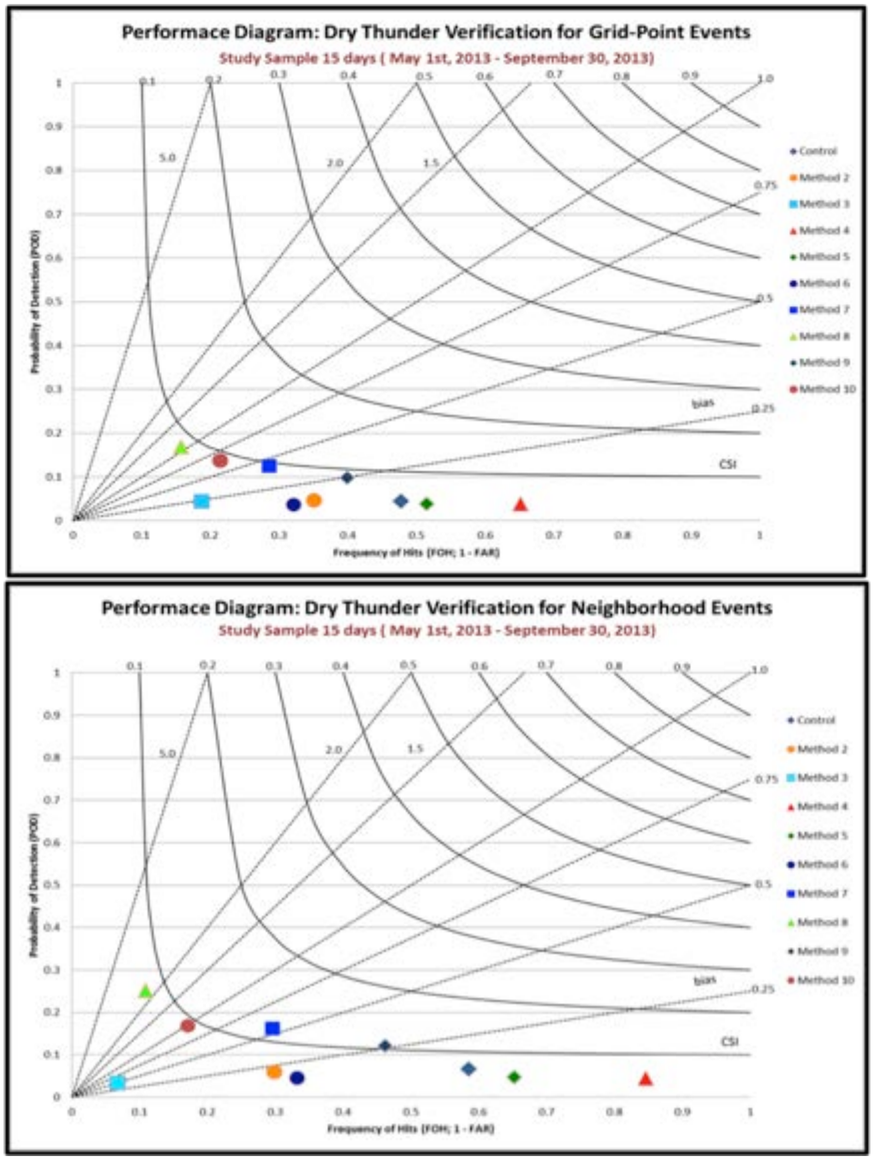
4. Definition of Dry Thunderstorms for Use in Verifying SPC Fire Weather Products

Chris Melick (CIMMS at SPC)

Forecasts for fire weather are performed on a routine basis by the SPC. The SPC provides outlooks, out to eight days, predicting the likelihood of dry thunderstorms within the prescribed area. Several classification methods were examined for identifying cases of dry thunderstorms from observational data in order to develop a more specific definition that can be used to verify fire weather outlooks. Observations from 148 days in 2013 were analyzed using ten various combinations of thresholds from quantitative precipitation estimates (QPE), lightning flash data, and other environmental parameters. For the evaluation, a 2x2 contingency table was created by comparing the events classified by each method and the initial Day 1 SPC dry thunderstorm outlooks. Traditional forecast verification statistics (e.g., critical success index [CSI) were then calculated for individual days as well as in an accumulated sense for the entire period considered in the investigation.

Results showed that by including environmental parameters into the classification process, an increase in the restrictiveness of the method was found (Flanagan et al 2015). This meant that dry thunderstorm events were not defined in the observations in areas where dry thunderstorms were not forecast to occur. However, this improvement was often offset by increases in false alarms given the reduced number of observed events found within the outlook areas. Despite the aforementioned drawback, statistical analysis still showed that these more realistic approaches tended to outperform methods that only used lightning flash data and QPE. Finally, a neighborhood diagnosis was also pursued to ensure that isolated observed events were not considered in the

verification, which more closely follows the coverage criteria used in SPC fire weather outlooks (e.g., compare bottom panel to top panel the figure below).



Performance diagram (Roebber 2009) showing accumulated results for contingency table forecast verification metrics from just the SPC Outlook days for dry thunder. These results were obtained for the grid-point (top panel) and neighborhood (bottom) events computed for all ten methods. The color legend reveals the matching type of verification method.

5. Social Science Collaboration

James Correia, Jr. (CIMMS at SPC)

a. Test and Evaluation of Rapid Post-Processing and Information Extraction from Large Convection-Allowing Ensembles Applied to 0-3 Hour Tornado Outlooks

The purpose of this project is to design, implement, and evaluate a new post-processing paradigm, designed for any convection-allowing modeling and ensemble system. This new paradigm will allow information extraction for severe weather forecasting, specifically tornado forecasts. This new post-processing paradigm has the benefit of being adaptable, scalable, and fast. To achieve these benefits, we propose using an object-based approach to refine gridded datasets into features of interest, a result of the data mining and information extraction, in order to achieve reduced dataset size for transmission, allow the viewing of all ensemble members, create an ability for forecasters to adapt to the problem of the day and maximize effective use of numerical guidance. Evaluation of our work will allow attribution of forecast improvements to the specific, direct cause, be that the experimental products, forecast tools, or other confounding factors.

We will be utilizing an ensemble-based, radar data assimilation system within the HWT to generate hourly and three hourly tornado outlooks. Forecasters will use the proposed object based post-processing to derive the information they need to make these forecasts. Multiple variables and thresholds will be available for them to make full use of the guidance, rapidly prototyping and data mining to meet the problems of the day. An evaluation of how this strategy will affect forecaster workload will be conducted to further refine our post-processing strategies. This project is a necessary first step in achieving full use of rapidly updating, large convection-allowing ensemble systems and making them useful and usable to forecasters while producing consistent and reliable risk analyses in between the warning and watch time scales. This in turn, enables forecasters to provide effective decision support to help partners effectively mitigate the impacts of severe weather.

b. Collaboration for Applying Social Science Within SPC

Organized and conducted teleconferences with social scientists Susan Jasko, Kim Klockow, and Laura Myers, SPC staff, and FEMA liaison Somer Erickson to discuss issues of communicating to the various publics and partners, near real-time challenges of highlighting important events, and the creation, development, and use of new graphical content.

c. Continued Work on the May Tornadoes of 2013 and 2015

Our collaborative research, with groups throughout OU (CASR, CAPS) and NOAA/NWS (SPC and the Norman forecast office) continues to analyze sheltering behavior following our understanding of the response to the May 2013 tornadoes in central Oklahoma. We

presented some of this work both internally and externally at the National Tornado Summit. This year we fielded a survey of people taking shelter at the National Weather Center. Analysis of these surveys is ongoing.

6. Student Mentoring

James Correia, Jr. (CIMMS at SPC)

A project with 2014 Hollings Scholar Pamela Eck involved verifying SSEO forecasts from 2011 through 2014 to understand individual model performance including skill and reliability. Her summer project resulted in multiple poster presentations and one oral presentation at subsequent conferences this year. A second project with Research Experience for Undergraduates student Julia Ross, co-supervised with REU Director Daphne LaDue, focused on analyzing survey data collected in the wake of the 3 major tornado events in May 2013. Stories of participants were coded and analyzed to understand more about awareness of threats and sheltering behavior including fleeing. This work was presented at the AMS Annual Meeting in Atlanta in 2014.

7. GOES-R Proving Ground Activities

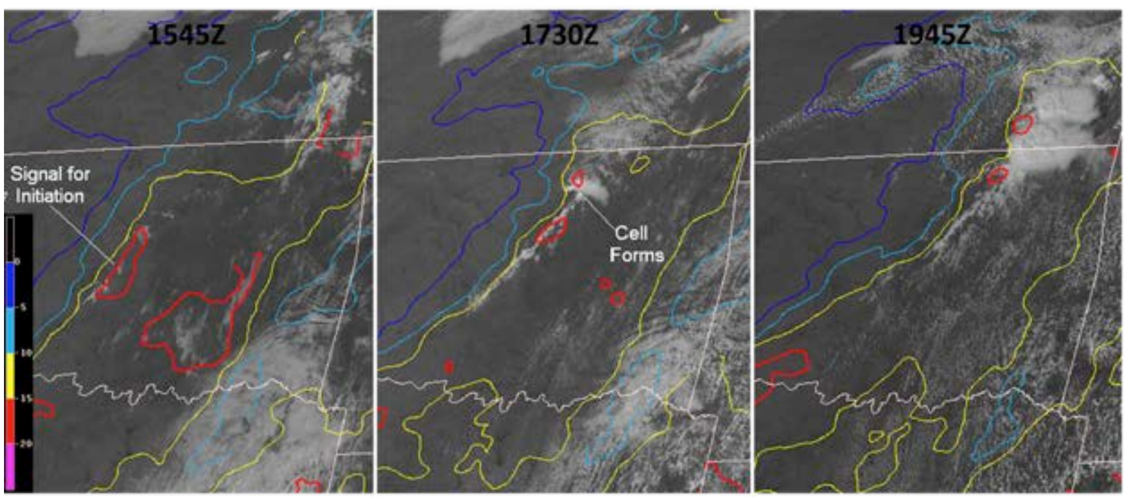
William Line (CIMMS at SPC)

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. The education and training received by SPC forecasters fosters excitement for satellite data and helps to ensure day-1 readiness for the receipt of GOES-R data. Products implemented into the SPC operational N-AWIPS system experimentally include the Overshooting Top Detection algorithm, Cloud Top Cooling algorithm, NearCast model analyses and forecasts of atmospheric moisture and instability (figure below), and a Lightning Threat algorithm for NWP. Additionally, GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) 1-minute imagery was available to forecasters during periods in August 2014 and May 2015, demonstrating a capability of the GOES-R Advanced Baseline Imagery. Finally, a satellite-based High Resolution Rapid Refresh (HRRR) model validation and guidance webpage was also demonstrated to forecasters. Additional satellite-based products have been under evaluation by Line to determine their suitability for testing and evaluation in SPC operations.

Other GOES-R demonstrations took place as part of the NOAA HWT Spring Experiment in Norman, OK from 4 May to 12 June 2015. The Proving Ground activities were focused in the EWP, with informal demonstrations taking place in the EFP. A total of 25 NWS forecasters representing five NWS regions and an additional five broadcast meteorologists evaluated up to seven experimental GOES-R and JPSS products, capabilities and algorithms in the real-time simulated short-term forecast and warning environment of the EWP using AWIPS-II. Products included GOES-R Legacy

Atmospheric Profile algorithm atmospheric moisture and stability fields using GOES Sounder data, GOES-R Convective Initiation algorithm, ProbSevere statistical model, Pseudo Geostationary Lightning Mapper total lightning, and Lightning Jump algorithm. Additionally, GOES-14 SRSOR 1-minute imagery was available from 18 May to 11 June for participants to view in AWIPS-II (EWP) and NAWIPS (EFP). Finally, the NOAA Unique CrIS ATMS Processing System from the JPSS Suomi NPP satellite was also demonstrated in AWIPS-II. Many visiting scientists also attended the EWP over the five weeks to provide additional product expertise and interact directly with operational forecasters. Product feedback from the evaluation was abundant and came in several forms, including daily surveys, daily debriefs, weekly debriefs, over 500 blog posts, informal conversations in the HWT and the weekly "Tales from the Testbed" webinars.

Line has been coordinating with the Total Operational Weather Readiness – Satellites (TOWR-S) project to further prepare SPC for the receipt and display of GOES-R data. This project seeks to test end-to-end GOES-R dataflow pre-launch, and to ensure AWIPS-II functionality for GOES-R and JPSS data. Line has contributed to the Satellite Proving Ground HWT Blog and the Satellite Liaison Blog, documenting forecaster use of GOES-R and JPSS products in the SPC and HWT. Results from GOES-R and JPSS product demonstrations in the SPC and HWT were documented by Line in final reports and presented at various science meetings. Finally, Line has contributed to the development of the NWS satellite training plan.



1500, 1700, and 1900Z 01 October 2014 NearCast Model negative theta-e difference analyses (contours; K) and 1545Z, 1730Z, and 1945Z GOES-East visible satellite imagery over Oklahoma. Convection developed within an instability maximum along a tight instability gradient as indicated in the NearCast Model.

Publications

Gravelle, C. M., J. R. Mecikalski, W. E. Line, K. M. Bedka, R. A. Petersen, J. M. Sieglaff, G. T. Stano, and S. J. Goodman, 2015: Demonstration of a GOES-R satellite convective toolkit to "bridge the gap" between severe weather watches and warnings: an example from the 20 May 2013 Moore, OK tornado outbreak. *Bulletin of the American Meteorological Society*, in press. doi:10.1175/BAMS-D-14-00054.1.

WDTD Project 12 – Warning Decision-Making Research and Training

NOAA Technical Leads: Ed Mahoney, Jami Boettcher, Brad Grant, James LaDue, Michael Magsig, and Robert Prentice (WDTD)

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, Flash Flood, and Severe Tracks

Stephen Mullens, Chris Spannagle, Jill Hardy, Andrew Wood, Alex Zwink, and Tiffany Meyer (CIMMS at WDTD)

The Advanced Warning Operations Course (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). When first implemented in 2004, AWOC was the first initiative to deliver warning decision-making training to all forecasters in the NWS since the WSR-88D Operations Course of the 1990s. CIMMS scientists have been heavily integrated into the development, delivery, and support of WDTD's AWOC throughout the years. This year, WDTD have three AWOC courses available for forecasters to complete: Core, Severe, and Flash Flood.

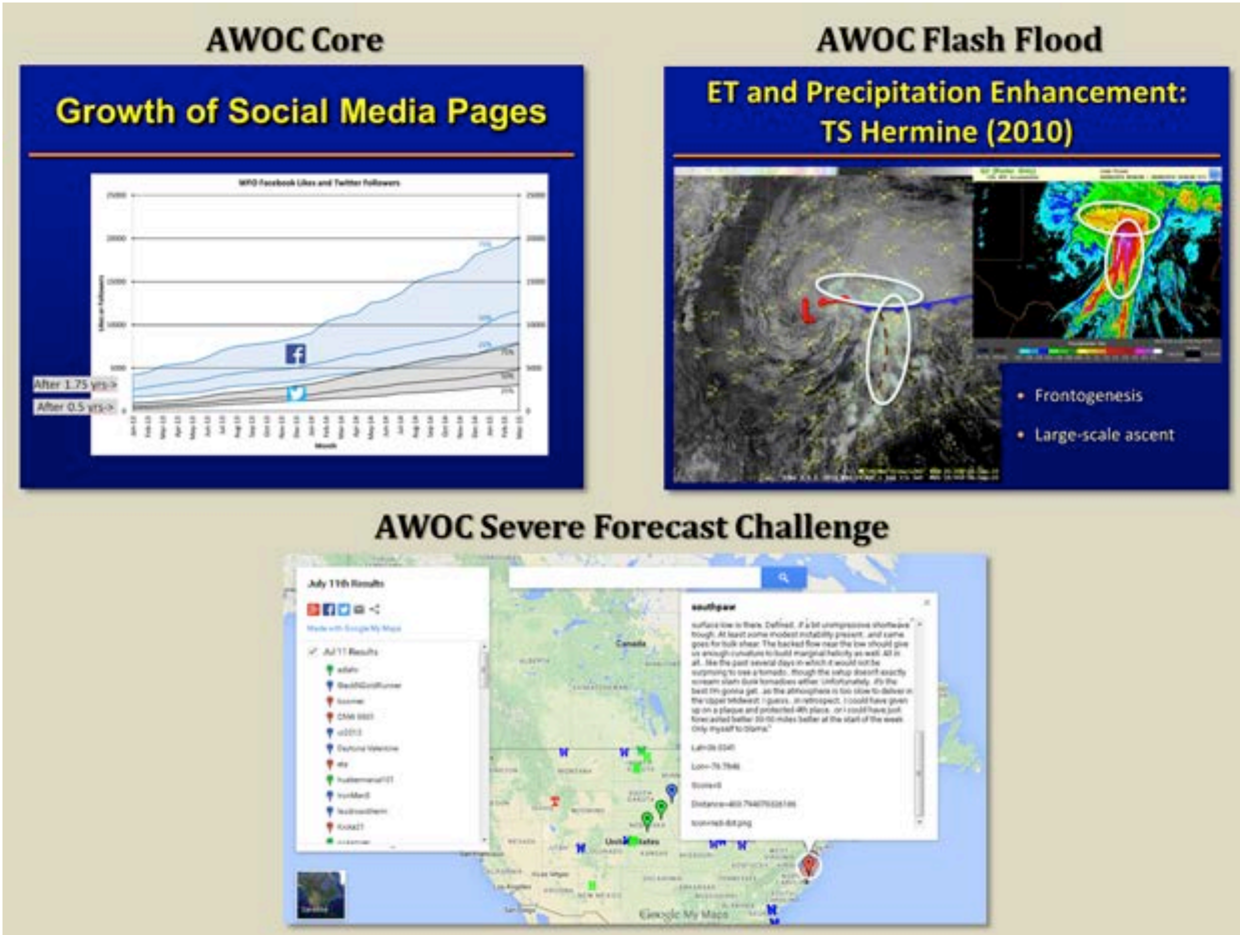
In collaboration with WDTD instructors, CIMMS scientists made numerous changes to all three AWOC courses. These course changes include the following items:

- AWOC Core: CIMMS scientists developed two new modules on the best practices of social media use by NWS weather forecast offices (WFOs) to disseminate and collect information in near real-time. Additionally, CIMMS scientists updated two communications-related modules describing the social science aspects of the warning response process.

- AWOC Severe: CIMMS scientists developed new lessons on locating updrafts by satellite. CIMMS scientists also managed the AWOC Severe Forecast Challenge (and its associated webinars), an applied learning exercise where forecasters can apply concepts learned from AWOC Severe training in a forecasting environment. This past year, the forecast challenge was opened up to all NWS forecasters. This change resulted in 150 NWS warning forecasters issuing 3000 individual forecasts during the ten-week-long event. Lastly, CIMMS scientists did the initial preparation work on the first WES-2 simulation to be included in the AWOCs (due for release at the end of Summer 2015).

- AWOC Flash Flood: CIMMS scientists developed four new lessons on recognizing conceptual models for flash flooding and updated the WES simulation for this year's version of the course. Portions of AWOC Flash Flood were included in a national training initiative for all WFO forecasters to complete by the end of 2015. As part of this requirement, CIMMS scientists have collaborated with WDTD instructors to provide NWS management with monthly reports on forecaster progress through the training curriculum.

CIMMS scientists also contribute logistical support for all three AWOC courses and their management. This support includes responding to questions from NWS forecasters, assisting local facilitators, providing certificates of completions to students, and producing statistical progress reports of students and forecast offices using NOAA's Learning Management System.



Composite image shows example visuals from each AWOC course: (upper left) AWOC Core lesson discusses the use of social media in routine operations at WFOs; (upper right) AWOC Flash Flood lesson on recognizing the conceptual models of mechanisms that can trigger flash flooding; (bottom) AWOC Severe Forecast Challenge webpage showing the locations of all participant forecasts, as well as daily Local Storm Reports for comparison.

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

Jill Hardy, Eric Jacobsen, Dale Morris, Mason Rowell, Chris Spannagle, Stanislav Speransky, Matt Teraldsen, Aaron Ward, and Alex Zwink (CIMMS at WDTD)

The NWS has nearly reached completion on its technology upgrade to its next generation weather data display system Advanced Weather Interactive Process System 2 (AWIPS-2). The transition of NWS forecast offices, national centers, and River Forecast Centers to this software is nearing completion, with only one forecast office left to switch as of July 2015. Throughout this process, CIMMS scientists at the WDTD support the deployment and attendant training requirements of AWIPS-2, including both the new, cutting edge enhancements being integrated into that platform and the simple “variances” between the old and new platforms. CIMMS scientists monitor certification

for this training, and regular updates address new features and changes to existing ones amidst an accelerated schedule of version releases from the AWIPS contractor. These releases have included at least two major versions in the past year, 14.3.1 and 14.4.1, with a number of minor versions that also introduced changes.

CIMMS scientists at the WDTD continue to build high-level expertise in AWIPS-2, which allows them to serve as focal points supporting the technical needs of the training mission of the WDTD. This includes baseline day-to-day efforts and tool development for maintaining a comprehensive dataset to be used in case analysis and simulations. CIMMS also operate in-house test beds in which new software and products are tested against legacy tools. This year's product testing included Multi-Radar/Multi-Sensor (MRMS) product grids, Earth Networks total lightning data, the tracking meteogram, and the next-generation warning generation environment known as Hazard Services. A majority of development and subsequent training entails close collaboration between NSSL, HWT, and other NOAA partners.

In addition to infrastructure support, deliverables produced by CIMMS scientists directly reach field offices in the form of training on new algorithms and products. In the past year, this has included a module on incorporating dual-polarization (or dual-pol) radar data into the High-resolution Precipitation Estimation (HPE) and Bias HPE, which results in the default precipitation estimation algorithms now relying on this dual-pol data. This training enables forecasters to understand the advanced new algorithms available to them and the trade-offs inherent in an ever-increasing toolkit for precipitation estimation. In addition, archiver instruction is now available to aid training officers in retaining local weather data, a capability which is critical to the event simulation and training needs of their staff. Given the continuing need to familiarize forecasters with new AWIPS-2 functionality, and in particular with the anticipated rollout of multiple new products and major upgrades, training for the coming year is expected to remain a major need which WDTD CIMMS staff will address.

Choosing the Optimal FFMP QPE Source

	Maximized coverage?	Bias corrected?	Dual-Pol? (as of 14.3.1)	Resolution?
HPE mosaic	Yes	No	Yes	1 km x 1 km 5 min
Bias HPE mosaic	Yes	Yes	Yes	1 km x 1 km 5 min
Single radar DPR	No	No	Yes	0.25 km x 1 deg 3-6 min
Single radar DHR	No	No (default, but configurable at RPG)	No	1 km x 1 deg 3-6 min

This image shows an example slide from the lesson Incorporating Dual-Pol HPE/Bias HPE into Flash Flood Decision Making. This particular slide shows a framework to help NWS forecasters decide which data source to use when launching the Flash Flood Monitoring and Prediction (FFMP) application in AWIPS-2 to maximize its effectiveness.

3. Distance Learning Operations Course (DLOC)/Radar and Applications Course (RAC)

Alyssa Bates, Michael Bowlan, Jill Hardy, Eric Jacobsen, Stephen Mullens, Dale Morris, Stanislav Speransky, Chris Spannagle, and Andrew Wood (CIMMS at WDTD)

The WSR-88D Distance Learning Operations Course (DLOC) continues to be an area of active collaboration between CIMMS and WDTD. 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. WDTD teaches this course via a combination of teletraining, web-based instruction, on-station training, and residence training.

CIMMS staff members are heavily involved with the development of DLOC. The collaborative work with WDTD instructors includes applied research on recent radar improvements and current WSR-88D capabilities to assess severe weather and flash flooding threats, as well as developing training. CIMMS scientists worked 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 effort allowed CIMMS staff and their WDTD collaborators to develop and update significant portions of DLOC for the latest available science and technology during the past year. Another area where CIMMS staff members played a critical role with DLOC is during the residence component of the course. The collaborative work with WDTD during these classes included developing lecture materials, exercises, and simulations; delivering presentations, and providing expertise on warning-decision making issues to the class participants.

This work is ongoing. Recently, WDTD decided to rename the DLOC to provide a better title describing the course's content. The new name of the course is the Radar and Applications Course (RAC).

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

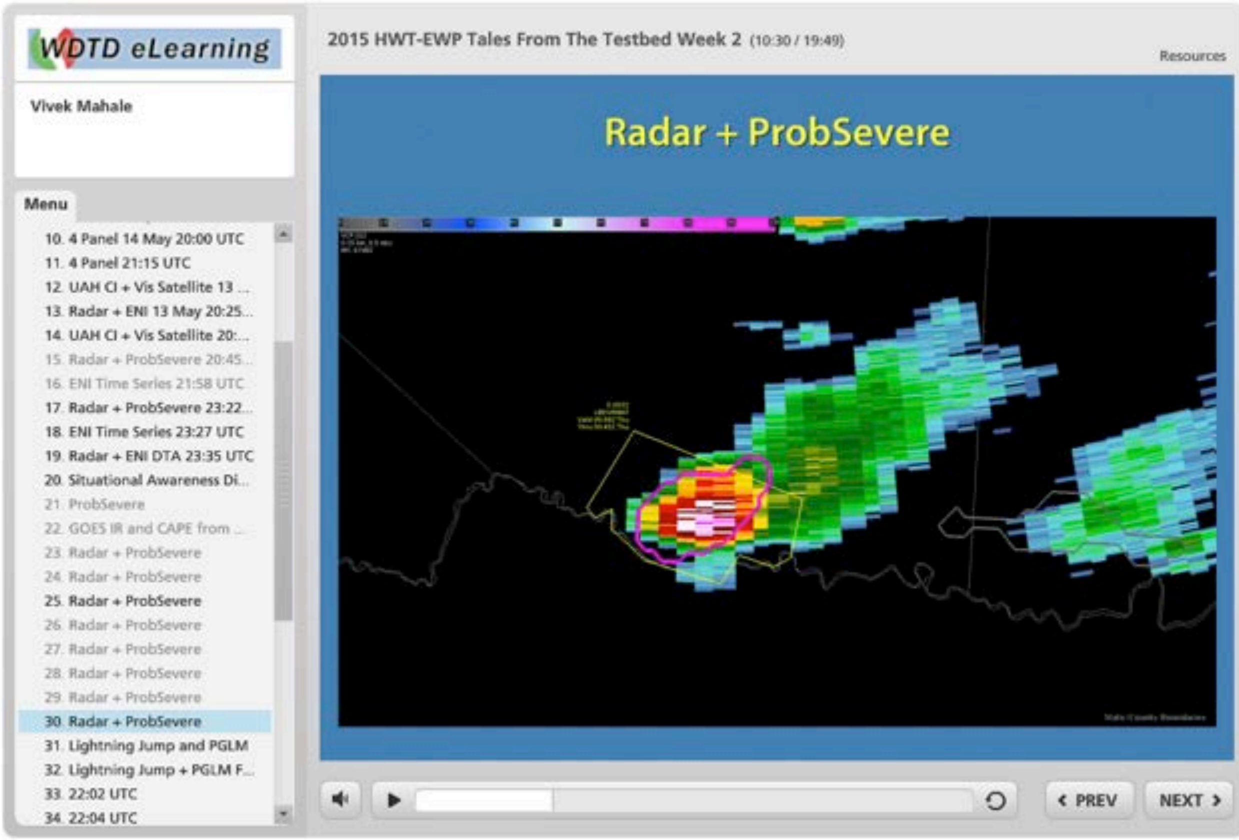
4. Experimental Warning Program/NOAA Hazardous Weather Testbed Support: Tales from the Testbed Webinars

Michael Bowlan and Matt Elliott (CIMMS at WDTD)

The 2015 Spring Experimental Warning Program occurred from 4 May 2015 to 12 June. 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. They were the evaluations of: (1) multiple simulated GOES-R convective (including lightning) products, (2) the Joint Polar Satellite System (JPSS) NOAA Unique CrIS/ATMS Processing System (NUCAPS) Soundings, and (3) various Earth Networks' lightning products.

Forecasters participated in the experiment one week at a time, with five NWS forecasters and one broadcast meteorologist each week (for a total of 25 NWS forecasters and 5 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 scientists 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 scientists 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.

In addition to facilitating these webinars for the Spring Experiment, a separate experiment (called the Hydro Experiment) was conducted by the Hydrometeorological Testbed for four weeks from 7 July 2014 to 1 August 2014. Forecasters also participated in this experiment for one week at a time, with four forecasters each week (all from WFO's and RFCs). This experiment was geared toward testing and evaluating numerous Multi-Radar/Multi-Sensor (MRMS) and Flooded Locations And Simulated Hydrographs Project (FLASH) products to support WFO Flash Flood operations. CIMMS scientists again facilitated these weekly webinars and attended weather briefings throughout the experiment.



This image shows a screen capture from one of the "Tales from the Testbed" webinars facilitated by CIMMS staff during the 2015 Spring Experiment. The graphic shows the GOES-R ProbSevere product (purple) overlaid on radar Reflectivity being utilized to issue an experimental severe thunderstorm warning (yellow). The purple outline indicates a high probability of severe weather within the hour.

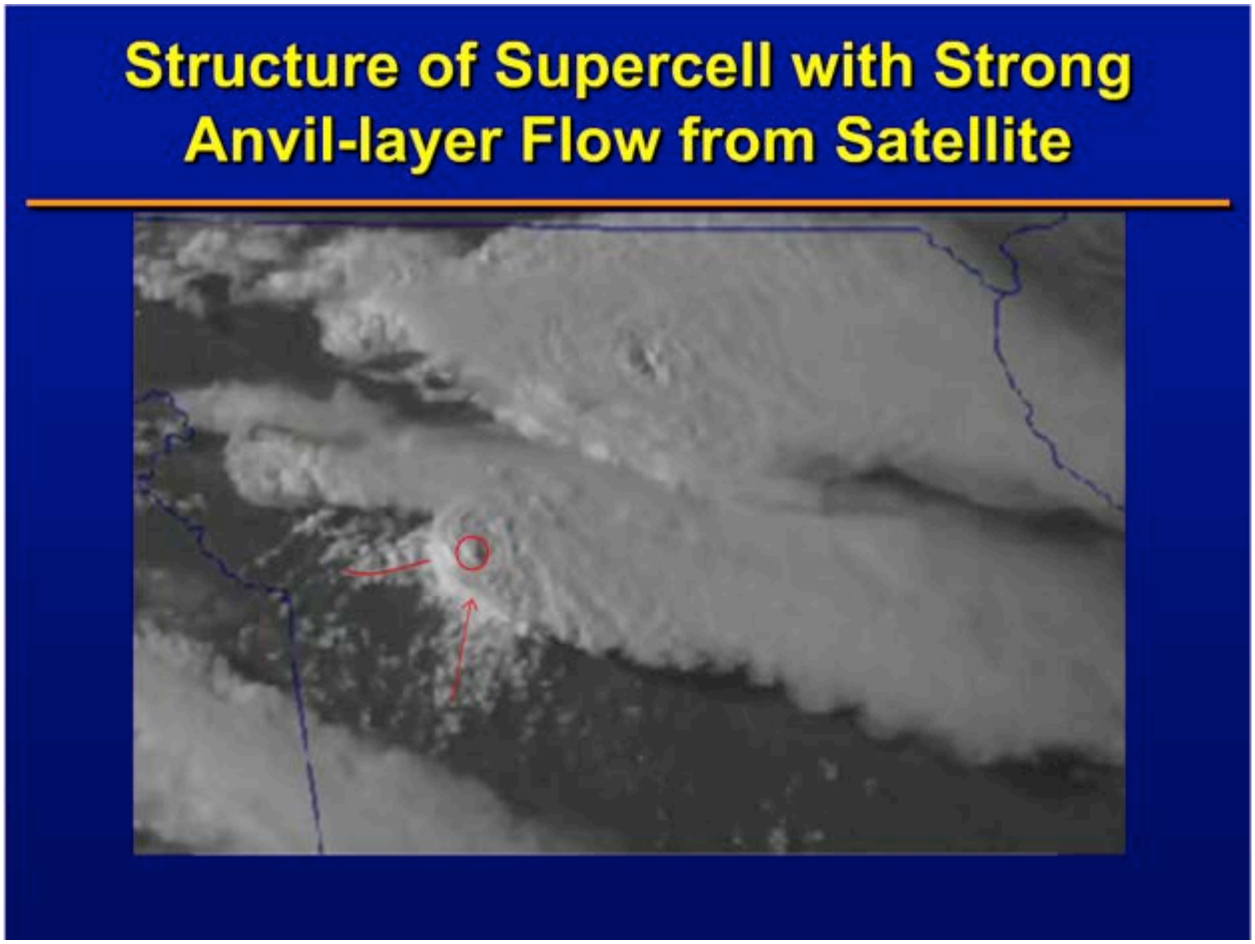
5. Geostationary Operational Environmental Satellites – R Series (GOES-R) Science Infusion into WDTD Training

Michael Bowlan (CIMMS at WDTD)

With the launch of GOES-R rapidly approaching, forecasters need to be prepared for all of the new data it will make available for use during WFO operations. The Hazardous Weather Testbed has included many simulated GOES-R convective products and applications during their experiments for the last few years. However, more can be done to aid forecasters to incorporate these tested applications into their local forecasting and warning operations. The infusion of GOES-R products and data into the WDTD AWOC and other training is a crucial component in this process to transfer GOES-R research into operations by the time the satellite is launched.

Over the last year, CIMMS scientists have worked to update the existing satellite training in the AWOC Severe Track in preparation for GOES-R. While the training cannot show actual GOES-R imagery yet to highlight the important details, the updated

AWOC Severe lessons reflect some of the recent GOES-R and other satellite-based research that is ready for operational use. This work is preliminary and will continue as the GOES-R satellite is launched and live data becomes available. Eventually, GOES-R will be infused across the three hazard-based AWOC courses at WDTD (Severe, Flash Flood, and Winter).



This image shows a screen capture from one of the updated AWOC Severe modules depicting the structure of a supercell in a strongly sheared environment as seen from satellite.

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

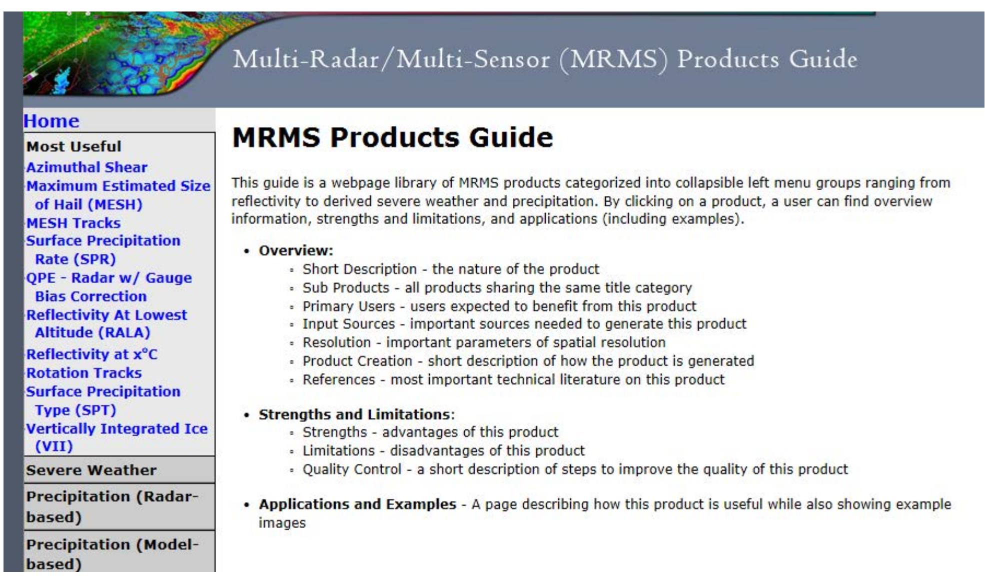
Alyssa Bates, Matt Elliott, Jill Hardy, Chris Spannagle, and Matt Teraldsen (CIMMS at WDTD), and Steven Martinaitis (CIMMS at NSSL)

NSSL has been developing MRMS products over the past decade to overcome limitations inherent in single-sensor data products. The initial suite of operational MRMS products was recently fielded for use across the NWS via the Internet (using either web pages or Unidata's Local Data Manager, or LDM, software access) and their internal Satellite Broadcast Network (SBN). WDTD has assisted NSSL in this effort by testing

the data ingest and application of these data in the Advanced Weather Interactive Processing System (AWIPS), as well as producing training on the use of these data in an operational environment. The MRMS development and operational implementation project recently received a 2015 Department of Commerce Silver Medal for the developers' efforts.

CIMMS scientists at WDTD were extensively involved in the testing and training development process on MRMS products. In October 2014, WDTD instructors and CIMMS scientists released introductory on-line training modules for NWS forecasters to become familiar with the products during the initial web-based release. The lessons introduced the MRMS system, discussed some of the special data processing involved, and highlighted several new products (severe, aviation, and hydrological) contained within the MRMS suite. Simultaneously with the initial training release, WDTD released (in collaboration with CIMMS scientists) an in-depth reference website providing details about the MRMS products and their associated references. In Spring 2015, production began on a new webinar series (entitled "MRMS Application of the Month") to support MRMS implementation. These half-hour webinars feature a NWS warning forecaster or NSSL research scientist showcasing a recent severe weather event and how MRMS impacted (or, in the case of NSSL presenters, could have been used in) their warning decisions or operations.

The work on MRMS training is ongoing. WDTD instructors and CIMMS scientists plan on releasing a second set of training lessons in the summer of 2015. These lessons will include in-depth, application-based lessons, an overview of new lightning products, and lessons on incorporating MRMS data in warning decision-making. Future work is planned for training modules on aviation impacts, hydrology, and research with MRMS.



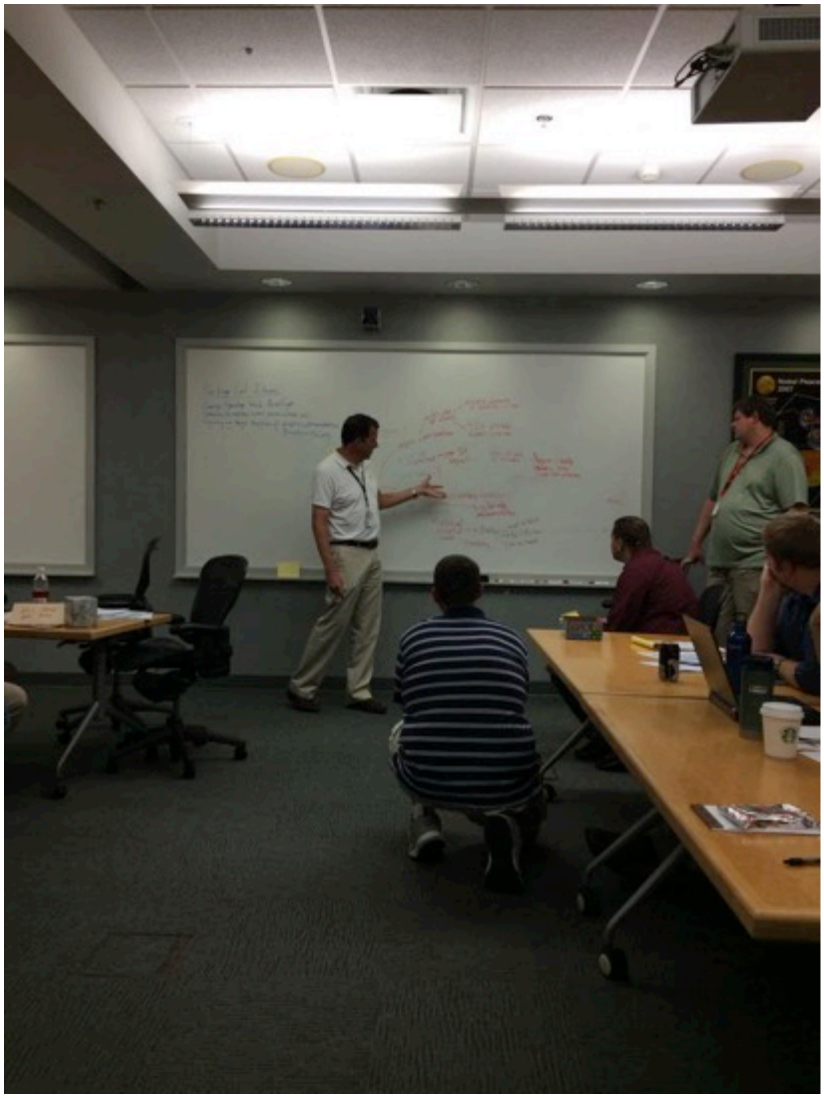
As part of the initial training provided on MRMS, an on-line product reference guide was developed to help forecasters as they started integrating the products into their operational workflow.

7. Science and Operations Officer (SOO)/Development Operations Hydrologists (DOH) Facilitation Workshop

Michael Bowlan, Matt Elliott, Eric Jacobson, Dale Morris, Stephen Mullens, Chris Spannagle, Stanislav Speransky, Andrew Wood, and Alex Zwink (CIMMS at WDTD)

NWS Science and Operations Officers (SOOs) and Development Operations Hydrologists (DOHs) serve an important role for WDTD distance learning. These individuals facilitate professional development for the staff in each NWS Warning Forecast Office and River Forecast Center, respectively, throughout the U.S. The WDTD provides facilitation training to newly hired SOOs and DOHs in order to help them be more effective in this role. This training occurs as a three-and-a-half day “train the trainer” workshop, which is available to both new hires and, when spots are available, veteran facilitators who need refresher training. For the first time in three years, WDTD offered one of these workshops in September 2014 and CIMMS scientists participated in the development and implementation of the workshop.

The training provided during the workshop supports these NWS training officers by improving their proficiency at coordinating, implementing, and managing local training programs. Participants should be able to facilitate learner-centered, performance-based training activities to help transform forecasters in their office in a way that improves performance and provided services. Specific topics covered at the September 2014 workshop included: principles of adult learning, managing cognitive overload, transferring learning to desired performance, and root cause analysis. Topics covered by CIMMS scientists at that workshop included using simulations, graphics and media, and webinars to meet learners’ needs. CIMMS scientists also facilitated group projects that were worked on during the week and presented at the end of the workshop. After the workshop is over, WDTD instructors and CIMMS scientists maintain contact with workshop participants through a Facebook group page that they can join at the workshop. This social media group allows participants to not only connect with instructors and fellow attendees, but also attendees from previous workshops as well. The next SOO/DOH Facilitation Workshop is planned for August 2015.



SOO/DOH Facilitation Workshop participants presenting their results of their Root Cause Analysis exercise.

8. Weather Event Simulator – I (WES)

Alex Zwink (CIMMS at WDTD)

Although it's been fourteen years since its initial release, the CIMMS-developed Weather Event Simulator is still the primary tool used in NWS forecast offices to apply training knowledge in an operational environment. Every NWS forecaster with warning responsibility is required by NWS Directive 20-101 to take two simulations using the WES per significant weather season each year. WDTD training continued to incorporate the WES-1 in the development and implementation of training simulations used for AWOC and DLOC this year.

Almost every NWS forecast office has transitioned to AWIPS-2. Due to this transition and the impending Weather Event Simulator - II Bridge (WES-2 Bridge) deployment, new WES-1 development has ceased. However, the WES-1 software (and associated hardware) needs to be maintained so offices can review archived AWIPS-1 data. WES-1 workstation parts fail occasionally due to hardware age, too. To meet the needs of NWS forecasters, CIMMS staff provided extensive support for installation and troubleshooting of WES-1 software, hardware replacement, and case data in this transition period to the WES-2 Bridge.

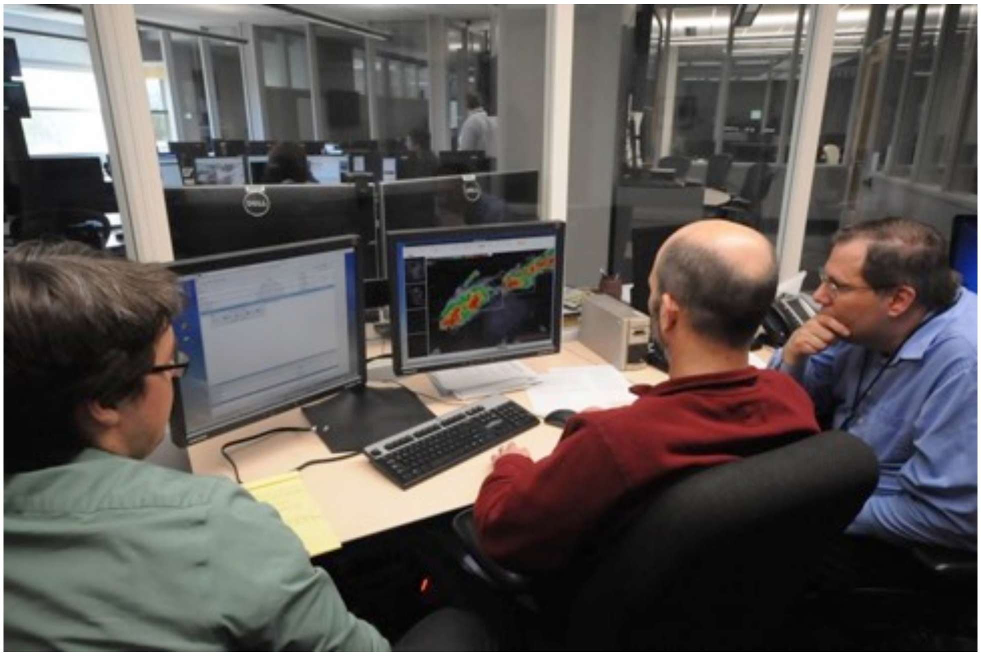
9. Weather Event Simulator – II (WES-2) Bridge

Dale Morris, Tiffany Meyer, Thao Pham, Mason Rowell, Ali Virani, and Alex Zwink (CIMMS at WDTD)

CIMMS scientists at WDTD have developed a new Weather Event Simulator to support the NWS Directive 20-101 (i.e., all forecasters complete two simulations prior to each significant weather season) in the AWIPS-2 era. This new AWIPS-2 simulator, the WES-2 Bridge, fills multiple objectives besides just being a training simulator. WES-2 Bridge incorporates both displaced real-time simulations (time-sequenced revelation of data) and case-reviews (data is displayed based on time set by the user) based on data that is locally archived at a Forecast Office. The simulator software 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 scripting capability provides a method to engage forecasters with feedback as they complete simulations. The WES is also the primary method staff at a local Weather Forecast Office use to view and analyze any archived weather data from AWIPS. The simulator software also supports data reprocessing to ensure compatibility with future AWIPS versions. Lastly, the WES-2 Bridge was developed to serve as a prototype (hence the term bridge) for incorporating training functionality into the “baseline” AWIPS-2 system.

To support this development and to ensure compatibility between AWIPS-2 and WES-2 Bridge, CIMMS scientists at WDTD serve as subject matter experts for the AWIPS Program at the NWS and for the AWIPS contractor. The WES-2 Bridge technology represents significant engineering development because WES-2 Bridge has many requirements above and beyond the AWIPS-2 system that operates alongside (including simultaneous availability of multiple archived data cases from multiple locations). Initial testing of WES-2 Bridge has occurred at the Norman Forecast Office. Three additional forecast offices will perform testing of a full-scale release in the late summer of 2015. WES focal points at three of these four test sites are former CIMMS scientists at WDTD: Aaron Anderson at Norman, OK; Matt Elliott at Sterling, VA; and Mason Rowell at Billings, MT. The initial release, which should follow shortly after this test period, will be accompanied by a requisite training package for WFO focal points. Additional releases with functional and compatibility enhancements are scheduled throughout the coming year.

In addition to simulator development, CIMMS scientists at WDTD collaborated with the NWS and the AWIPS-2 contractor on the design and implementation of an updated archival solution. Because the WES-2 Bridge will be the primary method for NWS forecasters, meteorology researchers, and university students to access archived AWIPS-2 data, CIMMS scientists at WDTD performed significant amounts of testing on the AWIPS-2 archiver. These tests included verifying the archive software functions correctly interfaces well with WES-2 Bridge and producing a dependable archive of all data available in AWIPS-2 (e.g., numerical model, radar, and satellite). CIMMS scientists made recommendations to the AWIPS-2 contractor based on changes in both the AWIPS-2 architecture and the playback requirements of WES-2 Bridge. As the final step in the process, CIMMS scientists developed training materials on using the new archival system for use by NWS forecasters. These training materials, available to forecasters in the NWS learning management system (LMS) and an internal link on their AWIPS, were published and released to NWS forecast offices in fall 2014. To create this training material, configuration exercises, and associated reference documentation, CIMMS scientists researched the transmission, storage, and processing of numerous existing and emerging sources of data. The data sources researched in this effort included, but were not limited to, numerical models, observations, radar, satellite, and guidance as well as the impact of the storage, transmission and processing of these data upon the archival system. CIMMS scientists are working to add simulator support of key hydrological applications used at NWS forecast offices to support training and archived data playback for forecasters who provide hydrologic products and services.



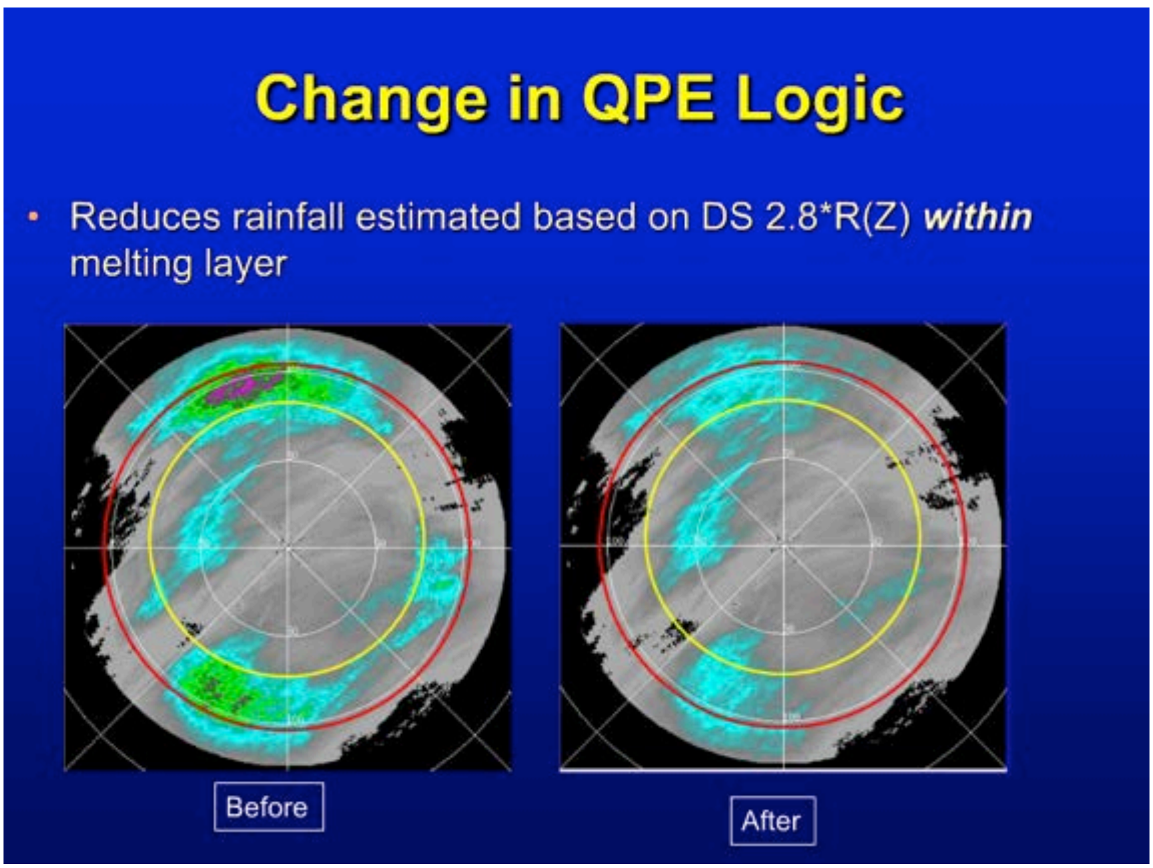
Photograph from the successful WES-2 Bridge test at the Norman Weather Forecast Office. It depicts WES-2 Bridge running on the simulator at the WFO alongside the AWIPS software using archived data captured by the WFO staff (archival procedures also developed by CIMMS).

10. WSR-88D Build Improvement Training

Matt Elliott and Andrew Wood (CIMMS at WDTD)

During the past year, the ROC made several major upgrades to the WSR-88D Radar Data Acquisition Unit (RDA) and Radar Product Generator (RPG) software. The latest software upgrades (Builds 15.0 & 16.0) contain several improvements to existing applications, including the dual-pol QPE algorithm, the Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS), and the RPG Graphical User Interface (GUI). These builds also include two new applications: Differential Reflectivity bias estimation based on Bragg scattering and the Automated Microburst Detection Algorithm (AMDA). CIMMS scientists have worked closely with WDTD 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.



A slide from the on-line training developed by WDTD for WSR-88D Build 15.0. This slide discusses the impact of changing the QPE algorithm to use fewer bins identified as dry snow in the calculation of precipitation estimates in the melting layer.

Publications

National Severe Storms Laboratory, 2015: Flooded Locations and Simulated Hydrographs Project (FLASH). Available at: http://blog.nssl.noaa.gov/flash/hwt-hydro/

National Severe Storms Laboratory, 2015: NOAA Hazardous Weather Testbed Spring Experiment – 2015 Tales from the Testbed. Available at: http://hwt.nssl.noaa.gov/ewp/

Warning Decision Training Division, 2015: Advanced Warning Operations Course (AWOC). Available at: http://www.wdtb.noaa.gov/courses/awoc/index.php

Warning Decision Training Division, 2015: Distance Learning Operations Course (DLOC). Available at: http://www.wdtb.noaa.gov/courses/dloc/index.php

Warning Decision Training Division, 2015: Multi-Radar/Multi-Sensor (MRMS) Training. Available at: http://www.wdtb.noaa.gov/courses/MRMS/index.php

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Warning Decision Training Division, 2015: WSR-88D Build 15.0 Training. Available at: http://www.wdtb.noaa.gov/buildTraining/Build15/index.php

Warning Decision Training Division, 2015: WSR-88D Build 16.0 Training. Available at: http://www.wdtb.noaa.gov/buildTraining/Build16/index.php

Awards

CIMMS scientists were key contributors to winning the NOAA 2015 Silver Medal for the "successful transition of the Multi-Radar, Multi-Sensor system into operations to provide critical radar-based products to forecast weather hazards."

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.

Accomplishments

1. General Overview

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

The eleventh full year of the CIMMS/NWS-Meteorological Development Laboratory (MDL) scientist position was completed during this review period. During this year, the scientist was a co-principal investigator on an independent experiment for the

Experimental Warning Program's (EWP) spring experiments in the NOAA Hazardous Weather Testbed (HWT) (described in a separate section). 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 remote 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 completed in FY15, and the CIMMS/MDL scientist has been involved in the following activities related to the MRMS tech transfer: 1) analyzing data from an advanced experiment in the HWT 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 NWS Warning Decision Training Division (WDTD); 2) serving as 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 (WDTD)

The CIMMS/MDL scientist was a co-principle investigator for an independent experiment within the HWT, conducted separately from the regular spring experiment in the 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. 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 WDTD.

The analysis of the data collected concluded in FY15, including a presentation at the National Weather Association Annual Meeting in October 2014. Results present included: 1) we proved that storm diagnosis happens 2-3 times faster with MRMS data

than without with statistical significance; and 2) we could not prove that Lead Time and False Alarm Time were improved with MRMS data than without MRMS data because our sample size was too small. Lessons learned from this experiment were that it is challenging to create an unbiased control group (those denied MRMS data) because the members could still work harder to "beat" the experimental group (those who had MRMS data) – this is known as the "John Henry Effect". One possibility was to use actual NWS operational warnings as a control group. However, it would be difficult to level the two groups due to the variable warning durations of the operational warnings. It was decided that the planned peer-reviewed publication be shelved, and that future controlled experiments in the HWT consider these factors.

The CIMMS/MDL scientist also worked with WDTD scientists in the development of the MRMS operational training modules for NWS forecasters.

3. MRMS Product Display for AWIPS2

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB) and Darrel Kingfield (CIMMS at NSSL)

The operational MRMS system at NCEP went online and began disseminating data to the weather enterprise on 1 October 2014. The National Weather Service is one of the main customers of these data. Work was completed to design and develop the initial display of the MRMS data in the NWS's Advanced Weather Interactive Processing System 2 (AWIPS2). The CIMMS/MDL scientist was the development manager overseeing an NSSL employee doing the software coding. Two phases of source code were delivered to AWIPS2. The first was delivered with AWIPS2 Build 14.4.1 (deployed to the field by June 2015), and the basic display of the subset of MRMS Initial Operating Capability (IOC) products from the Satellite Broadcast Network (SBN) feed being disseminated from the NCEP MRMS system. The second phase of source code was for the additional of an "all-tilts" capability for the three-dimensional reflectivity cube data. This was delivered for AWIPS2 Build 16.1.1 (deployed to the field by December 2015). In the role of the MRMS display development manager for AWIPS2, the CIMMS/MDL scientist worked with NCEP and Raytheon implementation teams to complete a latency analysis of MRMS data transmission.

The CIMMS/MDL scientist also led the design reviews for the MRMS Operational Web Display.

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/WDTD training documentation. In addition, the CIMMS/MDL scientist serves on the VLab Support Team, to help design, develop, and implement the NWS VLab as a whole. During FY15, the CIMMS/MDL scientist assumed the leadership of the monthly NOAA VLab Focal Point Meetings.

5. Probabilistic Hazard Information (PHI) Tool

Greg Stumpf (CIMMS at NWS/OST/MDL/DAB), and Chris Karstens and Brandon Smith (CIMMS at NSSL)

The CIMMS/MDL scientist continued to be involved with the AWIPS2 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. 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. New for the 2015 test were: 1) evaluation of new probabilistic guidance from the University of Wisconsin CIMSS "ProbSevere" algorithm and an NSSL tornado probability guidance algorithm, both built on the MRMS concept; and 2) evaluation of various human-machine mix scenarios, including forecaster –in, -over, and –out-of the loop situations with the probabilistic guidance. Also new for this year was a collaborative experiment with Emergency Managers, operating in a different room, evaluating PHI output in various real-time and archive decision support scenarios.

The CIMMS/MDL scientist was a co-investigator on a USWRP R2O grant that was awarded during FY15. He is co-investigator, along with scientists at NOAA/ESRL/GSD, to develop a real-time verification system for the PHI Tool, which will use 1) a new way to blend, in real-time, remotely-sensed data from the MRMS system with live storm reports, and 2) innovative warning verification techniques that have been under development for several years, which include new measures such as False Alarm Area and False Alarm Time in verified warnings as well as location-specific lead- and departure-time. This project is funded for the next three years, and is just getting underway in FY15.

The CIMMS/MDL scientist served as the lead reporter on the various aspects of the PHI project at MDL quarterly status briefings.

Publications

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**, 1229-1237. http://dx.doi.org/10.1175/WAF-D-14-00039.1

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Jiang, H., S. Albers, I. Jankov, D. Birkenheuer, Z. Toth, Y. Xie, G. Stumpf, D. Kingfield, B. Motta, M. Scotten, and J. Picca, 2015: Real-time applications of the variational version of the Local Analysis and Predication System (vLAPS). *Monthly Weather Review*, **143**, in press. http://dx.doi.org/10.1175/BAMS-D-13-00185.1
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Awards
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NWSTC Project 14 – Forecast Systems Optimization and Decision Support Services Research Simulation and Training

NOAA Technical Leads: John Ogren, Jeffrey Zeltwanger, and Jim Poole (NWSTC), and Kim Runk (NWS/Operations Proving Ground – OPG)

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

Funding Type: CIMMS Task II

Objectives

1. Forecast Systems Optimization

Sub-Objective 1: Provide end-user training for meteorologists and hydrologists using Advanced Weather Interactive Processing System (AWIPS) in the NWS. This includes updating previously created training to more useful and functional products.

Sub-Objective 2: Support and maintain end-user training for meteorologists and hydrologists using the Community Hydrologic Prediction System (CHPS) in the NWS. This includes updating previously created training to more useful and functional products.

Sub-Objective 3: Create and deliver training for Broadcast Message Handler for both the Operational Testing and Evaluation (OT&E) period, and for deployment. This sub-objective is a result of the Hurricane Sandy Assessment objective, "Improve availability and accessibility of NWS data and information for NOAA Weather Radio."

Sub-Objective 4: Provide support and maintenance for courses required for many NWS employees. This includes assisting the main course author or instructional designer with updates.

Sub-Objective 5: Create and deliver a course to aid those NWS employees that report data errors using the National Centers for Environmental Information (NCEI) Datzilla ticketing system.

Sub-Objective 6: Continue to support training efforts for Cooperative Observer Focal Points and Observing Program leaders through distance learning courses, residence courses, and testing the new Station Information System (SIS).

Sub-Objective 7: Support Hazard Services instructors and technical leads as they strive to reduce AWIPS II warning tools, by creating a tool that provides all warning services. Supporting this effort includes staying up-to-date on progress and providing ideas for future training.

2. NWS Proving Ground Operational Service Delivery Simulations

Conduct an Operational Readiness Evaluation (ORE) to analyze the use and implementation of GOES-14 SRSOR 1-minute satellite imagery.

3. Impact Based Decision Support Services Research and Development

Sub-Objective 1: Prepare NWS employees for deployment in the field, and train them to communicate weather information to the public and partners effectively. Accomplishing this is the main goal of the Impact-Based Decision Support (IDSS) Deployment Boot Camp residence course.

Sub-Objective 2: Transform the IDSS residence course into a traveling version, and teach concepts to any national center or regional office that requests it.

Sub-Objective 3: Conduct training sessions that complement the online Media Training for NWS course. In these sessions, students should learn about applying the course materials and practice interviewing. These sessions are a primary session in residence courses such as the Hydro Program Managers (HPM) course, IDSS Deployment Boot Camp, and many Leadership Academy courses.

Sub-Objective 4: Deliver in-class presentations about how humans communicate, how to give feedback, how to deliver information, and how different modes of communication, such as body language, affect our message.

4. Advanced Training Development

Sub-Objective 1: Develop expertise in useful technology, best practices, and methodologies in effort to produce better training and share information. This might include attending professional development training and conferences, and pushing the boundaries of instructional design, training, and technology.

Sub-Objective 2: Help NWSTC employees grow and learn new tools for training and collaboration.

Sub-Objective 3: Reach out to others in the agency through various methods, and spread information about available training, professional development, and the roles NWS “staff play” in a Weather Ready Nation.

Sub-Objective 4: Use expertise to join and help NWSTC and OPG focal point teams.

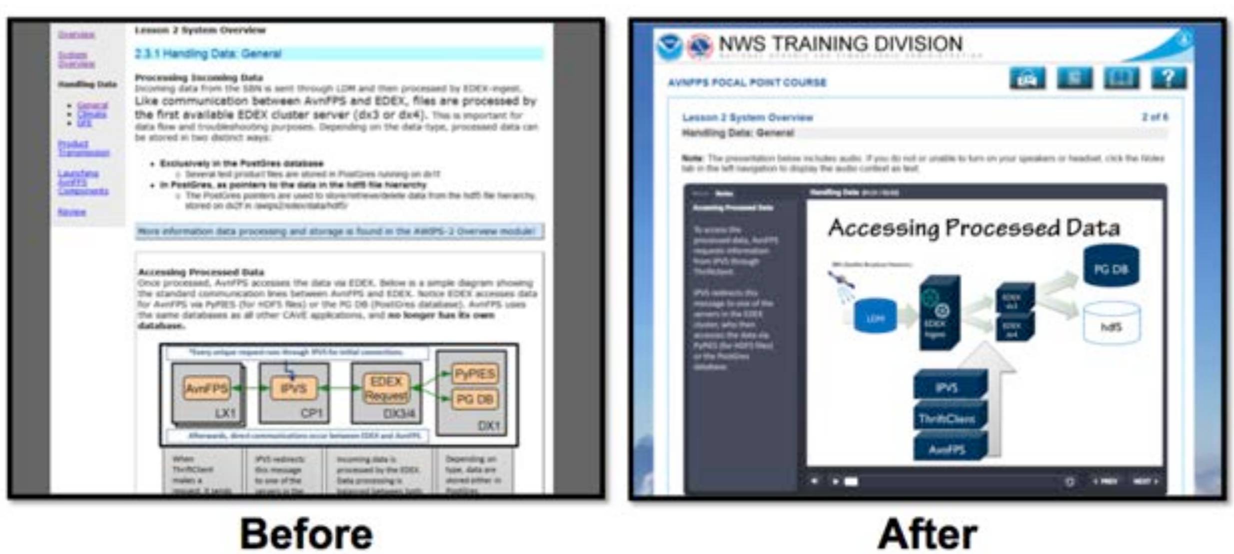
Accomplishments

1. Forecast Systems Optimization

a. Sub-Project 1: Advanced Weather Interactive Processing System (AWIPS II) Distance Learning

Sarah Grana (CIMMS at NWSTC), and Jeffrey Zeltwanger and Hattie Wiley (NWS Leadership Academy)

Distance learning modules for AWIPS II applications have aged. Over the past year, Sarah Grana updated the AvnFPS Focal Point Training, AvnFPS Transition Focal Point Training, and completed in an updated format Collaboration Tool training. These courses also received new quizzes for the new NWS Learning Center transition.



A sample AWIPS course (back) in the old format and the AvnFPS AWIPS II course (front) in the new format.

b. Sub-Project 2: Community Hydrologic Prediction System (CHPS) Distance Learning

Sarah Grana (CIMMS at NWSTC), Teresa Murphy (NWS HQ), Doug Streu (NWS Decision Support and Communication Services), and Hattie Wiley (NWS Leadership Academy)

Distance learning modules for CHPS created in previous reporting periods require continued support and maintenance. Sarah Grana updated two of the ten CHPS courses and put them into the new, user-friendlier formats. This project will continue as time allows in the upcoming year.

c. Sub-Project 3: Deliver Broadcast Message Handler (BMH) Training

Sarah Grana and Megan Taylor (CIMMS at NWSTC), Teresa Murphy (NWS HQ), Doug Streu (NWS Decision Support and Communication Services), Jeffrey Zeltwanger and Hattie Wiley (NWS Leadership Academy), Jim Poole (Electronics and IT Division)

The Broadcast Message Handler (BMH) is a software and hardware update that replaces the Console Replacement System for NOAA Weather Radio. CIMMS' Sarah Grana and Megan Taylor helped develop two types of training. The first stage for BMH is Operational Testing and Evaluation (OT&E). This stage requires both Configuration Training and User Training. Sarah Grana worked with NOAA technical leads to develop expertise in the BMH software. She also wrote lesson plans and job sheets for both an OT&E User Training Distance Learning Course, and a BMH Focal Point OT&E Training course to be held at the NWSTC the week of August 24, 2015. In addition, Sarah gave a BMH demo to the AWIPS II System Administration class. Megan Taylor reviewed BMH materials for content and design, and designed and built the OT&E User Training distance learning course. This project will go into deployment phase after the OT&E period, and will require full focal point and user training distance learning courses.

(Left) Screen shot of the Broadcast Message Handler (BMH) OT&E online user training. (Right) Sarah Grana working with the BMH application.

d. Sub-Project 4: Assist Instructors with Distance Learning Updates and Maintenance

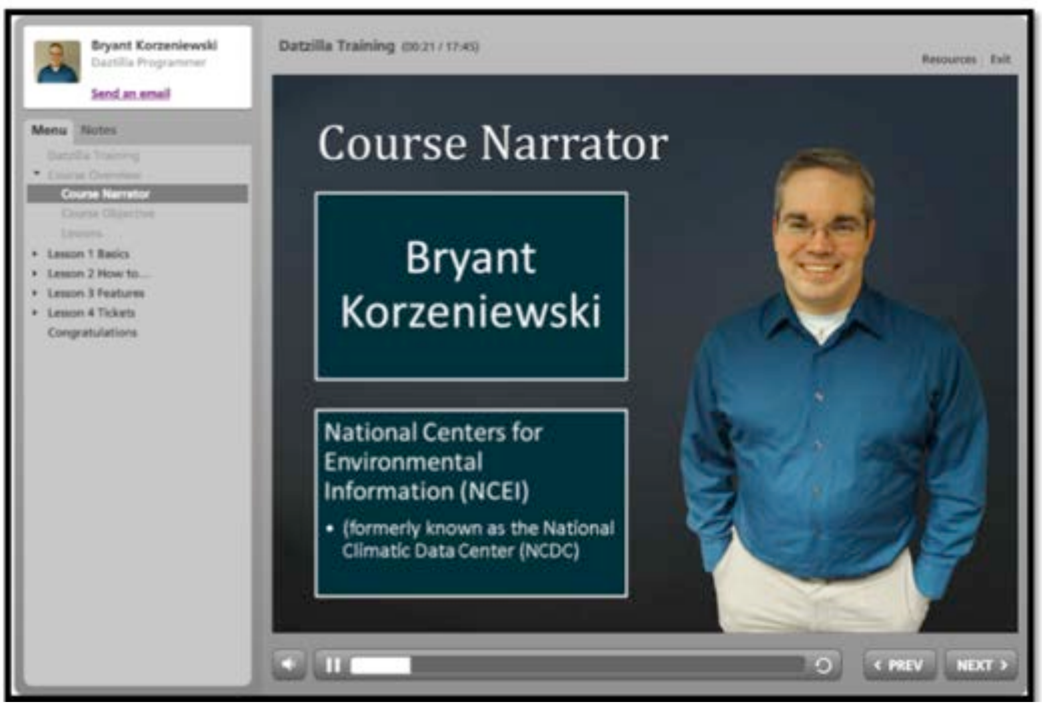
Sarah Grana and Megan Taylor (CIMMS at NWSTC), and Hattie Wiley (NWS Leadership Academy)

Part of the distance learning process is updating and maintaining existing courses. Sarah Grana assisted NWSTC Instructional Designer Hattie Wiley with reviewing and updating key portions of the Introduction to the NWS and Media Training distance learning courses. This included recreating old or broken images, videos, and interactions, and creating quizzes for the new NWS Learning Center. Megan Taylor also consulted and reviewed these materials.

e. Sub-Project 5: Datzilla User Training

Megan Taylor (CIMMS at NWSTC), Hattie Wiley (NWS Leadership Academy), Bryant Korzieneiwski (NWS NCEI), and Jim Zdrojewski (NWS HQ)

The NWSTC created a user course for the Datzilla data error ticketing system. Megan Taylor kicked off this project with analysis and information gathering with Bryant Korzieneiwski and Jim Zdrojewski. Then, the project went to the NWSTC Instructional Designer, Hattie Wiley, for content, design, and development. Anticipated release of the course is August or September 2015.



Screen shot of the Datzilla Training course.

f. Sub-Project 6: Cooperative Observer Course and Station Information System Support

Megan Taylor (CIMMS at NWSTC), Marco Bohorquez (NWS Decision Support and Communication Services Division), and Jim Zdrojewski (NWS HQ)

In August 2014, the NWSTC released the NWS Observing Program distance course. Management also selected Marco Bohorquez as the new course lead to replace Jim Jones (retired). During the reporting period, Megan Taylor trained Marco on the aspects of the Cooperative Observer Program, the residence course, and updates to the program. This concurrently with Megan’s preparations for the March 2015 residence course, and design of a new student observer plot for the NWSTC. Megan also participated in beta tests for the new Station Information System (SIS), which is used in the program to track station data. This was integrated into the March course. Marco officially took over the course and training aspects of the NWS Observing Programs in April 2015. Megan continued as a consultant for the duration of the reporting period.



(Top Left) Students working on equipment. (Top Right) Megan Taylor teaching communications. (Bottom) Megan demonstrating a technique.

g. Sub-Project 7: Hazard Services Training

Sarah Grana (CIMMS at NWSTC), Dave Cokely (NWS Decision Support and Communication Services Division), and Tom Piper and Bob Rood (NWS HQ)

Hazard Services is a team of technical leads (and instructors) striving to reduce AWIPS warning tools, and integrate them into one program. This project will require training as it develops. At this point, Sarah Grana is auditing calls and helping instructor Dave Cokely assess future training needs.

2. NWS Proving Ground Operational Service Delivery Simulations

Katie Crandall and Derrick Snyder (CIMMS at NWSTC), Chad Gravelle (CIMSS-University of Wisconsin), Kim Runk (NWS OPG), and Jack Richardson (NWSTC Contractor). In collaboration with Matthew Foster and Gregory Noonan (NWS), and Katie Bowden (CIMMS at NSSL)

In preparation for the launch of the Geostationary Operational Environmental Satellite (GOES)-R Series, the Operations Proving Ground hosted six weeklong evaluations of 1-minute satellite imagery in the first part of 2015. Seventeen National Weather Service (NWS) operational forecasters from four regions (Central, Southern, Western, and Eastern) participated in these operational readiness evaluations with the primary purpose of assessing the value and usefulness of integrating high temporal resolution satellite imagery into various analysis and forecast applications. Simulations were developed using GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) cases from 2013 and 2014.

After the initial six week-long evaluations, two additional weeks were added with the specific purpose of assessing the ability of forecasters to integrate live high temporal resolution satellite imagery from GOES-14 SRSOR into the convective warning process. Six forecasters from Central Region participated in these evaluations.

Katie Crandall and Derrick Snyder both helped with the planning and execution of the operational readiness evaluations. Before the evaluations took place, Katie Crandall designed decision logs and surveys to be taken by participants during evaluation in both Vlab and Google Docs. She also compiled social media posts and created storm report PowerPoint presentations for the evaluations. During the six-week evaluations she took notes during Recent Case Walkthroughs, took notes during discussions, assisted forecasters during evaluations, participated in NWSChats, and setup and monitored archived storm reports and social media PPTs. During the live data evaluations, she took notes during discussions, assisted forecasters during evaluations, monitored NWSChats, and monitored incoming storm reports and social media posts. After the evaluations, she analyzed the data acquired from the evaluations, helped write the ORE final report to NWS management, helped create presentations of findings from evaluations, and created abstracts, presentations and posters describing findings from this ORE for upcoming NWA and AMS annual meetings.

Before the evaluations took place Derrick Snyder pre-processed datasets of satellite imagery, radar, surface observations, and derived satellite products for ingest into AWIPS-II. He also recorded a weather briefing customized to each simulation that was played for the forecasters before each simulation. In both the simulation and live data portion of the ORE, Derrick set up and configured AWIPS-II for use by the forecasters, created and found situational awareness material (reference maps, pictures, webcams, posts to social media, etc.) to aide forecasters in making decisions. During the six-week evaluations, he took notes during Recent Case Walkthroughs, assisted forecasters during evaluations, and participated in NWSChats. During the two weeks of live data evaluations, he assisted forecasters during evaluations, monitored NWSChats, and monitored incoming storm reports and social media posts. After the evaluations, he wrote up simulation and live weather summaries for the ORE final report to NWS management, and created abstracts, presentations and posters discussing findings from this ORE for upcoming NWA and AMS annual meetings.

Front Row: Kim Runk (OPG); Katie Crandall (OPG); Marcia Cronce (WFO Milwaukee, WI); Jack Richardson (OPG)
Back Row: Derrick Snyder (OPG); Marc Spilde (WFO Medford, OR); Paul Wolyn (WFO Pueblo, CO); Chad Gravelle (OPG)

Front Row: Kim Runk (OPG); Chad Gravelle (OPG); Katie Crandall (OPG); Rebecca Mazur (WFO Cheyenne, WY)
Back Row: Jack Richardson (OPG); John Goff (WFO Burlington, VT); Derrick Snyder (OPG); Jeff Davis (WFO Tucson, AZ)

Front Row: Todd Chambers (WFO Billings, MT); Eleanor Vallier-Talbot (WFO Taunton, MA); Katie Crandall (OPG); Stephen Konarik (WFO Miami, FL)
Back Row: Jack Richardson (OPG); Kim Runk (OPG); Derrick Snyder (OPG); Chad Gravelle (OPG)

Front Row: Jack Richardson (OPG); Kim Runk (OPG); Katie Crandall (OPG); Chad Gravelle (OPG)
Back Row: Derrick Snyder (OPG); Brian Boyd (WFO Elko, NV); Bryan Jackson (WFO Sterling, VA); Andrew Moulton (WFO Morristown, TN)

Group pictures from ORE Week 1-5. Names of participants listed with each image.

Front Row: Jimmy Taeger (WFO San Diego, CA); Katie Crandall (OPG); Paul Frisbie (WFO Grand Juction, CO)
Back Row: Jack Richardson (OPG); Derrick Snyder (OPG); Kim Runk (OPG); Chad Gravelle (OPG)

Front Row: Kim Runk (OPG); Chris Jakub (WFO Wichita, KS); Jack Richardson (OPG); Katie Crandall (OPG);
Back Row: Chad Gravelle (OPG); Derrick Snyder (OPG); Mike Kochasic (WFO Goodland, KS); Fred Glass (WFO St. Louis, MO)

Front Row: Kim Runk (OPG); Katie Crandall (OPG); Jim Caruso (WFO Wichita, KS)
Back Row: Derrick Snyder (OPG); Dan Nietfeld (WFO Omaha, NE); Jenni Laflin (WFO Kansas City, MO); Chad Gravelle (OPG)

Group pictures from ORE Week 6, and Weeks 1-2 (Convective Only). Names of participants listed with each image.

From Left to Right: Stephen Konarik (WFO Miami, FL); Todd Chambers (WFO Billings, MT)

From Left to Right: Ryan Ellis (WFO Raleigh, NC); Ryan Husted (WFO Goodland, KS); Robert Bohlin (WFO Flagstaff, AZ)

From Left to Right:Paul Frisbie (WFO Grand Juction, CO); Jimmy Taeger (WFO San Diego, CA)

From Front to Back: Bryan Jackson (WFO Sterling, VA); Andrew Moulton (WFO Morristown, TN); Chad Gravelle

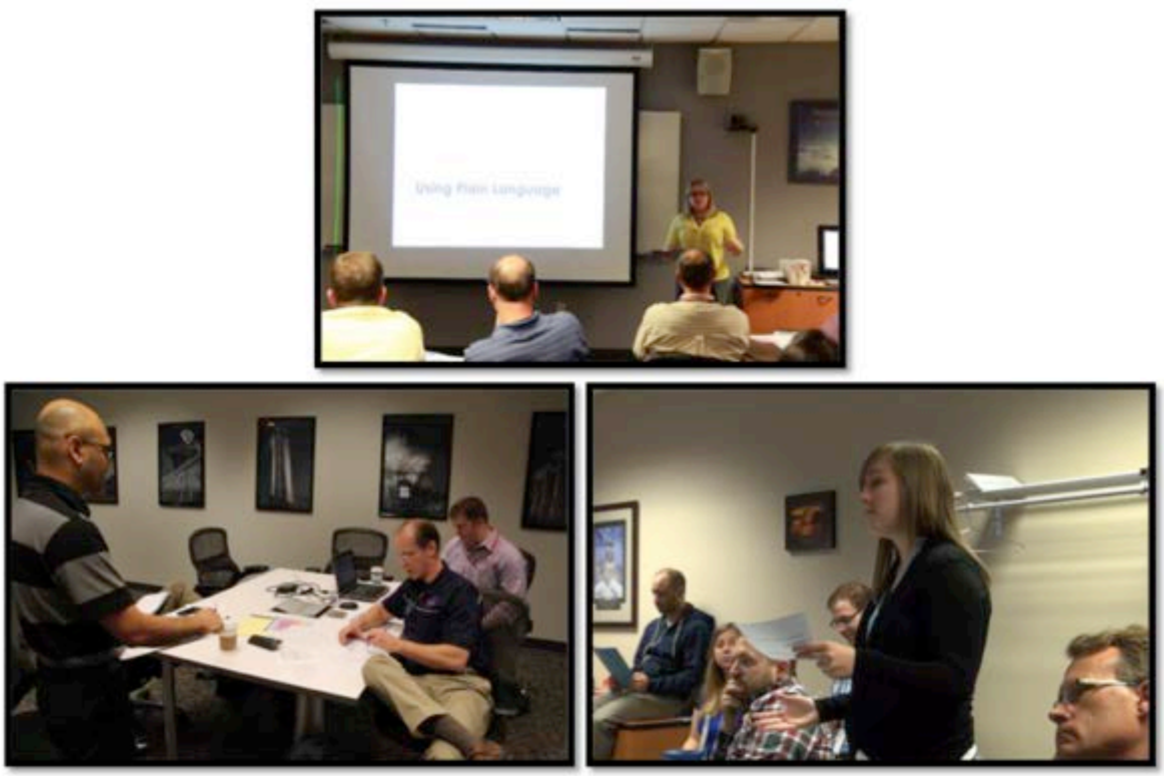
Forecasters working during ORE.

3. Impact-Based Decision Support Services Research and Development

a. Sub-Project 1: Impact-Based Decision Support Services (IDSS) Deployment Boot Camp

Megan Taylor, Sarah Grana, Katie Crandall, and Derrick Snyder (CIMMS at NWSTC), Jeffrey Zeltwanger (NWS Leadership Academy), and Marco Bohorquez and Doug Streu (NWS Decision Support and Communication Services)

During the reporting period, the NWSTC held two IDSS Deployment Boot Camp courses. The goal behind these courses is to prepare NWS employees for deployment in the field and train them to communicate weather information to partners and the public. Megan Taylor has been part of this course since 2012. Her role is to act as a subject-matter expert on media, and to review key interviewing principles from the NWS Media Training online course. She also plays the role of reporter in the course's full-day simulation. She interviews each participant and provides individualized critique and coaching. CIMMS Sarah Grana had a chance to sit in the course in April 2015. Sarah Grana, Katie Crandall, and Derrick Snyder now also play reporters in the full-day simulation's press conference.



(Top) Megan Taylor teaches about Plain Language. (Bottom Left) Students engage in full-day simulation tasks. (Bottom Right) Sarah Grana asks questions in a mock press conference.

b. Sub-Project 2: Create and Deliver a Traveling IDSS Boot Camp Course

Megan Taylor (CIMMS at NWSTC), Jeff Zeltwanger (NWS Leadership Academy), Chris Foltz and Derek Deroche (NWS CRH), and Dave Novak, Brian Hurley, and Scott Jacobs (NWS WPC)

The IDSS Deployment Boot Camp course has been a large success in the past few years. However, many national centers would like the opportunity to participate, but cannot send an entire staff to the NWSTC. The NWSTC created a traveling version to provide this training opportunity to national centers. In April 2015, Megan Taylor helped Chris Foltz, Derek Deroche, and Jeff Zeltwanger create a travel version customized for the Weather Prediction Center (WPC) at the National Centers for Environmental Prediction (NCEP). Chris, Derek, and Megan presented this course in May 2015. There were 23 participants from the WPC, Climate Prediction Center (CPC), and Ocean Prediction Center (OPC). Other national centers have expressed interest in this course.

(Top Left) Outside of NOAA Center for Weather and Climate Prediction. (Top Right) Participants from the first session of the IDSS Training. (Bottom Left) Participants in Session 1 work discuss effective IDSS. (Bottom Right) Participants from Session 2 discuss condensing a message.

c. Sub-Project 3: Conduct Training Sessions to Compliment Online Media Training

Megan Taylor (CIMMS at NWSTC), and Jeffrey Zeltwanger and Hattie Wiley (NWS Leadership Academy)

The NWSTC released the NWS Media Training online course in 2013. This is now a primary prerequisite for many NWSTC residence courses. Some courses review these concepts in class before moving on to application. Megan Taylor conducted these review sessions in the IDSS Deployment Boot Camp and Hydro Program Managers Course (HPM). Megan will conduct this session in other classes in the future.

d. Sub-Project 4: Create and Deliver Training Sessions on Communication

Megan Taylor (CIMMS at NWSTC), and Jeffrey Zeltwanger and Hattie Wiley (NWS Leadership Academy)

The NWSTC added communication-training sessions to many courses during the reporting period. Megan Taylor helped deliver these sessions along with Jeff Zeltwanger and Hattie Wiley. Communication topics included body language, listening, effective messaging, feedback, and more. Megan delivered sessions on body language for the Management and Supervision, Field Operations Management, Warning Coordination Meteorologist/Service Coordination Hydrology, and Hydro Program Manager courses. She also delivered a robust communication training session in Cooperative Network Operations courses.

Communication presentation topic slides.

4. Advanced Training Development

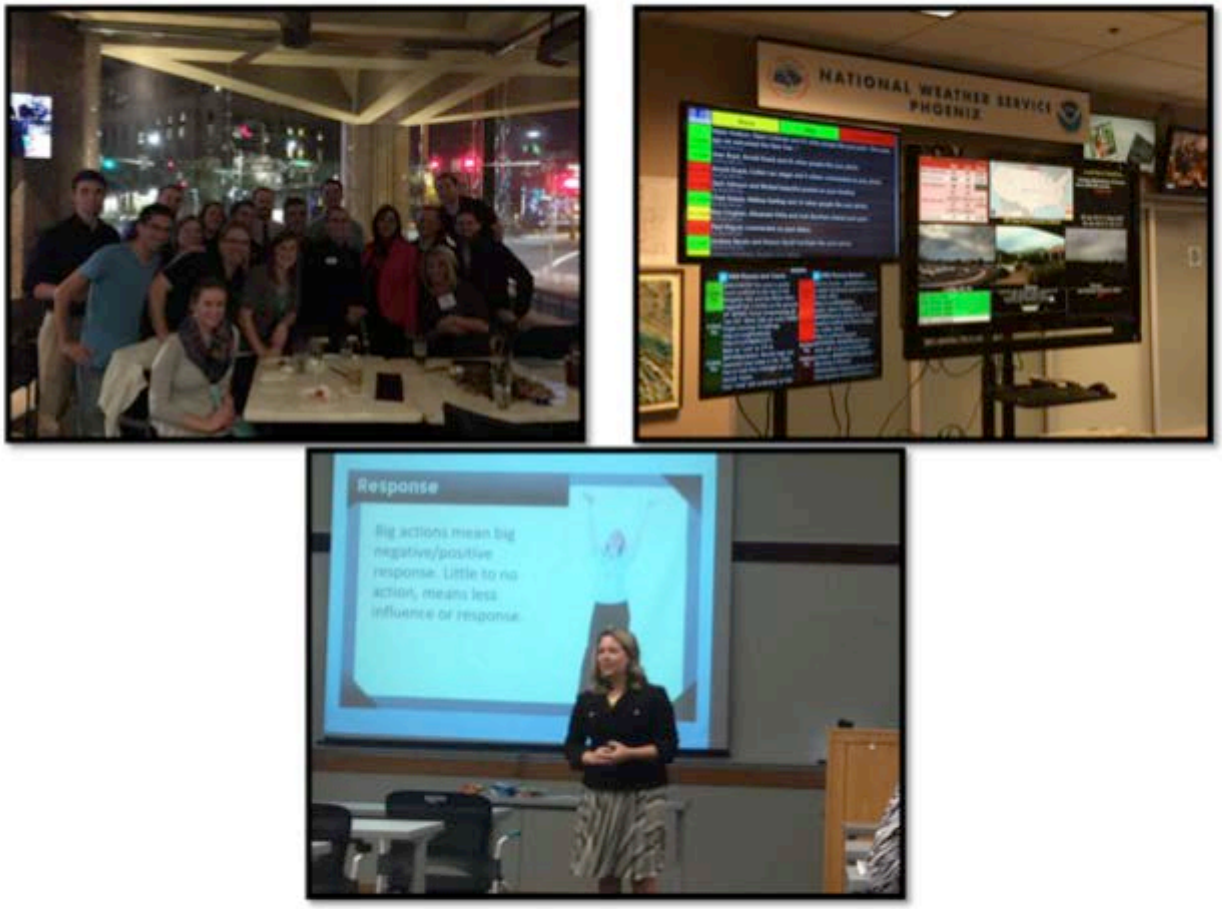
a. Sub-Project 1: Sub-Matter Expertise in Learning Technology and Techniques

Katie Crandall, Sarah Grana, Derrick Snyder, and Megan Taylor (CIMMS at NWSTC), Hattie Wiley and Jeffrey Zeltwanger (NWS Leadership Academy), and Kim Runk (NWS OPG). Also, NWS EAX and NWS HQ Technical Leads.

Katie Crandall, Sarah Grana, Derrick Snyder, and Megan Taylor developed subject-matter expertise through internal and external professional development and training opportunities in order to serve their given roles. Katie and Derrick focused on training related to AWIPS II, GOES-R, and WFO operations. Sarah Grana also focused on those topics, but additionally trained on Broadcast Message Handler (BMH), instructional designing processes, and training tools and techniques. Megan Taylor gained knowledge in instructional design, the Cooperative Observer Program, and graphic design and photography. The following is a short list of training and development opportunities from this reporting period:

- Adobe and Articulate Products (Sarah, Katie)
- AMS Annual Meeting (Katie, Derrick, Sarah)
- Animated GIFs Webinar (Digital Gov – Megan)
- AWIPS II – Application training (Sarah, Katie, Derrick)
- Graphical Editor Forecast (GFE) Training (Sarah)
- Blender 3D (Megan)
- BrightTALK – Power of Color webinar (Megan)
- EAX IWT Meeting (Katie, Derrick, Sarah, Megan)
- Flash Flood Workshop (Katie, Derrick)
- GOES-R Training (Katie, Derrick)
- GOES-R User Readiness Meeting (Katie, Derrick)
- Heat Health Conference (NOAA/CDC) (Katie)
- IDSS Boot Camp (Sarah)
- Instructional Design Review (Megan, Sarah)
- Instructor Training (Sarah)
- Job Shadowing at KC Forecast Office (Sarah, Derrick,)
- Kelby One Photography (Megan)
- Linux Essentials (Sarah)
- Media Training (Sarah)
- Missouri Academy of Science Annual Meeting (Katie)
- MTBI (Sarah, Megan, Derrick, Katie)
- Office Tools, Google, Social Media (Sarah)
- PowToons Present like Steve Jobs (Megan)
- Severe Weather Workshop (Katie, Derrick)
- Summer Institute for Design, Learning, and Instructional Technology 2014 (Megan)
- Visited Headquarters to Learn about Programs (Sarah – BMH, Megan – COOP)

- Visual Design Sessions – Monthly (Sarah, Megan, Katie)
- Web Basics (Sarah)
- EAX Winter Weather Workshop (Sarah, Derrick)
- Writing Basics (Sarah, Megan)



(Top Left) Katie Crandall and Sarah Grana snap a quick photo with Missouri alumni at the AMS Annual Meeting. (Top Right) Katie Crandall, Sarah Grana, and Derrick Snyder visit the Phoenix WFO. (Bottom) Megan Taylor teaches about performance at SIDLIT.

b. Sub-Project 2: Conduct Internal Training at the NWSTC

Sarah Grana and Megan Taylor (CIMMS at NWSTC) and Jeffrey Zeltwanger and Hattie Wiley (NWS Leadership Academy)

As CIMMS scientists develop expertise in many areas, they often share best practices and techniques during internal training sessions. During this reporting period, Sarah Grana led sessions on using Articulate Quiz Maker, and created job sheets for changing passwords in various applications. Megan Taylor took an active role in onboarding new CIMMS employees Sarah Grana, Katie Crandall, and Derrick Snyder.

c. Sub-Project 3: Create and Perform Outreach within the Agency

Sarah Grana, Megan Taylor, Katie Crandall, and Derrick Snyder (CIMMS at NWSTC), Jeffrey Zeltwanger and Cathy Burgdorf (NWS Leadership Academy), Jerry Griffin (NWS Decision Support and Communication Services), Kim Runk (NWS OPG), Bethany Perry (NOAA), Chris Strager and Derek Deroche (NWS CRH), Audra Hennecke (NWS TOP), Zach Wakefield (NWS EAX), and Marion Smith and Steve Brueske (NWS CRH)

A big part of the training process is letting people know the training exists. The NWSTC also participates in creation of outreach materials, upgrading training processes and web pages, and volunteer opportunities through the Combined Federal Campaign (CFC). During this reporting period, CIMMS Sarah Grana, Katie Crandall, Derrick Snyder, and Megan Taylor took active roles in both organizing and participating in events for the CFC.

Katie Crandall and Derrick Snyder volunteered at Science City for Science on a Sphere and gave presentations on various weather processes.

Sarah and Megan also helped update training processes. Megan helped test and provide feedback for a new online course template. Sarah helped test and refine the process for making quizzes and tests for the new NWS Learning Center.

Megan Taylor engaged in several projects that served as outreach. The reporting period began with aiding Bethany Perry in producing NOAA Sea Grant informational presentations. During the fall, Megan Taylor and Cathy Burgdorf took new staff pictures to increase the visibility of the NWSTC instructors. The two larger outreach projects this year were the Office of the Chief Learning Office video and the Weather Ready Nation 10-part video series. The Weather Ready Nation video is a 100-plus hour project that explores the roles of NWS employees in building a Weather Ready Nation. The Office of the Chief Learning Officer video is a quick video on the structure of the new office and the types of training that will be available. You can view these videos at:

Weather Ready Nation (10-part series):
https://www.youtube.com/playlist?list=PLYsC5TDceC_bfybW8YkrdIAC9DKX70Rrb

Office of the Chief Learning Officer: https://youtu.be/dQaMdSwlEj4

(Left) Katie Crandall participates in a Paper Airplane Contest for CFC. (Right) Title screens for Megan Taylor's Weather Ready Nation video series, and the Office of the Chief Learning Officer video.

d. Sub-Project 4: Join NWSTC Focal Point Teams

Sarah Grana, Derrick Snyder, Megan Taylor, and Katie Crandall (CIMMS at NWSTC)

Given the expertise of the CIMMS at the NWSTC/OPG, they have joined and/or taken the lead in several internal teams. These teams include the following:

- Recycling Team: Sarah Grana (lead)
- Social Media Team: Megan Taylor (lead), Katie Crandall (joined in 2015)
- Intranet Team: Megan Taylor (lead)
- Internet Team: Megan Taylor (assist)
- iDevices Team: Megan Taylor (lead)
- NWS Graphicast Team: Megan Taylor (audit 2015)
- Audio-Visual/Photography: Megan Taylor (back-up)
- OPG Digital Media: Derrick Snyder (lead)
- Vlab: Katie Crandall (lead)

Publications

Crandall, K. L., P. S. Market, A. R. Lupo, L. P. McCoy, R. J. Tillott, and J. J. Abraham, 2015: The application of diabatic heating in Q-vectors for the study of a North American cyclone event. *Advances in Meteorology*, Article ID 269709, in press.

CIMMS Task III Project – The Lightning Jump Algorithm: A National Field Test for Operational Readiness

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

NOAA Technical Lead: Dan Lindsay (NOAA/NESDIS)

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

Funding Type: CIMMS Task III

Objectives

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

Based on initial promising results, the NWS Office of Science and Technology (OST) deemed it a high priority to evaluate the LJA for operational implementation on an expanded LMA and radar data set, using fully automated methods for storm cell identification and tracking and lightning jump detection, robust verification approaches, and new methodologies to assess the skill with and without the LJA in the forecasting process. The objectives of the current project are to continue operations of an improved operational LJA algorithm, to incorporate new lightning data sets across CONUS, utilize enhanced verification techniques, develop multi-sensor (e.g., lightning-radar) fused algorithms that incorporate the LJA, provide training on the LJA to NWS forecasters and conduct operational testing and evaluation (OT&E) of the LJA by NWS forecasters in the Hazardous Weather Testbed (HWT).

Accomplishments

A fully automated, real-time LJA was evaluated for the second time in the operational environment of the HWT during the 2015 Experimental Warning Program. While the 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 LJA pre-GLM in the 2015 HWT experiment was produced using data from the Earth Networks Total Lightning Network (ENTLN). The switch to ENTLN data allowed for the evaluation of the LJA by forecasters on a daily basis throughout the

experiment; this was possible due to the continental United States coverage of the ENTLN as opposed to the limited range the Lightning Mapping Arrays (LMA) that were utilized in the 2014 evaluation period. While the detection efficiency of the ENTLN is less than the LMA, this change ultimately provided more feedback regarding the algorithm display, integration within the warning-decision process, and best practices for future implementation. Along with ProbSevere, the lightning jump remained one of the most highly utilized products in the warning process for the 2015 GOES-R proving ground evaluation.

The LJA was provided to forecasters through a gridded display of tracked storm objects that highlighted the degree of jump (or sigma-level, figure below). Storm tracking and jumps were completed in the background while the LJA grid was updated every minute within the AWIPS2 display for the forecasters. The jump was calculated using the 2-min storm flash rate and the standard deviation over the previous 10-min period of activity (not including the period of interest). At the request of multiple forecasters during week one of the experiment, the display was expanded to include the visualization of negative jumps (or rapid decreases) in the storm-based flash rate. Forecasters utilized the LJA for both situational awareness and during the warning-decision process throughout the 5 weeks. Forecasters did not typically issue warnings on LJA signals alone, but often commented that the LJA added confidence in a warning decision.

The storm-based lightning Jump Grid (left) and 0.5 deg. reflectivity from KFTG on 4 June 2015.

Publications

Chronis, T., L. D. Carey, C. J. Schultz, E. V. Schultz, K. M. Calhoun, and S. J. Goodman, 2015: Exploring Lightning Jump Characteristics. *Weather and Forecasting*, **30**, 23-37. doi:10.1175/WAF-D-14-00064.1.

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: 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:

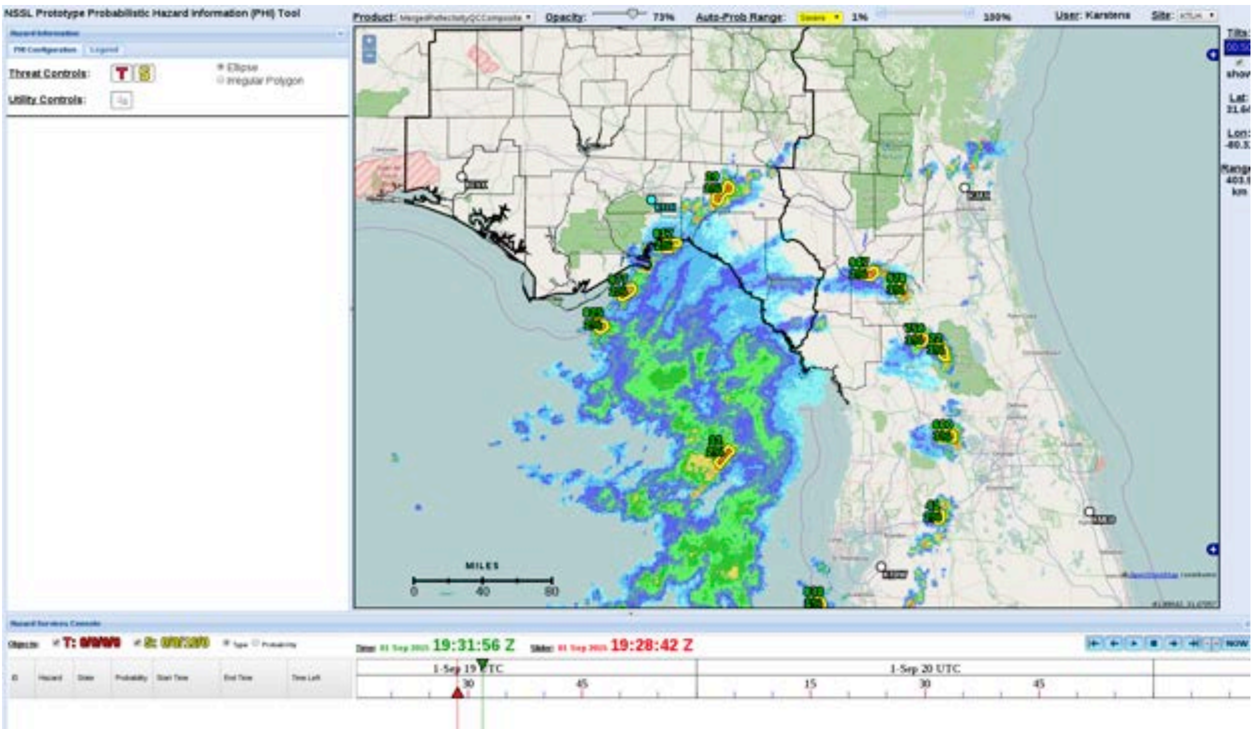
1. Add enhanced PHI Tools functionality and beginning transition into AWIPS-II
2. Conduct joint NSSL/GSD/SPC test and evaluation in HWT Spring Experiment
3. Reports and publications
4. Brief NWS management on FACETs concepts, development, testing, successes, lessons learned and remaining challenges

Accomplishments

1. Overview

Initial development of a new prototype web-tool began in May 2013, with efforts bolstered in June 2013. This tool expands upon the original PHI tool (Ortega 2008) by including more Graphical User Interface functionality for real-time previewing and more real-time GIS functionality. Seven 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).

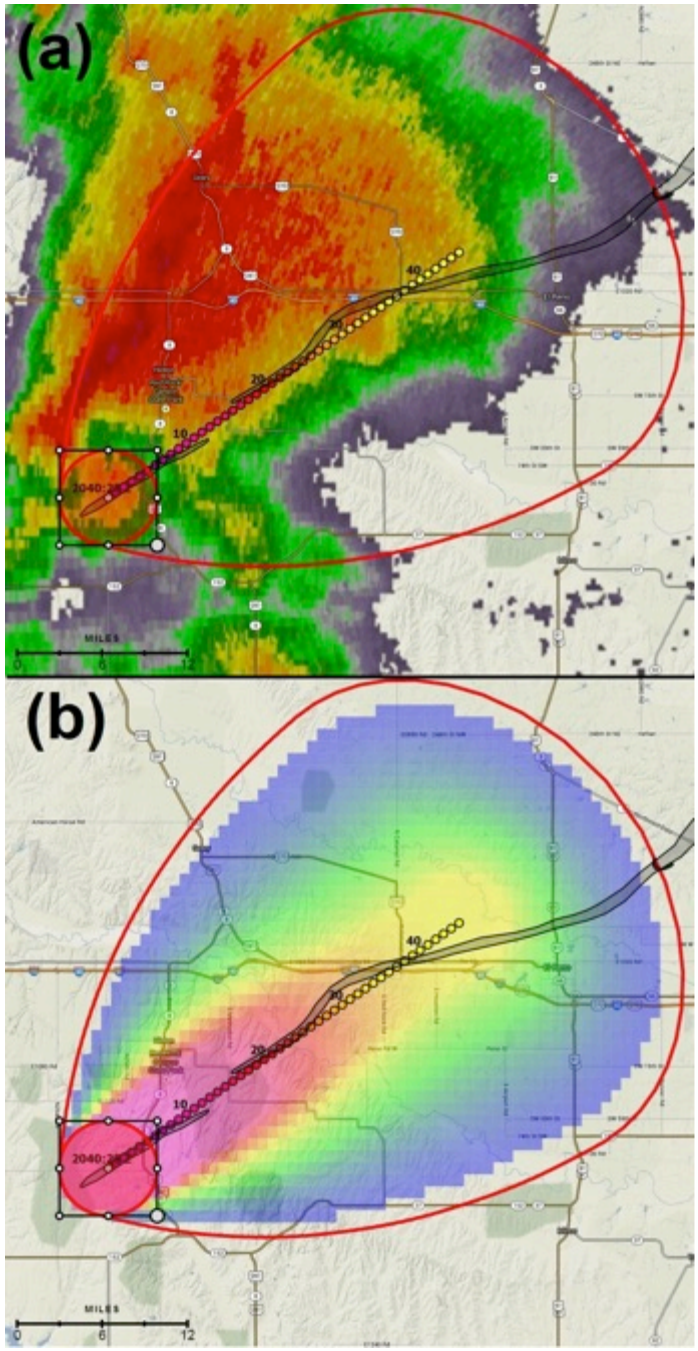
A screen capture of the most recent version of the prototype PHI tool is shown in the figure below. The interface is comprised of five main panels, including an information panel (top), hazard information configuration/display panels (left), map panel (center), quick-access controls panel (right), and 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.

2. PHI Objects

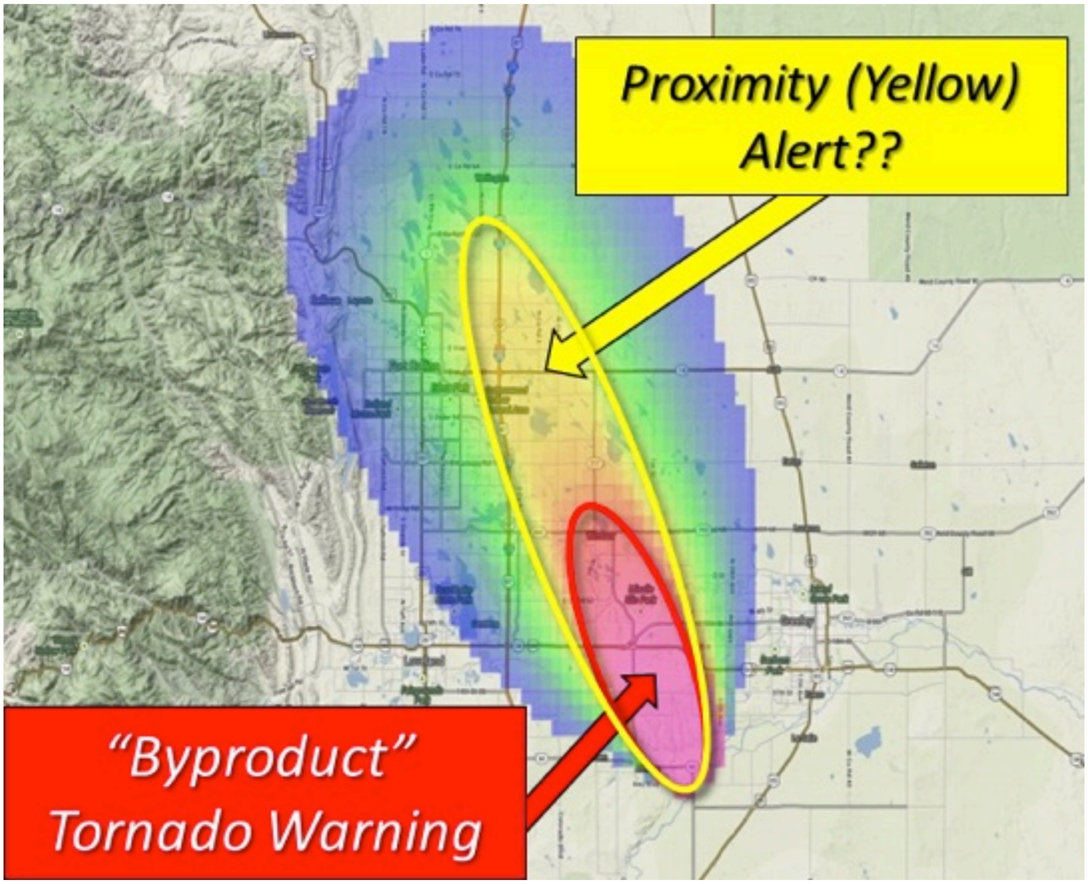
An example of a PHI object and its resulting PHI grid is given in the figure below. Conceptually, the PHI object's polygon geometry is intended to denote the region that is experiencing, or is forecast to experience, a particular threat or hazard over the forecast duration of the event (filled red polygon). The PHI 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; and (2) geospatially apply forecaster generated or approved prognostic probabilities of exceedance of 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 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 the exceedance of 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 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.

1. 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.

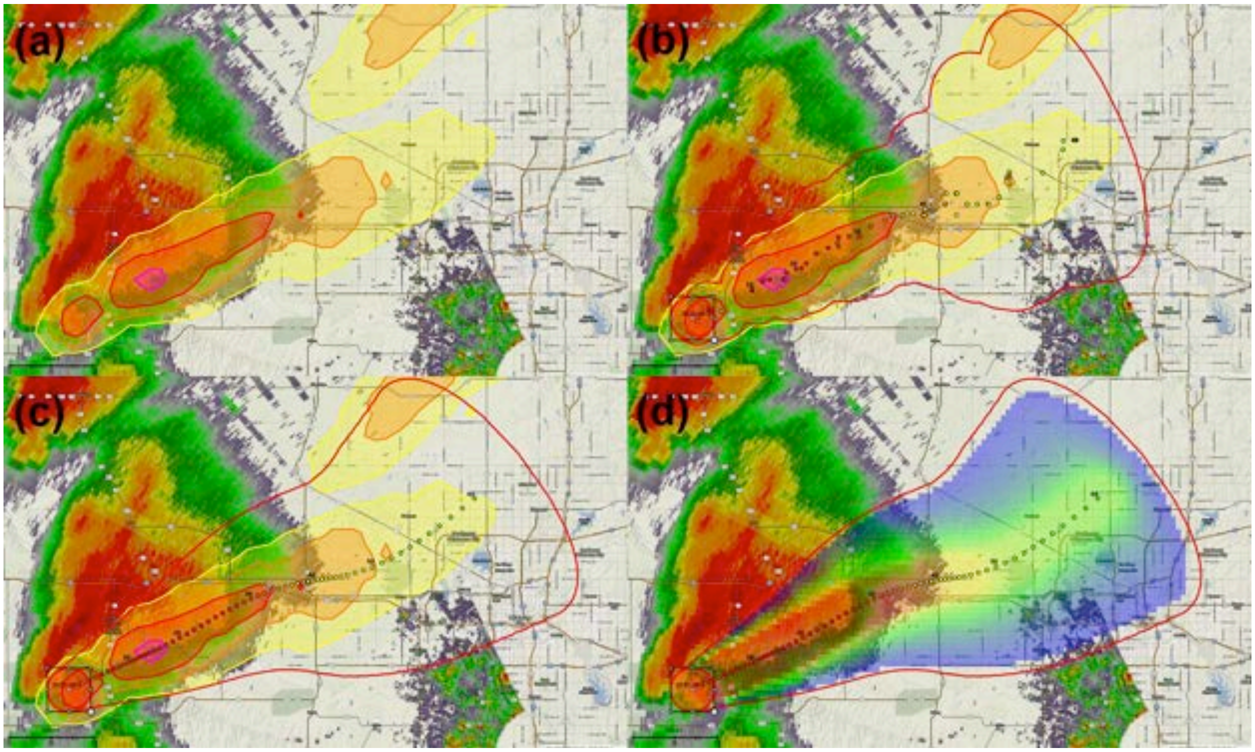
The ultimate goal is to build functionality that allows the forecaster to derive PHI using the following as inputs: (1) NWP model/ensemble diagnostics; (2) time period for threat guidance; and (3) radius of influence (e.g., probability that threat will occur within X miles of a point). From these inputs, 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 (discussed later).

1. 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, ProbSevere (Cintineo et al. 2014), 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.

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 process. However, we are exploring 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.

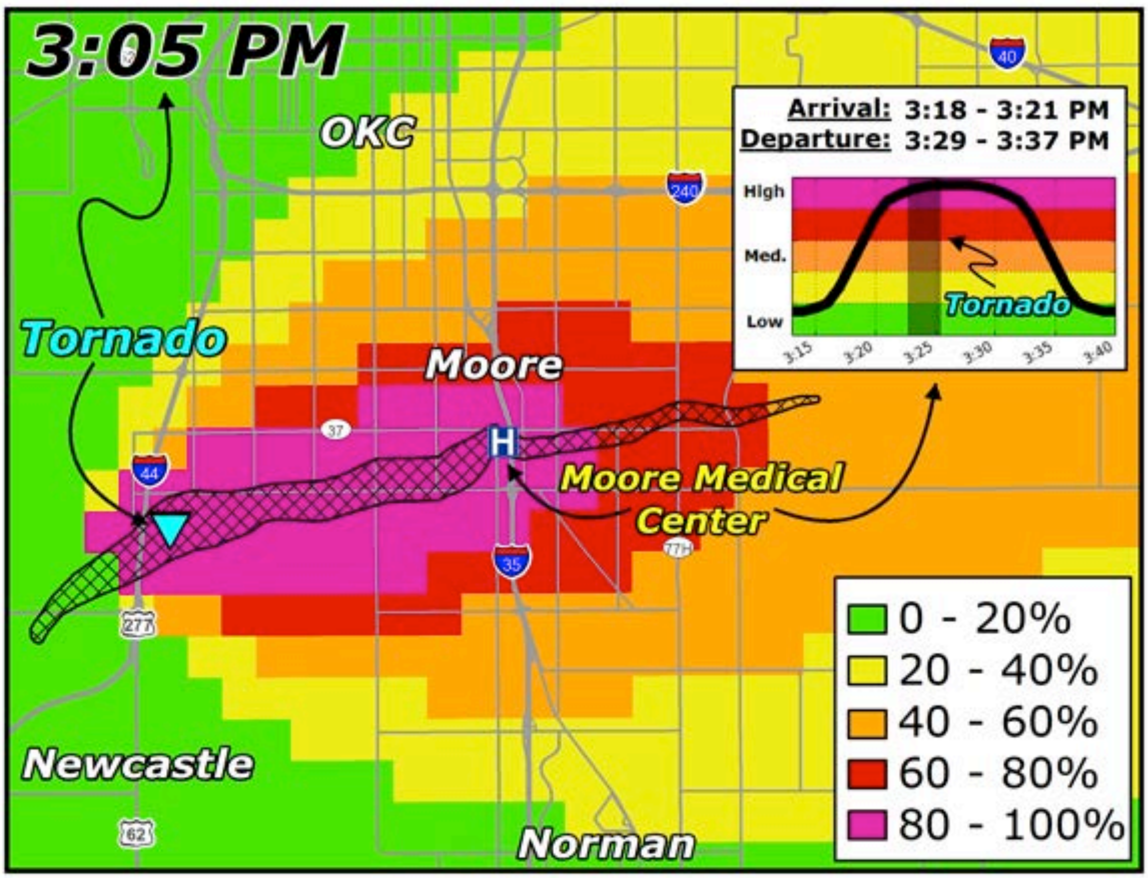
2. End-User PHI

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).

3. HWT Spring Experiment PHI Activities

Expanding upon efforts from 2008 and 2014, the 2015 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted in the Experimental Warning Program (EWP) during the weeks of 4-8 May, 19-23 May, and 1-5 June. In addition, a simultaneous experiment with emergency managers (3 per week) was conducted to gain an understanding of how end-users interpret and use the probabilistic information for (simulated) decision-making. Two forecasters participated each week by issuing probabilistic forecasts for severe convective phenomena, including any-severe (tornado, wind, hail) and specifically for tornado, in the 0-2 hour timeframe using a prototype web tool. Automated, object-based guidance was provided to the forecasters in real-time for each of the aforementioned probabilistic forecast types. The primary objective of this experiment was to develop an understanding how forecasters use the PHI system with the automated guidance by varying the forecasters' level of interactivity with the guidance information.

To achieve the objective of this experiment, three experiment strategies were developed and tested with forecasters: the loop, out of the loop, and in the loop. First, "the loop" strategy involved removing the automated, object-based guidance from the forecasters. Thus, the forecasters had to rely purely on their intuition for judgments under uncertainty. The second "out of the loop" strategy is the opposite of the first, in that forecasters are completely removed from the decision-making process. Thus, all forecasts were being generated by the automated system. The third "in the loop" strategy represents a mixture of the first two strategies, by giving the forecasters full access to the automated guidance for assistance in decision making. In each strategy, 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.

Each strategy produced interesting preliminary results. Results from the first "the loop" strategy reinforced findings from the 2014 HWT PHI experiment. The so called "on-the-fence" decision to warn or not warn is effectively removed from the forecaster because of the ability to issue information for storms based on their current and projected likelihood of producing severe weather. However, this liberating effect introduced a paradoxical increase in workload. Forecasters felt taxed when having to manage in excess of 4-5 hazard areas simultaneously. To speed up the pace of work, forecasters resorted to workload simplifiers, such as simple object geometries (analogous to WarnGEN-like warning polygons) and a general dearth of communication.

Results from the second "out of the loop" strategy revealed that forecasters quickly became frustrated with the inability to intervene with the automated system. Forecasters want to be part of the forecast process. In addition, with the only means of communication being routed through NWSChat, the emergency managers were forced to interrogate the storms themselves, relying on what training and intuition they had received or developed about radar meteorology. In effect, this strategy puts end-users

in the position equal to that of a forecaster (i.e., warning decision makers). This may work for savvy end-users, but most EMs felt uncomfortable in this position.

Results from the third “in the loop” strategy showed that, early on, forecasters had difficulty interacting with the automated guidance. In many instances, forecasters would issue a PHI object for a storm or hazard at approximately the same time as the automated system, thus resulting in two, often similar, forecasts for the same storm or hazard. After a few instances of these types of events, forecasters would frequently raise the thresholds of the automated system to block such guidance from entering the forecast process. In essence, forecasters gravitated back toward the first “the loop” strategy, thus reintroducing the aforementioned workload complications.

After observing and taking recognition of this effect, the facilitators developed a fourth strategy, a hybrid of the third “in the loop” strategy. This new strategy required the forecasters to allow the automated system to generate PHI objects, for any severe, within forecaster-defined severity thresholds. Forecasters could optionally override specific object attributes, including the object speed, direction, duration, discussion, and probability trend, in addition to allowing or blocking PHI objects completely. For tornado, the first “the loop” strategy was employed, as the automated guidance, still premature, had far too much false detection, and there are often fewer tornado hazards to manage simultaneously than any severe.

Results from the fourth hybrid “in the loop” strategy suggest that this was the optimal strategy, for both forecasters and emergency managers. Forecasters could leverage the rapid mechanical abilities of object generation from the automated system, thus prioritizing their decision making on a storm’s or hazard’s severity likelihood, movement, and longevity. These decisions were expressed in the PHI object attributes directly and in the object discussion (i.e., communication), thus working toward messaging consistency. The emergency managers appreciated the rapid flow information and updates enabled by this hybrid strategy. However, in at least one instance, a hazard was not collocated with the automated system’s object (surging winds ahead of a convective line). Forecasters communicated this observation, along with an estimation of the hazard intensity, via the object discussion, and emergency managers found this information to be effective.

The preliminary results of this experiment have highlighted areas needing further research and development. First, the communication from the forecaster to end-users via the prototype PHI tool is currently unstructured, given as a blank text box open for interpretation. It became clear that some forms of communication were found to be effective, while others were not. Therefore, we plan to use the information and data collected from the experiment to develop a set of communication protocols for various hazard situations, and implement tools that allow forecasters to quickly leverage such protocols in the next HWT experiment. Second, we plan to make improvements in the automated guidance, such as including more sources, improvements in these sources (understanding and reliability), presentation within the tool, and refinements of forecaster interactivity. Third, the notion of lead-time and its meaning will be of primary

focus during the follow-up emergency manager experiment, along with testing the receipt of the newly developed communication protocols.

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 4 – June 5). Forecasters working on the NSSL desk 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. On the SPC desk, forecasters issued 4-hour probabilistic outlooks for individual hazards (tornado, wind, and hail) from 18-22 UTC and 22-02 UTC and within 25 miles of a point. At both desks, updates to the morning forecasts were conducted in the afternoon. Forecasters were given the ability to create their own probabilistic forecasts, with tool functionality similar to that of NMAP (GEMPAK software), by examining experimental guidance from convection-allowing models and ensembles. 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.

Publications

Karstens, C. D., G. Stumpf, C. Ling, L. Hua, D. Kingfield, T. M. Smith, J. Correia, Jr., K. M. Calhoun, K. L. Ortega, C. J. Melick, and L. P. Rothfusz, 2015: Evaluation of a probabilistic forecasting methodology for severe convective weather in the 2014 Hazardous Weather Testbed. *Weather and Forecasting,* **143**, in press.

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

CIMMS Task III Project – Development of Short-Range Real-Time Analysis and Forecasting System Based on the ARPS for Taiwan Region

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

NOAA Technical Lead: Fanthune Moeng (NOAA/ESRL/GSD)

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

Funding Type: CIMMS Task III (Taiwan Central Weather Bureau; NSSL; and NOAA/ESRL/GSD)

Objectives

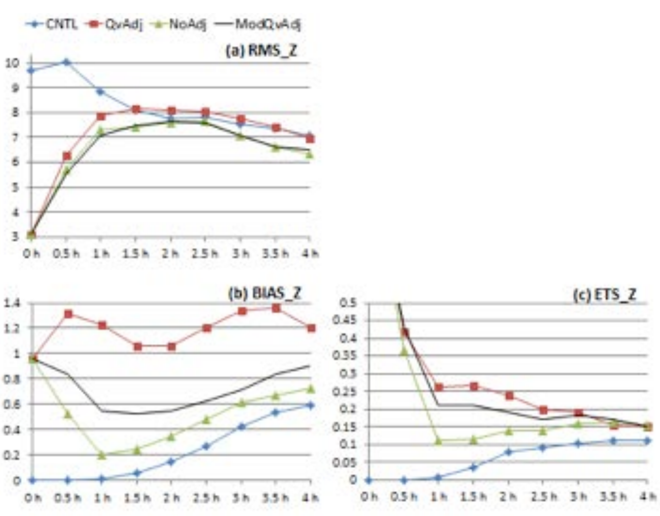
Establish a real-time forecasting system at convection-allowing resolution (~2.5 km), based on ARPS modeling and data assimilation system, for the Central Weather Bureau (CWB) of Taiwan, to obtain accurate 0-4h heavy precipitation forecasts. And, improve the very-short-range (1-4h) precipitation forecast by proposing modified cloud analysis procedures, based on the newly introduced observations (i.e. polarimetric radar

data) and an OSSE-based investigation of the criticality of different components in cloud analysis.

Accomplishments

The project is in a no-cost extension period. Research was performed to improve the ARPS cloud analysis making use of polarimetric radar data. A fuzzy-logic hydrometeor classification algorithm (HCA) making use of polarimetric radar variables Z, Z_{DR}, K_{DP}, and ρ_{hv} was incorporated in the ARPS cloud analysis procedure to assist with the hydrometeor analysis. With this modified procedure, coexistence of different hydrometeor species (e.g., liquid-iced mixtures) is possible so that the analyzed hydrometeor distribution is more realistic. Initial tests show slight improvement with precipitation forecasting.

Another study investigates the potential and limitations of the current ARPS cloud analysis through observing system simulation experiments (OSSE). The 19 May 2013 Central Plains mesoscale convective system (MCS) is used as the test case. By initializing the model states using the cloud analysis procedure with different configurations, the individual impact of different analysis variables (i.e., hydrometeors, in-cloud temperature, and in-cloud moisture) is examined. Forecast results showed the largest sensitivity to the initial moisture field; however, the current moisture adjustment was found to over-moisten the precipitation regions, resulting in rapid error growth in the subsequent prediction. A modified q_v adjustment scheme is designed that makes use of the vertical velocity information. The original scheme adjusts qv to saturation within where reflectivity exceeds a small threshold while the modified scheme applies the saturation adjustment to regions with upward motion only. Figure 1 shows that the reflectivity error growth is slowed down with the modified scheme and the bias and ETS skill scores are better than the case with no adjustment to qv. The scores for all cases are better than the no cloud analysis CNTL case.



Forecast reflecitivity verifications: (a) root mean square error, (b) bias, and (c) equitable treat score of four OSSE experiments: CNTL (no cloud analysis, simply background), QvAdj (cloud analysis with current qv adjustment), NoAdj (cloud analysis with no qv adjustment), and ModQvAdj (cloud analysis with w-based qv adjustment).

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 (CAPS at OU)

NOAA Technical Lead: Mark DeMaria (NOAA/NESDIS)

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

Funding Type: CIMMS Task III

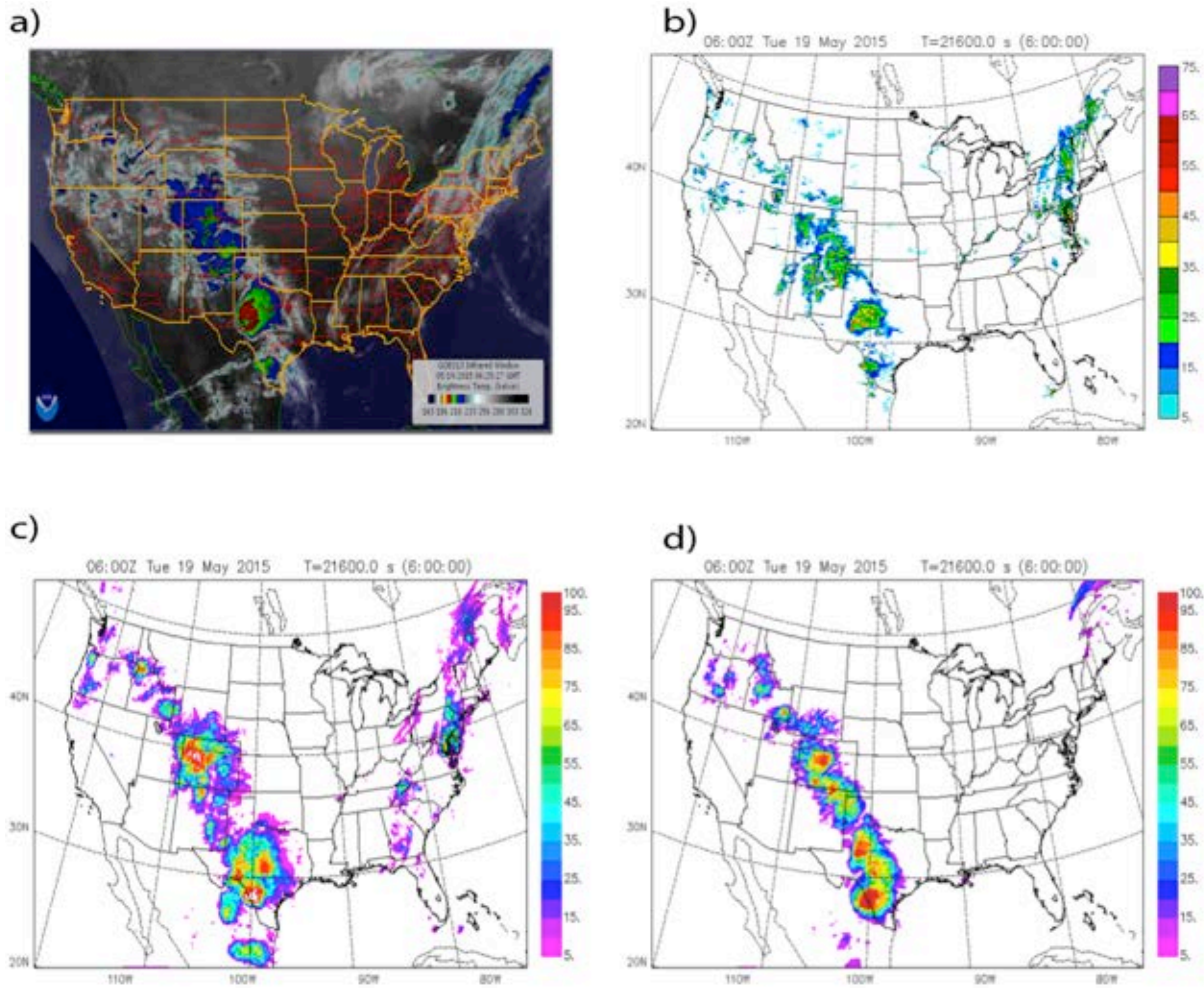
Objectives

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.

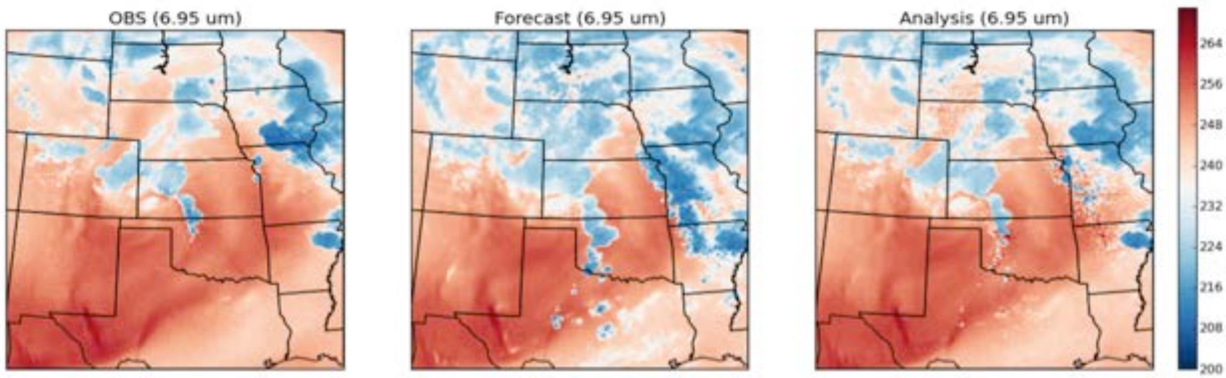
Accomplishments

During the 2015 HWT Spring Experiment season in May through early June, CAPS produced in real-time synthetic GOES-13 brightness temperature products using CRTM for all WRF-ARW members in its storm-scale ensemble forecast (SSEF) system. SSEF consists of two ensembles: 3DVAR- and EnKF-based ensemble. A more detailed descripts can be found in the CAPS HWT website (http://forecast.caps.ou.edu/). The CAPS SSEF was run at 3-km High-Resolution Rapid Refresh (HRRR) grid spacing and 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 10.7 µm Brightness Temperature (BT) were produced. Ensemble probability of 10.7 µm BT lower than -32 and -52 °C were made available to HWT participants in real-time (http://www.caps.ou.edu/~fkong/sub_atm/spring15.html and http://www.caps.ou.edu/~fkong/sub_atm/spring15-enkf.html). The first figure below shows examples of such products.

A vertical localization was added to the CAPS parallel EnKF framework for satellite brightness temperature (BT) based on the temperature from an external model dataset. Preliminary results show that localizing the covariance in the vertical direction helps improve stability of forecasts. Analysed BT at the end of assimilation window exhibited reasonably good fit with the simulated observations (second figure below). More testing and evaluation are still needed.



GOES-13 BT imagery of 10. µm valid at 0635 UTC 19 May 2015 (a), composite reflectivity (b), the probability of WRF simulated 10.7 µm BT ≤ -32C for the 3DVAR-based (c) and EnKF-based ensemble, valid at 0600 UTC 19 May 2015.



Simulated GOES-R BT at 6.95 µm for observation (left), ensemble mean forecast (center), and ensemble mean analysis after assimilating simulated observations (right) at 1900 UTC 10 May 2010.

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 and Gang Zhao (CAPS at OU)

NOAA Technical Lead: Stan Benjamin (NOAA/ESRL/GSD)

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

Funding Type: CIMMS Task III (NOAA/ESRL/GSD and 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 data assimilation capabilities in the EnKF and hybrid systems and eventually apply the systems to the High Resolution Rapid Refresh (HRRR) system.

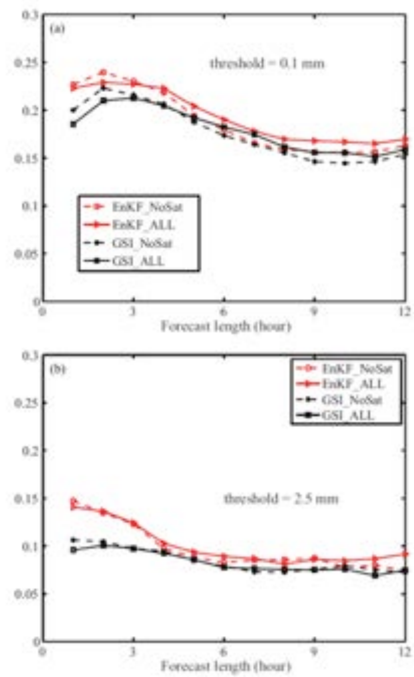
Accomplishments

Zhu et al. (2013) and Pan et al. (2014) established and tested GSI-based 40-km EnKF and coupled EnKF-En3DVAR hybrid schemes, and demonstrated superior performances of these schemes over the GSI 3DVar scheme. Since then, a dual-resolution (40/13km) hybrid system has been established and tested, over the same 8-

16 May testing period used in Zhu et al. (2013) and Pan et al. (2014) papers. The hybrid system uses the well-tuned 40 km EnKF system documented in Zhu et al. (2013) to provide flow-dependent covariances, while the hybrid En3DVar analyses are run at 13-km grid spacing. A large number of tests were performed with different configurations. The general conclusion is that high-resolution analyses on the 13 km grid with dual-resolution hybrid improves precipitation forecasts, but do not necessarily improve sounding verification. In fact, 13 km forecasts starting from interpolated 40-km analyses tend to fair worse for sounding verifications for short-range forecasts than 40 km forecasts. It is believed that smaller scale errors found in the higher resolution forecasts contribute to the increased “rmses” when verified with large-scale sounding data.

In Zhu et al. (2013), satellite data, included in the operational Rapid Refresh system, were not assimilated by the GSI-based EnKF. The impacts of satellite radiance data, including the Advanced Microwave Sounding Unit (AMSU), the Atmospheric Infrared Sounder Radiance (AIRS), the Microwave Humidity Sounder (MHS) and the High-resolution Infrared Radiation Sounder (HIRS) data, are tested separately. Using the same 40-km EnKF configuration, positive impacts of radiance data are obtained after careful tuning of the bias correction coefficients and using appropriate data thinning. Among the radiance datasets, the AMSU-A and AIRS data make greatest contributions. The assimilation of AMSU-A data improves the forecast for all verified variables especially for the wind components; the assimilation of AIRS data greatly improves the forecast of relative humidity; when all the radiance data are assimilated, the forecast is the best. Additionally, we compared the EnKF results with those GSI 3DVAR. Forecasts from both EnKF and GSI are improved by the assimilation of radiance data while the forecasts started from EnKF analysis are consistently better than those from GSI 3DVar. The downscaled precipitation forecast skills on 13 km grid are also improved with radiance assimilation (see figure below). Results are summarized in Zhu et al. (2015).

Another importance piece of work is the development of capabilities to directly assimilation radar reflectivity data within the GSI 3DVar and GSI En3DVar systems, based on sophisticated reflectivity observation operators that involve ice hydrometeors. The capabilities have been developed and passed initial testing. It will be coupled with GSI-based EnKF system and tested on the 3-km HRRR grid.



Average hourly precipitation ETS scores of all Rapid Refresh model forecasts on the 13-km grid, starting from GSI-based EnKF and GSI 3DVAR analyses with and without satellite radiance data, for (a) 0.1 mm h^{-1}, and (b) 2.5 mm h^{-1} thresholds.

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, and M. Xue, 2015: The impact of assimilating satellite radiance data using GSI-based ensemble Kalman filter for the rapid refresh system. *Monthly Weather Review,* to be submitted.

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, and Nathan Snook (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

Objectives

As a partner of the Warn-on-Forecast project, CAPS focuses most of its efforts on developing, refining and applying ensemble-based data assimilation systems to storm-

scale deterministic and probabilistic predictions. Efforts also will be made to develop a hybrid ensemble-variational data assimilation system that seeks to combine the strengths of both variational and ensemble methods. The main objectives of the CAPS portion of the project include: development and application of convective-scale ensemble data assimilation methods and systems; and participation in intercomparisons of data assimilation methods on selected cases.

Accomplishments

CAPS's parallel ensemble Kalman filter (EnKF) data assimilation (DA) system was enhanced to be able to assimilate MPAR radar data, and to directly support the WRF ARW model. The 4DEnKF capabilities were fully tested for real radar data assimilation.

The enhanced EnKF system with 4D capabilities was delivered to NSSL in summer 2014. NSSL scientists collaborated with CAPS scientists to apply the 4DEnKF system to a case with MPAR data, and demonstrated the benefits of the fast scan MPAR data over operational WSR-88D radar data (Yussouf et al. 2015). The 4DEnKF system was also applied to a fast-moving tornadic supercell storm case, and 4DEnKF was found to be superior to the 3DEnKF (Wang et al. 2015).

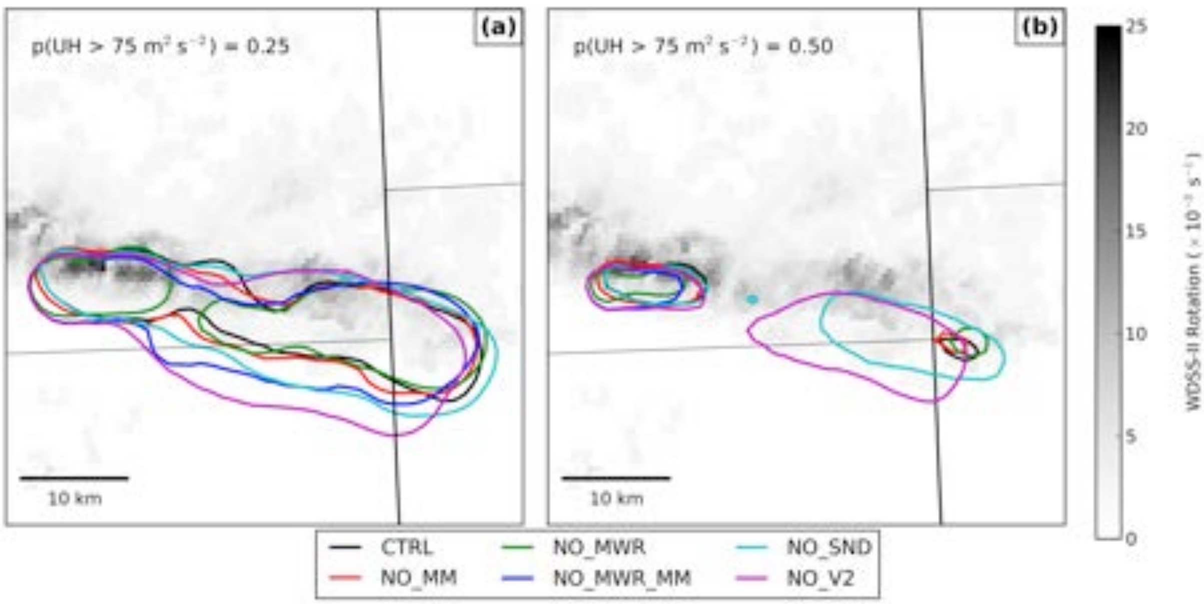
Ph.D. student Tim Supinie completed a study examining the impacts of special mobile mesonet and mobile Doppler radar data from the VORTEX-II field experiment in addition to operational 88D radar data for the 5 Jung 2009 Goshen County, Wyoming, tornadic supercell case, when the data were assimilated using CAPS's EnKF DA system. A paper reporting the results is conditionally accepted for publication (Supinie et al. 2015). Tim Supinie has started to work on another case with fast-scan MPAR data and will compare the performance of the 3D and 4D EnKF algorithms, and investigate the benefit of MPAR fast scan data.

During the 2015 Hazardous Weather Testbed Spring Experiment organized by NSSL and SPC, CAPS ran its parallel EnKF DA system in real-time, assimilating all conventional data plus data from the entire WSR-88D network on a grid covering the entire CONUS with a 3 km grid spacing, and the radar data were assimilated every 15 minutes for 1 hour. The ensemble analyses were used to initialize 48 hour-long ensemble forecasts. Initial evaluations show that this EnKF system produced forecasts better than similarly configured 3DVAR/cloud analysis system. The parallel EnKF system was computationally very efficient, and the assimilation of several millions of radar data took only 7 minutes to complete.

3D and 4D ensemble-variational (3DEnVar and 4DEnVar) algorithms and their relations were derived and clarified within a unified framework (Liu and Xue 2015), and the algorithms were recently implemented within the ARPS variational DA framework, and coupled with CAPS's EnKF DA system to form a hybrid system. The hybrid EnVar system will also be made to directly support WRF model. To properly assimilate reflectivity data variationally, reflectivity observation operators and their adjoint codes were refined and tested, and new background error models were developed for hydrometeor variables to improve the variational assimilation of reflectivity data. OSSEs

have been conducted to compare the results of 3DVar, EnKF, pure 3DEnVar, and hybrid 3DEnVar. The results are reported in Kong et al. (2015).

The Local Ensemble Transform Kalman Filter (LETKF) has been implemented within the CAPS EnKF framework, and its performance is found to be comparable to that of EnSRF algorithm, though slightly worse during the initial cycles. The nonlinearity of the reflectivity observation operator is believed to be the cause for the differences. A paper documenting the results is being finalized (Zhao and Xue 2015).



Neighborhood ensemble probability of updraft helicity (UH) ≥ 75 m^2 s^{-2} over the duration of the 1-hour forecast. UH is integrated over the 0-3 km AGL layer, and the neighborhood is 2.5 km in radius. The 0.25 probability contour is given in (a) and 0.5 probability contour is given in (b). The Warning Decision Support System - Integrated Information (WDSS-II) rotation swath product is in grayscale. CNTL assimilated routine (3 WSR-88D radar, ASOS and wind profiler data), MWR-05XP (an X-band phased array radar, denoted MWR), and mobile soundings, mobile mesonet and 'sticknet' (denoted MM) observations. NO_MWR, NO_SND and NO_MM exclude MWR, sounding, and MM data, respectively (From Supinie et al. 2015).

Publications

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Liu, C. and M. Xue, 2015: Relationships among four-dimensional hybrid ensemble-variational data assimilation algorithms with full and approximate ensemble covariance localization. *Monthly Weather Review*, conditionally accepted.

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Yussouf, N., J. Cheng, Y. Jung, M. Xue, and S. Wang, 2015: Comparison of the analyses and forecasts of a tornadic supercell storm from assimilating phased array radar and WSR-88D observations. *Monthly Weather Review*, in review.

Zhao, G. and M. Xue, 2015: A comparison between EnSRF and LETKF algorithms for convective-scale radar data assimilation: OSSEs and effects of nonlinear observation operator. *Monthly Weather Review*, to be submitted.

CIMMS Task III Project – National Sea Grant Weather & Climate Extension Specialist Activities

Kodi Monroe (CIMMS at OU), Joe Ripberger (CIMMS/CRCM at OU), and Lans Rothfusz (NSSL)

NOAA Technical Lead: Mike Liffman (NOAA Sea Grant)

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

Objectives

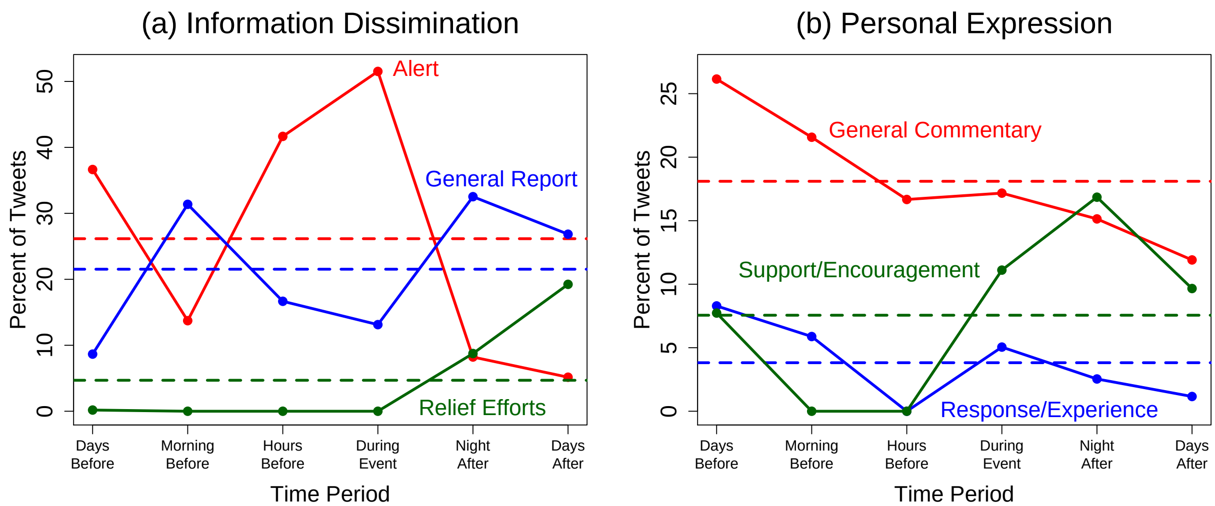
Connect NSSL research with the Sea Grant Extension Network; lead the Coastal and Inland Flooding Observation and Warning (CI-FLOW) project to predict total water level for coastal watersheds; assist in the evaluation of the end-to-end weather warning process by studying the way in which members of the public prepare for, respond to, and recover from incidents of severe weather.

Accomplishments

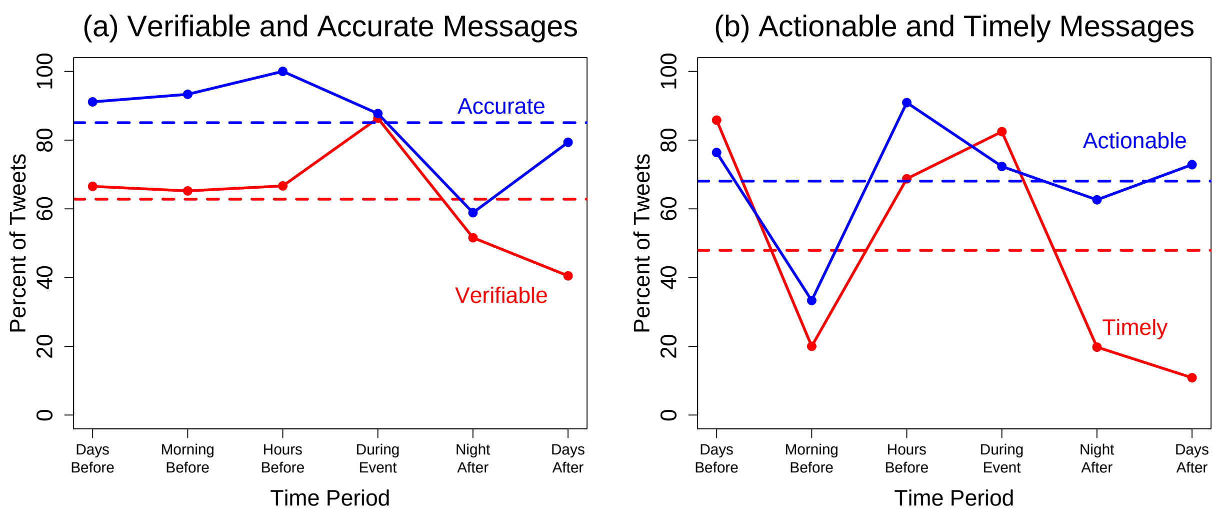
The Sea Grant Weather & Climate Extension Specialist at CIMMS/NSSL leads NOAA's CI-FLOW project and actively participates in NSSL's hydrometeorological research activities. During the 2014 and 2015 Atlantic hurricane seasons, the CI-FLOW collaborators maintained the real-time coupled modeling system. Quantitative precipitation estimates produced by the NSSL MRMS/Q3 system provided input data to the 128-member ensemble of the 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/) 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 National Water Center in Silver Spring to continue complementary research projects on the use of one- and two-dimensional hydraulic models within the CI-FLOW system. This research will help quantify the benefits of a coupled model system that can be more broadly implemented into NWS operations for the Gulf and Atlantic coasts. OU researchers set up a model of the Tar River basin similar to the CI-FLOW system, and collected and generated hindcast model forcing information for five test events - Hurricane Isabel, Hurricane Irene, Hurricane Floyd, Hurricane Sandy, and one extra-tropical storm. Comparative hindcasts are being performed on proposed coupling methods and modifications. The results of these hindcasts will help determine how and where the hydraulic model might best be incorporated with CI-FLOW, and what real benefits this coupling can be expected to provide in terms of time and accuracy. The Extension Specialist is actively participating in NOAA's Storm Surge Roadmap Team and collaborating with the National Hurricane Center to address important research questions related to their storm surge watch/warning. At the same time, the Extension Specialist served on the planning committee for Living With Extreme Weather: A Workshop to Integrate Understanding and Improve Societal Response.

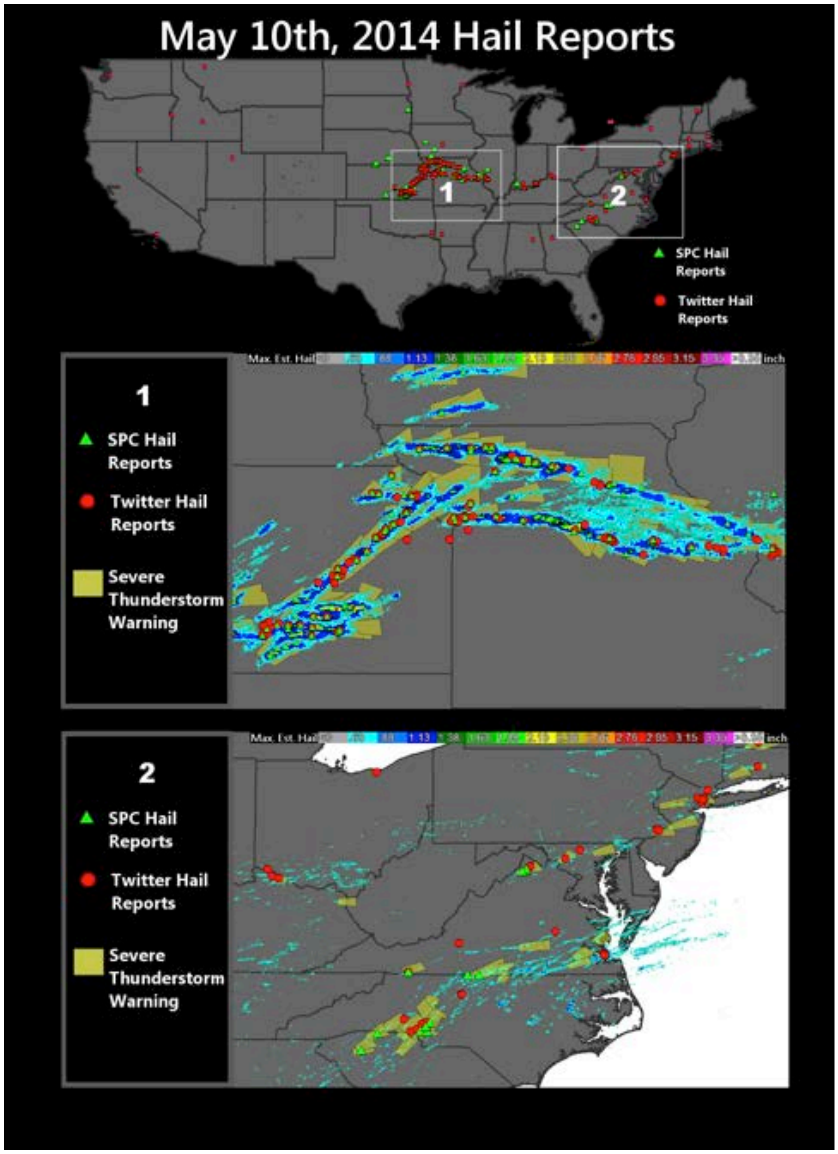
The Sea Grant Social Scientist is working with colleagues at the OU Center for Risk and Crisis Management, CIMMS, and NSSL to advance our understanding of the end-to-end weather warning process. The Scientist is exploring the way in which social media technologies (like Twitter) influence the warning process by answering three different questions: 1) Who uses social media to get information about severe weather and how has this evolved over time? 2) What do NWS forecasters and weather scientists think about social media and how has it changed the way they approach their jobs? 3) How does social media usage evolve throughout the course of a severe weather event? Preliminary results of this research have been disseminated throughout the NWS by way of multiple presentations, conference calls, and a NOAA report entitled: "Utilization of Real-Time Social Media Data in Severe Weather Events: Evaluating the Prospects of Social Media Data Use for Severe Weather Forecasting, Communication, and Post-Event Assessments." In addition, the Sea Grant Social Scientist is working with a group of graduate and undergraduate students at OU to study the correspondence between severe weather reports on social media and local reports of severe weather, as documented by the NWS. Preliminary findings reveal a moderate correspondence that improves when linguistic and geographic algorithms are employed, suggesting that social media reports may provide useful information to forecasters and model developers. Finally, the Sea Grant Social Scientist is collaborating with scientists at NSSL, OAR, GSD, and SPC on the Forecasting a Continuum of Environmental Threats (FACETs) research program. This research is intended to develop a baseline measure of public responsiveness to weather forecasts and warnings. This measure will then be used to systematically evaluate the effectiveness of NWS initiatives and products, like FACETs.



The Evolution of Message Content on Twitter Before, During, and After the 2013 Newcastle-Moore-South Oklahoma City tornado.



The evolution of message quality on Twitter before, during, and after the 2013 Newcastle-Moore-South Oklahoma City tornado.



The correspondence between hail reports on Twitter, SPC, severe thunderstorm warnings, and MESH hail swaths on 10 May 2014.

Publications

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 severe weather risk communication? *Weather, Climate and Society*, **6**, 520-530. doi:10.1175/WCAS-D-13-00028.1.

Ripberger, J. T., C. L. Silva, H. C. Jenkins-Smith, D. E. Carlson, M. James, and K. G. Herron, 2015: False alarms and missed events: The impact and origins of perceived inaccuracy in tornado warning systems. *Risk Analysis*, **35**, 44-56. doi: 10.1111/risa.12262.

Ripberger, J. T., C. L. Silva, H. C. Jenkins-Smith, and M. James, 2015: The influence of consequence-based messages on public responses to tornado warnings. *Bulleting of the American Meteorological Society*, **96**, 577-590. doi:10.1175/BAMS-D-13-00213.1.

CIMMS Task III Project – Prototyping and Evaluating Key Network-of-Networks Technologies

Fred Carr, Lee Carlaw, Nicholas Gasperoni, and Andrew Osborne (OU School of Meteorology)

NOAA Technical Lead: Tim McClung (NOAA/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

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 Experiments (OSEs); and (ii) evaluate observation sensor impact using a new ensemble-based forecast sensitivity to observations (EFSO) technique that uses a EnKF data assimilation scheme. The primary focus of the OSE work has been on evaluating the impact of non-conventional data from surface networks for high-resolution analyses and forecasts. The EFSO work has focused on developing an EnKF data assimilation system that provides data impact estimates in real-time for storm-scale modeling systems.

Accomplishments

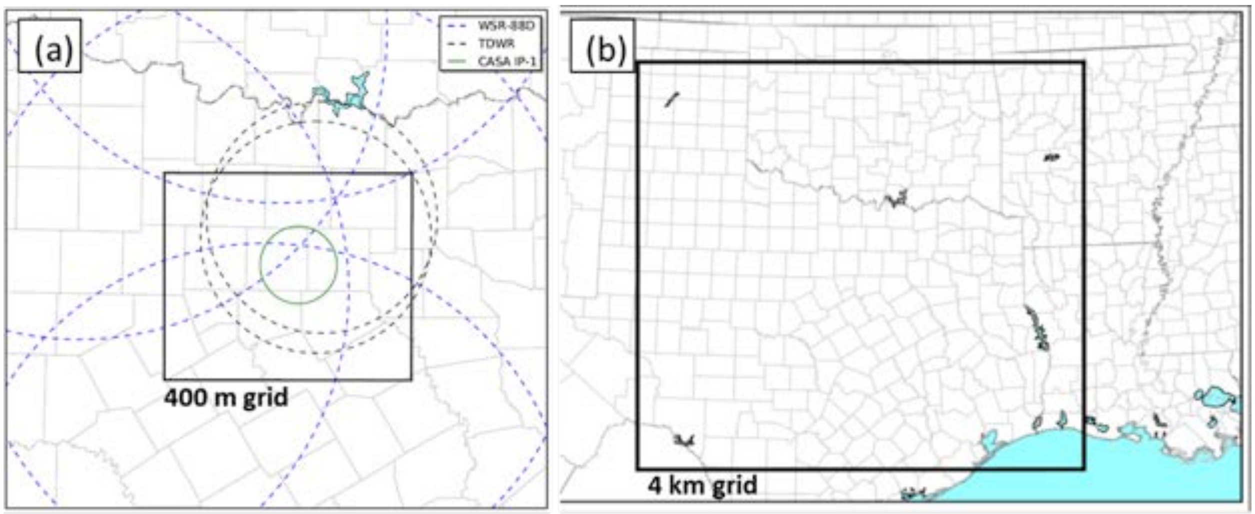
1. Evaluate Observation Sensor Impact Using an OSE

Our first OSE project concluded this year with the completion of Lee Carlaw's M.S. thesis, and subsequent publication. The study proceeded on 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 (second table below). 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.

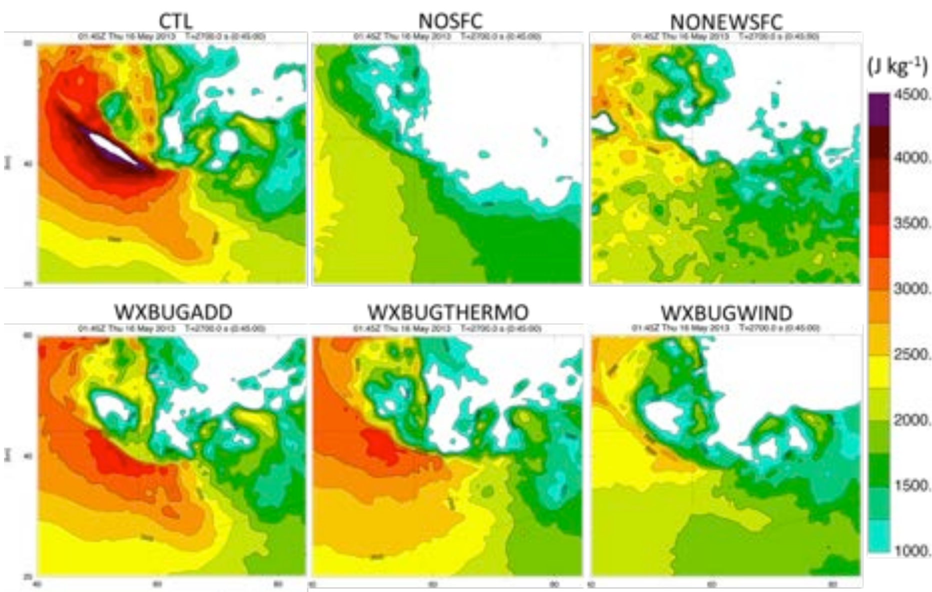
Details of the 400-m assimilation-forecast experiments

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

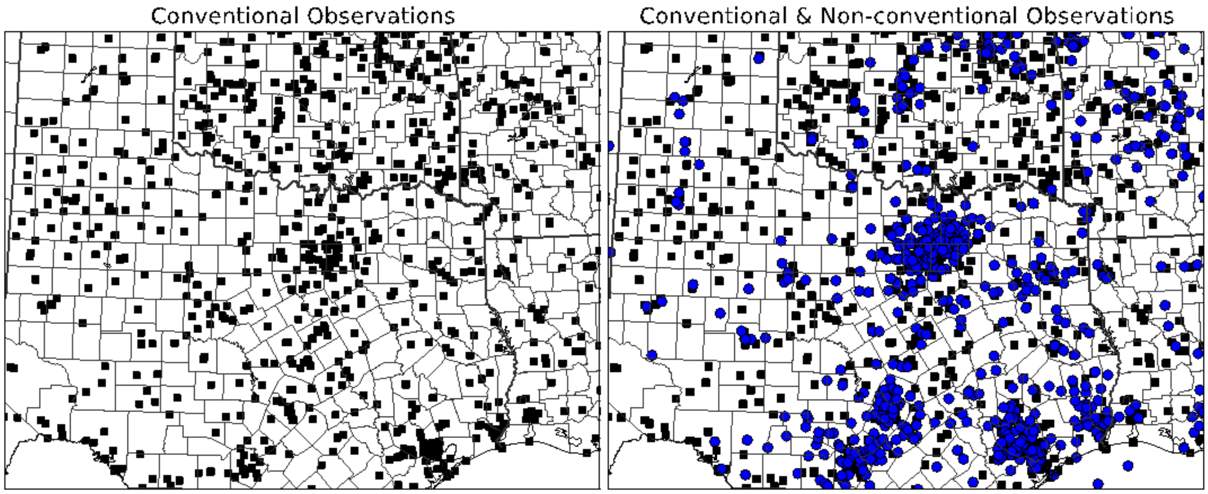
A series of forecasts were generated using each of the above analyses as the initial conditions. A review of these storm forecasts showed that *the thermodynamic information from a few select WeatherBug stations located within the storm inflow region had a significant impact on the storm evolution*. 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 was published in the *Electronic Journal of Severe Storms Meteorology*.



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 to 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.

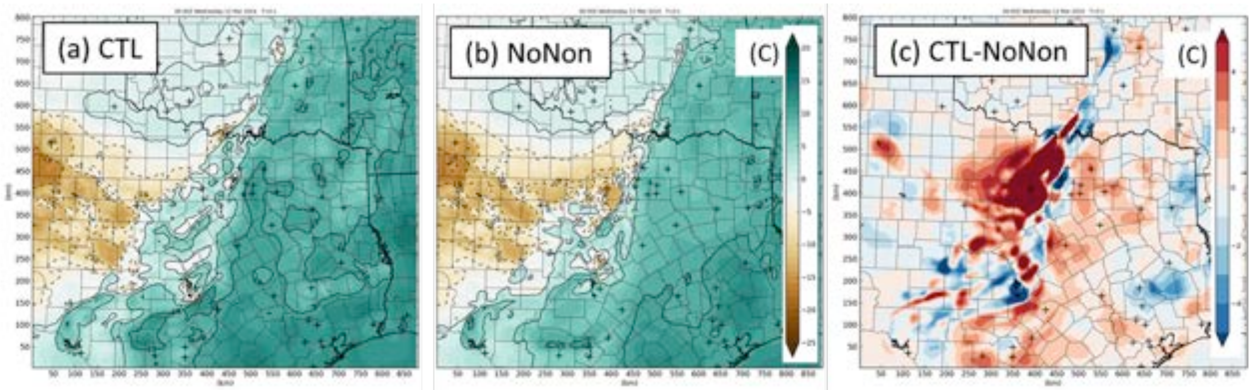


The site locations of data used from the (left) conventional only and (right) conventional and non-conventional stations.

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.

In order to use assimilation and forecast systems employed by the NWS at NCEP, new work has begun to set up a similar OSE framework using the hybrid GSI EnKF DA system and the WRF-ARW model in use by HRRR. These systems are currently being run on the May 15, 2013 case study but no new results to date. New case studies from 2015 will be sought that will have data from the 5 CASA X-band radars that were deployed in the DFW Testbed that spring.



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 EFSO

Over the past year, Ph.D. student Nicholas Gasperoni has been researching areas of improvement for the ensemble-based forecast sensitivity to observations (EFSO) metric. The EFSO method, introduced by Kalnay et al. (2012), is able to calculate the impact of subsets of observations on a forecast without the need for separate data denial experiments or adjoints. The method is appealing because it relies on readily-available products of any ensemble-based assimilation system. Due to limited ensemble sizes compared to the large degrees of freedom in state-of-the-art weather models, it is necessary to apply localization techniques to obtain accurate estimates. Fixed localization techniques do not guarantee accurate impact estimates, because as forecast time increases the error correlation structures evolve with the flow. In this work, we investigated the use of an adaptive localization technique to automatically determine the necessary shape of a more 'optimal' localization function for EFSO. The adaptive method, referred to as *regression confidence factor* (RCF), revealed that the shape, location, time-dependency, and variable-dependency of RCF localization functions are consistent with underlying dynamical processes of the model. Application of RCF localization to ensemble-estimated observation impact showed marked improvement especially for longer forecasts and at midlatitudes, when systematically verified against actual impact in RMSE and skill scores. It was discovered that an inherent relationship exists between the localization applied during the assimilation and the proper localization choice for observation impact estimates. Additionally, a practical application of RCF for automatically-tuned Gaspari-Cohn localization was developed and tested, which may help offset practical costs of using an adaptive method for more accurate impact estimates. The results of this research were recently published in the *Monthly Weather Review* under the 6^{th} WMO Data Assimilation Symposium Special Collection (Gasperoni and Wang, 2015).

Work began on the use of the GSI-based Ensemble Kalman Filter (EnKF) system together with the WRF-ARW model for real case studies over the DFW testbed domain.

Initial tests for the EnKF have been done to help identify optimal parameter settings for the assimilation system. There are two components to the research with the GSI-based EnKF. First, data denial experiments will be conducted to evaluate the added impact of the non-conventional high-resolution spatial and temporal observations over the testbed domain. These non-conventional data include amateur surface stations, Earth Networks Weather bug surface stations, data from mobile GST trucks, and radiometers. The data-denial experiments will focus on the impacts of the non-conventional data compared with the conventional data for a dryline convection initiation (CI) case. In particular, the focus will be on timing and location of CI within the DFW domain and the potential impact the added observations have on resolving the fine-scale details of the dryline and wind fields near these CI locations. One case study has been identified for focus on CI – April 3, 2014. On that day, tornadic supercells initiate along a NE-SW oriented dryline within the NW part of the DFW testbed domain (Wise County). The current EnKF configurations include high-frequency 5-minute cycling as well as observation-dependent localization to take advantage of the high-spatial resolution of non-conventional observations. It is hypothesized that small-scale changes in the shape and orientation of the dryline play a significant role in the timing and location of CI, and non-conventional observation assimilation will aid with better defining the dryline and improving the accuracy of CI.

The second component of this GSI-based EnKF research is the practical application of EFSO toward mesoscale forecasts of convection within the Dallas testbed. We have integrated the necessary code for EFSO with the GSI-based EnKF and are in the process of testing it on some cases. For this research, the GSI-based Ensemble Kalman Filter is used along with the WRF-ARW. This is one of the first studies to focus on applying EFSO on mesoscale forecasts of convection. These EFSO estimates will be compared with the data denial results for accuracy. The results of Gasperoni and Wang (2015) give us a starting point towards how to apply adaptive localization for the EFSO in this case, which is important in order to obtain accurate impact estimates. Other adaptive methods in addition to the RCF method of Gasperoni and Wang (2015) will be tested.

Publications

Carlaw, L. B., J. A. Brotzge, and F. H. Carr, 2015: Investigating the impacts of assimilating surface observations on high-resolution forecasts of the 15 May 2013 tornado event. *Electronic Journal of Severe Storms Meteorology*, **10**, 1-34.

Gasperoni, N. A., and X. Wang, 2015: Adaptive localization for the ensemble-based observation impact estimate using regression confidence factors. *Monthly Weather Review*, **143**, 1981-2000.

Awards

Nicholas Gasperoni (OU School of Meteorology) won the 2015 Douglas Lilly Best Ph.D. Publication Award from the OU School of Meteorology, and won Best Student Oral Presentation at the IOAS-AOLS Conference at the AMS Annual Meeting, January 2015.

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

M. Issa Lélé (CIMMS at OU), Rosalind Cornforth (University of Reading), and Aondover Tarhule (OU Department of Geography and Environmental Sustainability)

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.

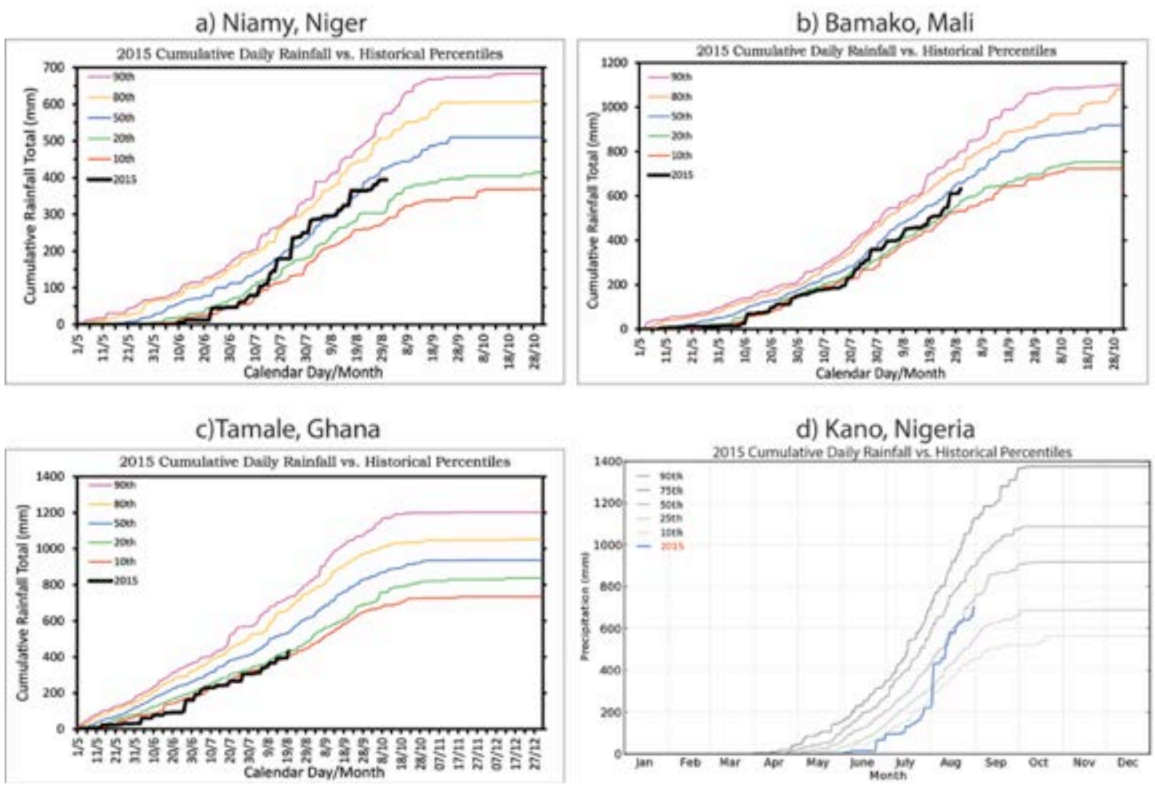
Accomplishments
Risk mitigation is critically important for managing the tragic consequences of Africa's climate variability. Those consequences include periodic food shortages, loss of lives, displacement of millions of people and adverse economic impacts especially on agriculture that depends directly and largely on rainfall. Recognizing this fact, adaption to an increasing and potentially irreversible global sustainability is become a challenge for people in the region. Given this situation and the fact that short-term weather and seasonal climate forecasting have limited skill for West Africa, the Rainwatch project illustrates the value of near real-time monitoring and improved communication between climate providers and users. Rainwatch is now coupled with a boundary organization (Africa Climate Exchange, AfClix) with the aim of integrating the expertise and actions of relevant institutions, agencies and stakeholders to broker ground-based dialogue to promote resilience in the face of recurring crisis. Since the end of 2011, Rainwatch-AfClix has been working on the ground at the sharp end of Africa's weather in Sub Saharan Africa, to explore how our science can best inform climate-related policy for improving people's food security. Rainwatch-AfClix, weather information systems are helping mitigate humanitarian disasters by prompting officials to take action sooner. While we recognize a gulf between the availability of information and the ability of vulnerable groups to act on that information, we maintain that timely information is a pre-requisite for informed decision-making.

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 2015 monsoon season is ongoing stations in Burkina Faso, Ghana, Mali, and Niger using Rainwatch-AfClix interface. In Addition, Rainwatch-AfClix focal point in Nigeria, Burkina Faso, Senegal, Guinea Conakry, Sierra Leon, The Gambia, and Mauritania have been designated by their respective Directors and trained by the Rainwatch-AfClix team in the method of uploading and interacting with the system. These countries stations together with the previous stations were available at http://cimms.ou.edu/rainwatch/. 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.

Publications

Issa Lélé M., L. M. Leslie, and P. J. Lamb, 2015: Analysis of low-level atmospheric moisture transport associated with the West African monsoon. *Journal of Climate*, **28**, 4414-4430.



Rainwatch cumulative precipitation depiction for Niamey (Niger), Bamako (Mali), Tamale (Ghana), and Kano (Nigeria) for 2015 rainy season. Comparison of progression of 2015 rainy season (thick black lines) with indicated historical percentiles calculated over a) 1965–2000; b) 1974-2003, c) 1950-2012, and d) 1961-2014 periods.

CIMMS Task III Project – The Assimilation, Analysis, and Dissemination of Pacific Rain Gauge Data (PACRAIN)

Mark Morrissey and Susan Postawko (OU School of Meteorology), and J. Scott Greene (OU Department of Geography and Environmental Sustainability)

NOAA Technical Leads: David Legler (NOAA Climate Program Office) and Howard Diamond (NOAA National Climatic Data Center)

NOAA Strategic Goal 1 – *Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts*

Funding Type: CIMMS Task III

Objectives

Tropical rainfall data taken over both land and ocean are particularly important to the understanding of the climate system. Not only is it a tracer of latent heat, it is vital to the understanding of ocean properties as well, including latent and sensible heat flux, salinity changes and concomitant local ocean circulation changes. In addition, rain gauge observations from low-lying atolls are required to conduct verification exercises of the TAO/TRITON buoy-mounted rain gauges, which are funded by NOAA's Ocean Climate Observing Program (OCO). Tropical island rainfall is also required for verification work by satellite rainfall algorithm programs funded by NASA, NOAA and various international programs.

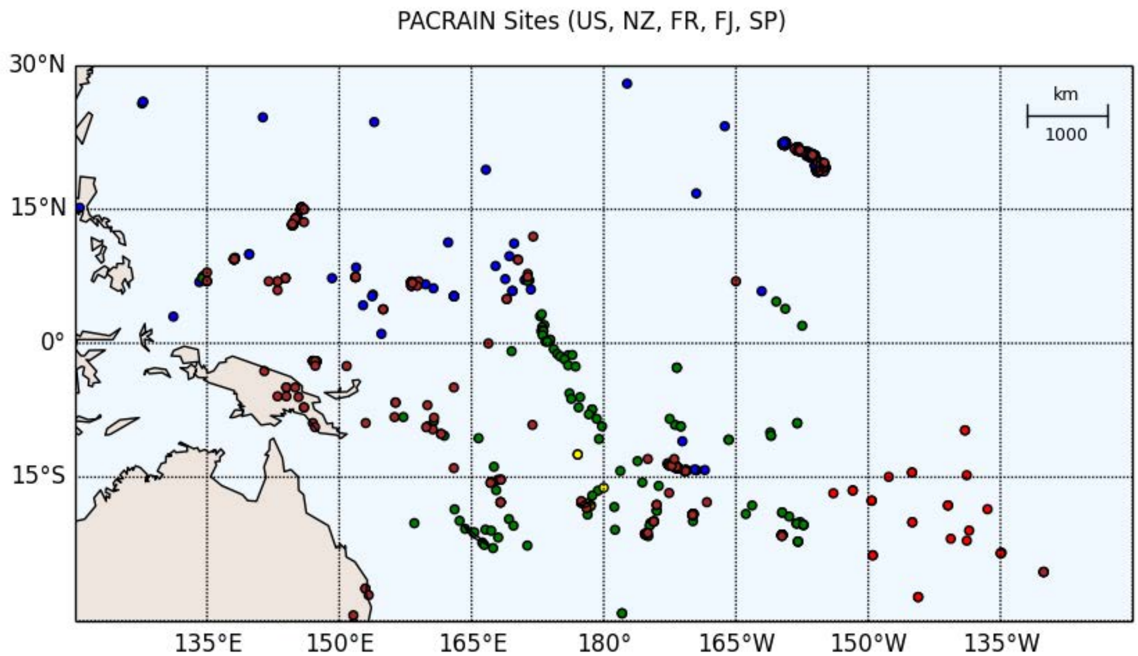
This project supports the effort to "build and sustain the global climate observing system that is needed to satisfy the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments". Our current and future efforts include 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

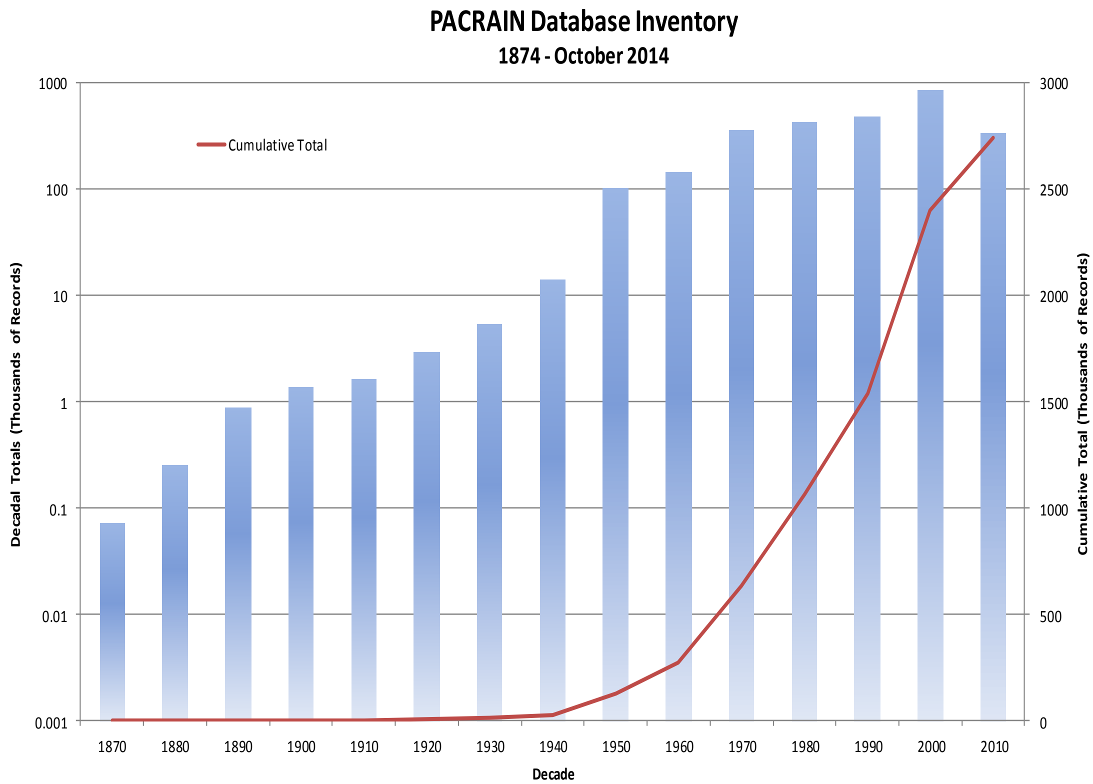
1. PACRAIN Database Status

As of October 2014 the database contains 2.74 million daily and monthly observations from 990 sites (see figures below). Data begin in January 1874. Data availability varies

by site. Data are not available in real time and thus are not distributed via GTS. Data are collected for climate research and frequently arrive from very remote locales after several months. 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 more than one query.



Past and current PACRAIN sites with daily data, color-coded by data source. Blue is NCDC data, green is NIWA data, yellow is Fiji Met. Service data, red is Meteo-France data, and purple is SPaRCE data.



PACRAIN data availability over time. Cumulative total is shown by the red curve. Decadal total are shown by the histogram.

2. Database Enhancements

PACRAIN operations are in the middle of a major hardware and software upgrade. A new server is in place that offers faster performance, better reliability, and the latest software. The database has been migrated to an upgraded version of the PostgreSQL database management system. The data ingest and processing software is currently being overhauled to take advantage of the Python programming language. The PACRAIN web site is also being rewritten to use Python. Using a common language for these components will ease future development and maintenance.

3. Investigation into Differences Observed Between the PACRAIN Data and the Global Historical Climate Network

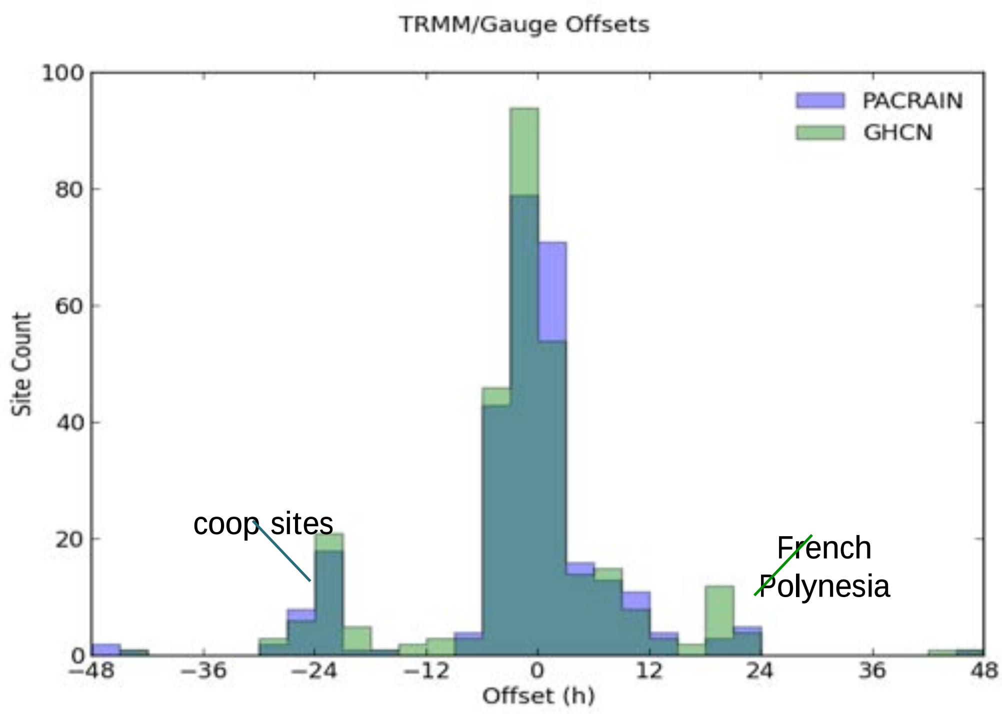
The primary purpose is to include PACRAIN into the GHCH and use the PACRAIN project to build and search for new and existing Pacific island rain gauge data that are not found easily.

The GHCN data set is NCDC's data set of record of global daily climate observations of many different variables. Starting with the 2011 data year, PACRAIN incorporated GHCN data for sites in the United States and its Pacific affiliates. Prior to 2011, PACRAIN used the original TD3200 Cooperative Summary of the Day data for US sites.

PACRAIN does not currently use any GHCN data for non-US sites. Thus, the PACRAIN database contains data that did not originate with GHCN, providing an opportunity to compare overlapping data and identify discrepancies between the datasets.

Within the PACRAIN domain there are 812 GHCN sites, compared 842 PACRAIN sites that have daily data. GHCN has greater coverage north of the Equator, primarily from CoCoRaHS sites in Hawaii and post-war US cooperative observer data from the Ryuku Islands in Japan. PACRAIN has much greater coverage south of the equator where GHCN data is limited mostly to ICAO aviation observation sites. Notably, there is GHCN rainfall data for Cook Islands, Niue, Pitcairn Islands, Samoa, or Wallis and Futuna. GHCN also does not include data from SPaRCE sites, although they could if needed.

A comparison of coincident GHCN and PACRAIN data shows that, overall, the data are in good agreement. However, there are some significant discrepancies with the reported observation times for some sites. For example, the data for a number of French Polynesia sites are offset by ~1 day. In this case the PACRAIN data are in temporal agreement with satellite estimates from the NASA TRMM project, so it is possible that the GHCN data are attributed to the wrong day for these sites. Work continues with NCDC to identify and classify the differences between the PACRAIN and GHCN data, and we are currently preparing a manuscript on the results of this work for publication.



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)

For the past 23 years the Schools of the Pacific Rainfall Climate Experiment (SPaRCE) project at the University of Oklahoma has been working directly with elementary and high school teachers, as well as other organizations (such as the Secretariat of the Pacific Regional Environment Programme) around the Pacific. During this time, we have also worked informally with the Pacific island meteorological services to aid them with their own local educational outreach projects. The SPaRCE program is uniquely situated to be able to both continue collaborating directly with schools, and to aid the meteorological personnel in the islands to develop easily understood educational materials that can be used in a variety of circumstances. Over the past year we have worked on updating many of the SPaRCE materials to include more recent/relevant information on topics such as ENSO, global climate change, cyclones, cyclone preparation brochure, etc.

Continued funding for the SPaRCE program will be used to provide Pacific island meteorological services with low-cost rain gauges for their cooperative observer networks, and to support our undergraduate student to work with meteorological service personnel to develop and deliver educational materials aimed at both potential cooperative observers as well as the general public.

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

Improve various aspects of weather warnings both in the short, medium and long terms. During the project period, CIMMS researchers propose to perform research to: (1) create numerical weather guidance; (2) warning decision-making; and (3) the production of valuable warnings for users

Accomplishments

1. Creation of Numerical Weather Guidance

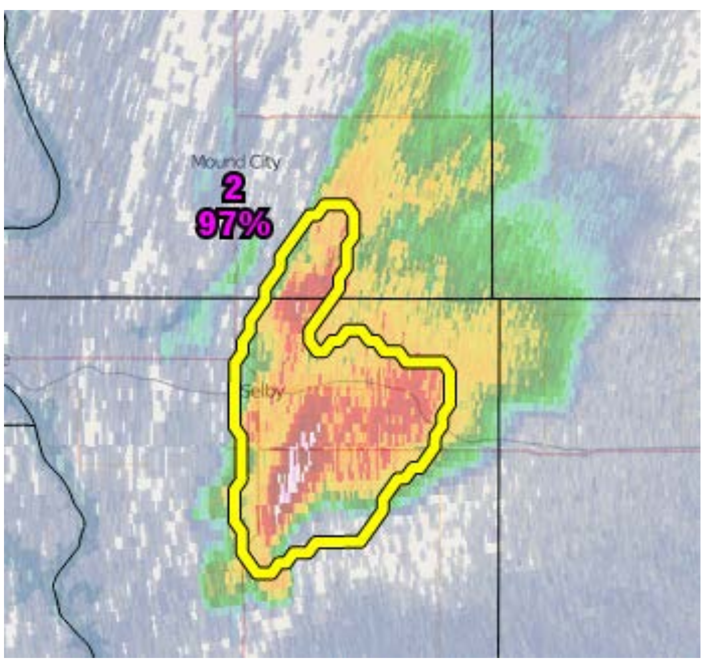
James Correia, Jr. (CIMMS at SPC) and Chris Karstens (CIMMS at NSSL)

Numerical Weather Guidance was provided to forecasters participating in both the Experimental Warning Program (EWP) and the Experimental Forecast Program (EFP) during the 2015 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 by incorporating the NOAA ProbSevere model (Cintineo et al. 2014) into a prototype web application for generating probabilistic forecasts for any severe convective hazard (tornado, wind or hail; first figure below). The ProbSevere model produces a diagnostic probability that the radar-derived object will produce severe weather within the next 60 minutes. In addition, an implementation of the k-means clustering and object identification algorithm was produced that tracked mid-level azimuthal shear clusters (second figure below). Using an empirical relationship between the peak value of azimuthal shear within the object and tornado warning performance, a diagnostic probability for the occurrence of a tornado was produced. Forecasters could use these objects to generate probabilistic forecasts while optionally overriding the guidance probabilities to ideally add value to the forecast. The usage of this guidance information is discussed in the next section.

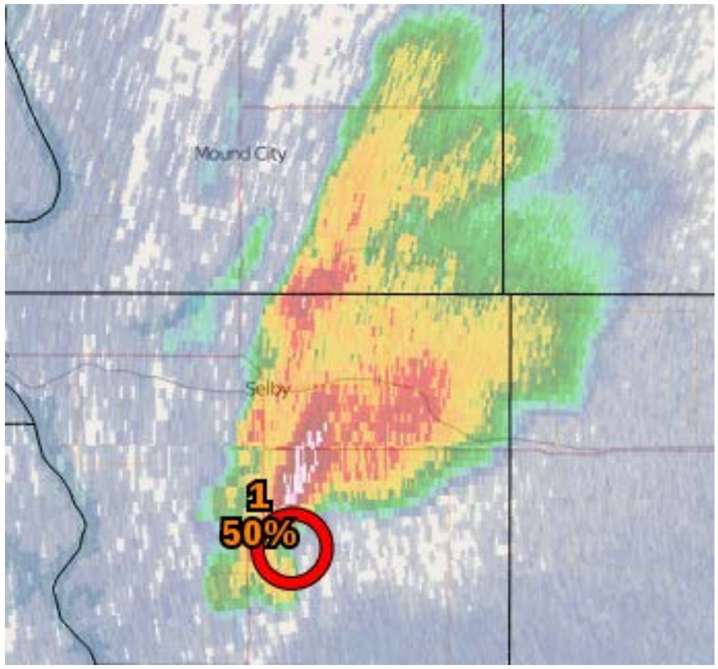
In the near future, we will be conducting testing and evaluation of rapid post-processing and information extraction from large convection-allowing ensembles applied to 0-3 hour tornado outlooks. The purpose of this project is to design, implement, and evaluate a new post-processing paradigm, designed for any convection-allowing

modeling and ensemble system. This new paradigm will allow information extraction for severe weather forecasting, specifically tornado forecasts. This new post-processing paradigm has the benefit of being adaptable, scalable, and fast. To achieve these benefits, we propose using an object-based approach to refine gridded datasets into features of interest, a result of the data mining and information extraction, in order to achieve reduced dataset size for transmission, allow the viewing of all ensemble members, create an ability for forecasters to adapt to the problem of the day and maximize effective use of numerical guidance. Evaluation of our work will allow attribution of forecast improvements to the specific, direct cause, be that the experimental products, forecast tools, or other confounding factors.

We will be utilizing an ensemble-based, radar data assimilation system within the HWT to generate hourly and three hourly tornado outlooks. Forecasters will use the proposed object based post-processing to derive the information they need to make these forecasts. Multiple variables and thresholds will be available for them to make full use of the guidance, rapidly prototyping and data mining to meet the problems of the day. An evaluation of how this strategy will affect forecaster workload will be conducted to further refine our post-processing strategies. This project is a necessary first step in achieving full use of rapidly updating, large convection-allowing ensemble systems and making them useful and usable to forecasters while producing consistent and reliable risk analyses in between the warning and watch time scales. This in turn, enables forecasters to provide effective decision support to help partners effectively mitigate the impacts of severe weather.



Example of a NOAA ProbSevere object incorporated into the prototype PHI tool as numerical weather guidance.



As above, except for a mid-level azimuthal shear object.

2. Warning Decision-Making

Chris Karstens (CIMMS at NSSL) and James Correia, Jr. (CIMMS at SPC)

Planned and supported various activities within the Experimental Forecast Program (EFP) activities of 2015 included: (1) ensemble forecasts of severe weather using updraft helicity objects for 4 systems (NCAR, SSEO, NSSL, CAPS) at higher temporal resolution; (2) production of experimental probabilistic forecasts using a web-based prototype tool, and (3) perform briefings to Experimental Warning Program participants to highlight EFP forecasts.

The EFP experiment included several forecasters (8-10) each week for five weeks (3 May to 5 June). Forecasters working on the NSSL desk 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. On the SPC desk, forecasters issued 4-hour probabilistic outlooks for individual hazards (tornado, wind, and hail) from 18-22 UTC and 22-02 UTC and within 25 miles of a point. At both desks, updates to the morning forecasts were conducted in the afternoon. Forecasters were given the ability to create their own probabilistic forecasts, with tool functionality similar to that of NMAP (GEMPAK software), by examining experimental guidance from convection-allowing models and ensembles. 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.

Planned and supported various activities within the Experimental Warning Program (EWP) Probabilistic Hazard Information (PHI) experiment of 2015 included: (1) conduct the Probabilistic Hazard Information (PHI), and PHI-Emergency Manager experiments to explore the use of PHI and its communication with emergency managers; and (2) provide briefings for real-time cases, and provide some graphics for case study briefings.

Expanding upon efforts from 2008 and 2014, the 2015 Hazardous Weather Testbed (HWT) Probabilistic Hazard Information (PHI) experiment was conducted in the Experimental Warning Program (EWP) during the weeks of 4-8 May, 19-23 May, and 1-5 June. In addition, a simultaneous experiment with emergency managers (3 per week) was conducted to gain an understanding of how end-users interpret and use the probabilistic information for (simulated) decision-making. Two forecasters participated each week by issuing probabilistic forecasts for severe convective phenomena, including any-severe (tornado, wind, hail) and specifically for tornado, in the 0-2 hour timeframe using a prototype web tool. Automated, object-based guidance was provided to the forecasters in real-time for each of the aforementioned probabilistic forecast types. The primary objective of this experiment was to develop an understanding how forecasters use the PHI system with the automated guidance by varying the forecasters' level of interactivity with the guidance information.

To achieve the objective of this experiment, three experiment strategies were developed and tested with forecasters: the loop, out of the loop, and in the loop. First, "the loop" strategy involved removing the automated, object-based guidance from the forecasters. Thus, the forecasters had to rely purely on their intuition for judgments under uncertainty. The second "out of the loop" strategy is the opposite of the first, in that forecasters are completely removed from the decision-making process. Thus, all forecasts were being generated by the automated system. The third "in the loop" strategy represents a mixture of the first two strategies, by giving the forecasters full access to the automated guidance for assistance in decision making. In each strategy, 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.

Each strategy produced interesting preliminary results. Results from the first "the loop" strategy reinforced findings from the 2014 HWT PHI experiment. The so called "on-the-fence" decision to warn or not warn is effectively removed from the forecaster because of the ability to issue information for storms based on their current and projected likelihood of producing severe weather. However, this liberating effect introduced a paradoxical increase in workload. Forecasters felt taxed when having to manage in excess of 4-5 hazard areas simultaneously. To speed up the pace of work, forecasters resorted to workload simplifiers, such as simple object geometries (analogous to WarnGEN-like warning polygons) and a general dearth of communication.

Results from the second “out of the loop” strategy revealed that forecasters quickly became frustrated with the inability to intervene with the automated system. Forecasters want to be part of the forecast process. In addition, with the only means of communication being routed through NWSChat, the emergency managers were forced to interrogate the storms themselves, relying on what training and intuition they had received or developed about radar meteorology. In effect, this strategy puts end-users in the position equal to that of a forecaster (i.e., warning decision makers). This may work for savvy end-users, but most EMs felt uncomfortable in this position.

Results from the third “in the loop” strategy showed that, early on, forecasters had difficulty interacting with the automated guidance. In many instances, forecasters would issue a PHI object for a storm or hazard at approximately the same time as the automated system, thus resulting in two, often similar, forecasts for the same storm or hazard. After a few instances of these types of events, forecasters would frequently raise the thresholds of the automated system to block such guidance from entering the forecast process. In essence, forecasters gravitated back toward the first “the loop” strategy, thus reintroducing the aforementioned workload complications.

After observing and taking recognition of this effect, the facilitators developed a fourth strategy, a hybrid of the third “in the loop” strategy. This new strategy required the forecasters to allow the automated system to generate PHI objects, for any-severe, within forecaster-defined severity thresholds. Forecasters could optionally override specific object attributes, including the object speed, direction, duration, discussion, and probability trend, in addition to allowing or blocking PHI objects completely. For tornado, the first “the loop” strategy was employed, as the automated guidance, still premature, had far too much false detection, and there are often fewer tornado hazards to manage simultaneously than any-severe.

Results from the fourth hybrid “in the loop” strategy suggest that this was the optimal strategy, for both forecasters and emergency managers. Forecasters could leverage the rapid mechanical abilities of object generation from the automated system, thus prioritizing their decision making on a storm’s or hazard’s severity likelihood, movement, and longevity. These decisions were expressed in the PHI object attributes directly and in the object discussion (i.e., communication), thus working toward messaging consistency. The emergency managers appreciated the rapid flow information and updates enabled by this hybrid strategy. However, in at least one instance, a hazard was not collocated with the automated system’s object (surging winds ahead of a convective line). Forecasters communicated this observation, along with an estimation of the hazard intensity, via the object discussion, and emergency managers found this information to be effective.

The preliminary results of this experiment have highlighted areas needing further research and development. First, the communication from the forecaster to end-users via the prototype PHI tool is currently unstructured, given as a blank text box open for interpretation. It became clear that some forms of communication were found to be effective, while others were not. Therefore, we plan to use the information and data

collected from the experiment to develop a set of communication protocols for various hazard situations, and implement tools that allow forecasters to quickly leverage such protocols in the next HWT experiment. Second, we plan to make improvements in the automated guidance, such as including more sources, improvements in these sources (understanding and reliability), presentation within the tool, and refinements of forecaster interactivity. Third, the notion of lead-time and its meaning will be of primary focus during the follow-up emergency manager experiment, along with testing the receipt of the newly developed communication protocols.

3. Production of Valuable Warnings for Users

Chris Karstens and Jeff Snyder (CIMMS at NSSL), James Correia, Jr. (CIMMS at SPC), and Gabe Garfield (CIMMS at OUN)

A Hollings Scholar examined all NWS storm-based warnings (October 2007-May 2015) during summer 2015. This study examined four components of NWS storm-based warnings, including a general climatology, phenomenological representativeness, compliance with NWS directives, and warning workload (by NWS office). It was found that a majority of storm-based warnings are issued east of the Rocky Mountains, and concentrated in the Central/Southern Plains, Lower Mississippi Valley, and Southern Appalachian regions. Regional uniformity exists in the speed and direction of hazards indicated within the warning text, however, warning size and duration exhibited little regional uniformity. These results suggest that the warning software used to generate storm-based warnings reflect storm motion well, but questions remain regarding the ability to reflect storm size and duration. Storm-based warnings were found to generally conform to current NWS policies. Approximately 90% of all warnings received a follow-up severe weather statement (SVS). However, approximately 28% of all tornado warnings exceed 45 minutes in duration, while 17% of all severe thunderstorm warnings exceeded 60 minutes in duration. The appreciable number of tornado warnings exceeding the duration threshold set by NWS policy is interesting, suggesting that perhaps some situations warrant the extra lead time due to confidence in storm longevity, or perhaps that end-users are requesting longer-lead times for enacting mitigation plans. Finally, the Great Plains, and in particular the Central Plains, issued the greatest average number of severe thunderstorm warnings per convective day time period, while the Lower Mississippi Valley and Southeast regions tended to have larger tornado warning workloads. The Southern Plains and Lower Mississippi Valley were found to have the greatest number of severe thunderstorm warning outbreaks (i.e., number for days exceeding one standard deviation above the national mean) while the Lower Mississippi Valley maintained the most frequent tornado warning outbreaks during the seven-year span.

In addition to analyzing storm-based warnings, a series of tornado events have occurred locally, and thus, has enabled research on actions users take both before and during tornado warnings. On 31 May 2013, a series of supercells produced several tornadoes near the Oklahoma City metropolitan area, including an extraordinarily large, intense tornado near El Reno, Oklahoma. Thousands of residents across the southern

Oklahoma City metro left their homes to drive away from the perceived tornado threat. Subsequent traffic congestion – captured by traffic data provided by the Oklahoma Department of Transportation – likely increased the number of people vulnerable to threats associated with the supercells, including giant hail and extreme flash flooding. The response may have been enhanced by media suggestions that those in the path of the supercells "get underground" or "get out of the way," and by enhanced awareness following tornadoes in central Oklahoma on previous days. This GIS-based project improves on an earlier study by using OU RaXPol radar observations to estimate EF-scale contours in hypothetical tornadoes. Radar wind estimates and ground survey observations are combined with traffic flow data to examine potential impacts on vehicle-related casualty counts in hypothetical tornadoes in the Oklahoma City area. Given the desire to increase warning lead times (e.g., through "Warn-on-Forecast"), it is apparent that those involved in the integrated warning system may need to consider how people in heavily populated areas will respond to such information. In this particular case, the response of residents to flee in vehicles could have resulted in scores of casualties. Our collaborative research, with units throughout OU (CASR, CAPS) and NOAA/NWS (SPC and the Norman WFO) continues to analyze sheltering behavior following our understanding of the response to the May 2013 tornadoes in central OK. We presented some of this work both internally and externally at the National Tornado Summit. This year we fielded a survey of people taking shelter at the National Weather Center. Analysis of these surveys is ongoing.

Publications

Cintineo, J. L., M. J. Pavolonis, J. M. Sieglaff, and D. T. Lindsey, 2014: An empirical model for assessing the severe weather potential of developing convection. *Weather and Forecasting*, **29**, 639-653.

Karstens, C. D., G. Stumpf, C. Ling, L. Hua, D. Kingfield, T. M. Smith, J. Correia, Jr., K. M. Calhoun, K. L. Ortega, C. J. Melick, and L. P. Rothfusz, 2015: Evaluation of a probabilistic forecasting methodology for severe convective weather in the 2014 Hazardous Weather Testbed. *Weather and Forecasting,* in press.

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

Objectives

Design, prepare for, and execute the 2015 Phased Array Radar Innovative Sensing Experiment (PARISE).

Accomplishments

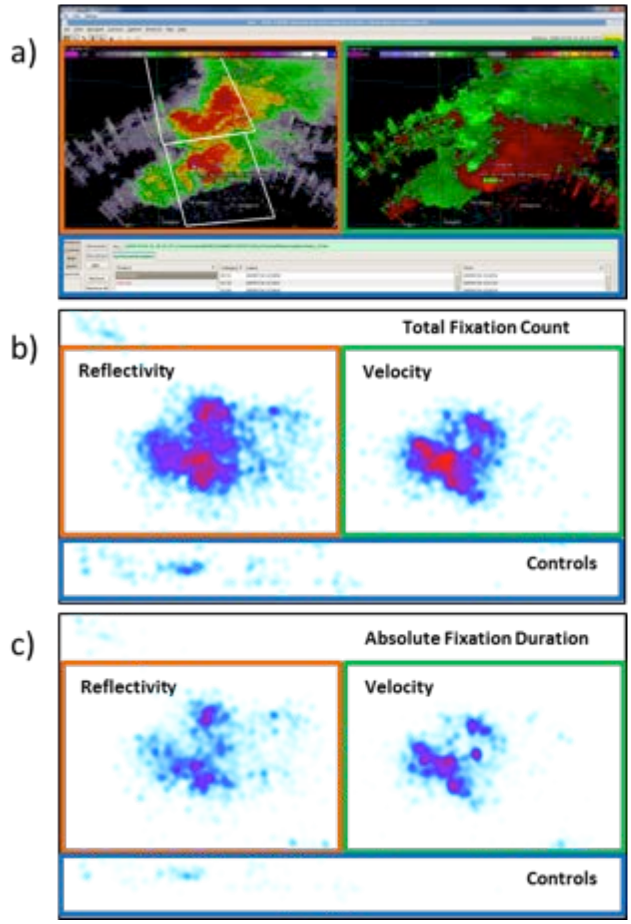
1. Eye-Tracking Pilot Study

Katie Bowden (CIMMS at NSSL and OU School of Meteorology), Pam Heinselman (NSSL), and Ziho Kang (OU Industrial and Systems Engineering)

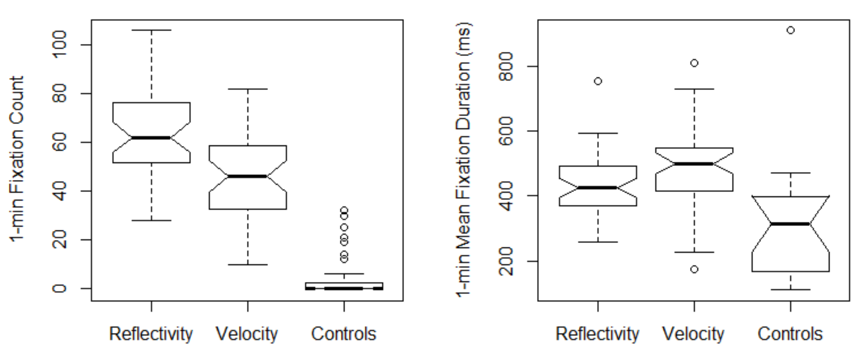
As part of an external PhD committee member search, Katie Bowden formed collaboration with Dr. Ziho Kang (OU Industrial Systems and Engineering). Dr. Kang specializes in eye-tracking research and his prior work primarily focuses on studying air traffic control professionals' eye- tracking data.

To explore whether eye-tracking methods could be applied to understanding NWS forecasters' warning decision processes, a pilot study was conducted in the spring of 2015. During this study, eye gaze data and retrospective recall data were collected from an NWS forecaster who worked one severe hail and wind even in simulated real-time. Dr. Kang's state-of-the-art Tobii TX300 eye-tracking system was used to collect eye gaze data.

Bowden analyzed the forecaster's eye gaze data using both qualitative and quantitative methods. For example, heat maps were created to visualize measures such as fixation count and absolute fixation duration during the entire simulation (first figure below). One finding was that the forecaster fixated more often but more broadly in the reflectivity panel compared to the velocity panel. Median values of the 1-min distributions of these measures differed significantly between three areas of interest: reflectivity, velocity, and controls (second figure below). Additional analysis included comparing fixation measure trends to the forecaster's retrospective recall. This comparison showed that the trends in the eye gaze data were representative of the forecaster's cognitive process as the weather case evolved. This study has motivated use of eye-tracking applications in the 2015 Phased Array Radar Innovative Sensing Experiment (PARISE).



Fixed areas of interest were identified as the (a) reflectivity, velocity, and control panels, in which heat maps for the (b) total fixation count and (c) absolute fixation duration were created. Warmer colors represent higher/longer fixation count/absolute duration.



Distributions of the 1-min fixation count (left) and 1-min mean fixation duration (right) for the reflectivity, velocity, and controls areas of interest.

2. The 2015 Phased Array Radar Innovative Sensing Experiment (PARISE)

Katie Bowden (CIMMS at NSSL and OU School of Meteorology), Pam Heinselman (NSSL), Ziho Kang (OU School of Industrial and Systems Engineering), and Charles Kuster, Darrel Kingfield, Tiffany Meyer, and Richard Adams (CIMMS at NSSL)

The 2015 PARISE consists of 30 NWS forecasters visiting Norman, Oklahoma over six weeks during August and September 2015. These forecasters will each participate in a weeklong experiment that is comprised of three elements including 1) a traditional experiment, 2) an eye-tracking experiment, and 3) a focus group.

The traditional experiment will build on earlier work of PARISE by using methodology applied in previous studies. During the traditional experiment, each forecaster will work a total of 9 archived PAR simulations, and will be exposed to 1-, 2-, and 5-min PAR updates. The generalizability of results will be improved during the 2015 PARISE compared to earlier experiments by boosting the sample size in number of forecasters participating and the number of cases worked. Performance measures such as forecaster accuracy and lead time will be calculated, and qualitative data from detailed retrospective reports will be analyzed. From this analysis, we hope to obtain an overarching understanding of how radar temporal resolution impacts forecasters' warning decision processes in a variety of scenarios.

While the traditional experiment will build on knowledge obtained from previous experiments, the eye-tracking experiment brings a new and exciting avenue to the work of PARISE. Forecasters' eye gaze data will be collected as they work one case in simulated real-time. The eye gaze data will be analyzed in conjunction with detailed retrospective reports provided by forecasters. This data will provide new insight into impacts of higher-temporal resolution on the forecaster warning decision process and allow us to analyze and compare forecasters' cognitive processes in a more objective manner.

The focus group is the final task each week. During the focus group, participants will be asked a number of questions that will draw on their experience from the 10 simulations they would have worked during the week. Participants will be able to share and discuss thoughts and ideas important to the development of a future PAR network.

Participants and researchers from week one of the 2015 PARISE.

Publications

Bowden, K. A., P. L. Heinselman, D. M. Kingfield, and R. P. Thomas, 2015: Impacts of phased-array radar data on forecaster performance during severe hail and wind events. *Weather and Forecasting*, **30**, 389-404, doi:10.1175/WAF-D-14-00101.1.

Heinselman, P., D. LaDue, D. M. Kingfield, and R. Hoffman, 2015: Tornado warning decisions using phased array radar data. *Weather and Forecasting,* **30**, 57-78.

CIMMS Task III Project – Southern Climate Impacts Planning Program (SCIPP) Phase II

Mark Shafer (primary; OCS at OU), Barry Keim (co-primary; 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 (OU South Central Climate Science Center), Randy Peppler (CIMMS at OU), Kevin Robbins (LSU), and Steven Quiring (Texas A&M University)

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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

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 FY15, 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, and SCIPP is ongoing.

1. Absence of Long-Term Trends in Hurricane Winds or Storm Surge Flooding Events along the U.S. Gulf Coast

SCIPP researchers Needham and Keim analyzed raw tide gauge data for more than 20 gauges along the U.S. Gulf Coast. NOAA's National Ocean Service provided most of these data. They discovered that including raw tide gauge data increased the number of storm surge observations by 20-30 percent for most locations. They have now analyzed these records and included these data in the SURGEDAT storm surge database. The SURGEDAT record now includes a combination of raw tide gauge data, high water marks, and measurements from various scientific sources, such as government reports that provide observations for specific hurricanes.

They also analyzed long-term hurricane wind and storm surge flooding trends along the U.S. Gulf Coast. They found no long-term trends in either of these hazards. These findings were documented in a research paper that provides an overview of their data sources and methodology, and also suggests that hurricane/storm surge impacts will

become more severe in this region due to population increase, land subsidence and relative sea-level rise. This paper was submitted to the International Journal of Climatology.

2. Temperature Threshold for Mangrove Mortality Reached Several Times Over Past 130 years along the US Gulf Coast

As climate change occurs, the frequency of freeze events will affect the presence and abundance of mangrove trees in Louisiana and neighboring states along the northern Gulf of Mexico coast. Black mangroves (Avicennia germinans) provide Louisiana with numerous ecosystem services, including habitat for wildlife, sediment stabilization, and carbon sequestration. However, these trees are highly sensitive to cold weather events. Fewer freeze events would allow for expansion of the black mangrove at the expense of salt marsh vegetation, while more frequent freeze events would result in the contraction or death of mangrove forests.

This project used historical temperature data to identify the frequency, duration, and intensity of cold-air outbreaks in and near the Louisiana coastline. Criteria for defining extreme events were based upon the expected mortality and presence thresholds of black mangrove trees, in particular minimum air temperatures in a range of -9 degrees C to -7 degrees C. This range represents a climate window where mangrove tree survival is at stake. Below the lower threshold, mangrove mortality is likely. Optimal mangrove growth and dominance is likely above the higher threshold.

This study also examined cold air outbreaks from the present dating back into the late 1800s, using data from the NOAA National Climatic Data Center, which includes the U.S. Historical Climatology Network and the 19th Century Forts and Voluntary Observers Database. Temperatures below -9 degrees C were rare along the Louisiana coastline, but all stations indicated multiple days reaching this threshold in the past 130 years. Stations along or near the Gulf of Mexico experienced minimum temperatures on average 3 degrees C warmer compared to those just 50 km inland. Collectively, these results help explain the current distribution of mangrove forests in Louisiana and can be used to evaluate the potential for future mangrove forest range expansion in response to climate change.

3. Drought Indices May be Effective in Explaining Variability in Waterfowl Habitat

In order to help monitor wintering waterfowl habitat the Gulf Coast Joint Venture (GCJV) sought to determine if one or more weather parameters might explain the abundance of ephemeral shallow wetland habitats. Three different time periods were used to assess the habitat. The early period was from 16 August to 31 October. The middle period was November 1 - January 15; and, the late period was from 16 January to 31 March. Additionally, certain weather parameters were assessed to see if they correlated with the flooded acreage. The Drought Atlas was used as criteria for determining the five weather stations in the different initiative areas provided by the GCJV. The Drought Atlas also provided calculations for weather variables used such as the Standard

Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI), and Standard Precipitation Evapotranspiration Index (SPEI). Using those calculations, some correlations were made to determine the relationship between the weather variable and the flooded acres. However, it is still early to determine if there is a direct correlation. Research found that during the early and late periods that SPEI 1 month showed a strong correlation. However, when all the periods were pooled together the SPI 4 month showed a correlation. The middle period did not show much of a correlation with any of the indices. Precipitation and average daily temperature also showed some correlations in different periods. These weather indices may prove to be effective in helping explain the variability in the waterfowl habitat. Adding more habitat acreage and weather data each year allows for the database to grow larger, and become more accurate.

4. Water Utilities in Oklahoma Possessing Dynamic Capabilities Better Suited for Innovation

This research examines and builds upon how water utilities in Oklahoma use dynamic capabilities to create sustainable value through technological, institutional, or social innovations, which may include supply capacity upgrades (e.g., pipelines), increasing the flexibility of water management (e.g., storm water management), integrating users into governance processes (e.g., adaptation planning and communication strategies), or decreasing demand through user management (e.g., conservation programs).

This study compiled and analyzed quantitative and qualitative data, including semi-structured interviews with 38 key decision makers of water systems across Oklahoma, in order to answer two questions: (1) what characterizes municipal water systems that are highly innovative, and (2) what explains the actual process of innovation in water utilities.

The results of question one suggest that population size, median household income, and education and training of water decision makers are positively correlated with increased innovation rates. Within the state, municipal water systems largely engaged in incremental innovation (80%) as opposed to radical innovation (20%). Innovation aimed at current infrastructure assets accounted for 82% of total innovations, while 18% targeted institutional innovations, such as rate increases, public education programs, and conservation plans.

The most frequent innovations occurred in water treatment systems, wastewater systems, distribution systems, and the pump and lift stations. The most innovative cities in Oklahoma had the highest levels of water system vulnerability, the largest populations, the greatest precipitation levels, the most advanced educational backgrounds of water decision makers, and are most likely to reside in Central or Northeast Oklahoma. On the other hand, financial barriers, the quality of water system infrastructure assets, and fear of climate change did not show a relationship to levels of innovation. Although water utilities are changing their water systems in response to system vulnerabilities, these innovations are not driven by the risk of climate change and its projected impacts on water systems in Oklahoma.

The results of question two show a strong and positive relationship between the level of dynamic capabilities and the level of innovation within Oklahoma's water systems. This is important because dynamic capabilities assist organizations in achieving long-term competitive performance that can lead to superior innovation and alternative trajectories. Oklahoma's most highly innovative water utilities possessed the most dynamic capabilities. Higher population size, median income, education, and geographic location in Central and Northeastern Oklahoma were also found to be influential factors in the creation and use of dynamic capabilities. In addition, dynamic capabilities have been shown to positively influence the adoption of radical innovations, which are crucial to increasing adaptive capacity and resiliency of water systems. Our results coincide with these findings, as water systems characterized by higher rates of dynamic capabilities were more likely to deploy radical innovations than municipalities that lack these capabilities. Municipal water utilities that possess higher rates of dynamic capabilities are better suited to engage in innovation that can increase the resiliency of their respective water systems.

The conclusion of this study is that while the factors that influence water system change vary across Oklahoma (e.g., the level of risk and vulnerability), the consistent driving force of higher levels and rates of innovation is dynamic capabilities. The implication is that water managers wishing to prepare their utilities for uncertainties including the future impacts from climate change should focus on developing dynamic capabilities regardless of the current level of risk or water system vulnerability.

5. Lake Pontchartrain-Maurepas Storm Surge Consortium

Dr. Hal Needham regularly participates in a new outreach venue called the Lake Pontchartrain-Maurepas Storm Surge Consortium. This organization seeks to raise awareness of storm surge and coastal flooding issues around Lakes Pontchartrain and Maurepas, including metropolitan New Orleans and suburban communities of the New Orleans metro area. Needham joined the steering committee for this consortium and participates in planning and outreach events every 4-6 weeks. Needham also gave a formal presentation of our SCIPP research to this consortium, and actively participated in regular meetings.

Another component of Needham's involvement was participating in a multidisciplinary, hazard reduction project that focused on building a smartphone app for commercial fishermen. The app provides information on docking and commercial facilities that are useful to the fishing industry, as well as natural hazard information, such as storm surge modeling and historical hurricane/ storm surge information. Needham provided SCIPP's storm surge and hurricane climatology data for this app. These data will enable fishermen to access historical climate information related to hurricanes and coastal flooding, which will improve decision making in both fair weather and when threatened by hurricanes. A test version of the app will launch during summer 2015.

6. Field Photos Weekend

For the past 3 years, SCIPP, CoCoRaHS, and the Earth Observation and Modeling

Facility have conducted a “Field Photos Weekend” project to create a national picture of our landscape. SCIPP asked CoCoRaHS observers and other citizen scientists to take pictures of the land around them - water bodies, fields, forests, or any other facet of our environment - at roughly the same time. These events began with Labor Day Weekend in 2012 and have continued over Presidents Day and Memorial Day ever since.

The project started out as a way to compare visual impacts of drought to the kinds of things we measure. But even if the weather seems normal, these photos give a point of reference for what will maybe be different next year or in another season or maybe have recovered from a previous year.

To participate, an individual needs to take a picture or two with their camera or smartphone and upload it via the EOMF iPhone app or Android app, the EOMF Field Photos Archive, or email it to us at fieldphotos@southernclimate.org. Participants are asked to include hashtags (e.g. #CoCoRaHSMay15) as keywords when uploading. For photos that are not geo-referenced, the participant can provide a description of where and when the photo was taken.

To date, no formal research has been conducted using the photos obtained from these Field Photo Weekends. However, SCIPP researchers are actively seeking funds to do so.

7. Climate Training for Native American Tribes

Four 2-day climate-training workshops were conducted last August and September across Oklahoma. There were 35 tribal attendees at the trainings and they represented 18 tribes. Since the workshops, the training materials were finalized and posted on the SCIPP website as a news story and on the SCIPP Documents page. Those activities completed the bulk of the grant, which will end in August 2015. However, remaining funds are being used to provide one-on-one assistance to some of the participants by analyzing climate data for them or helping them interpret climate data. Dr. Irenea Lodangco, a postdoctoral researcher who started working with SCIPP on May 18, was hired to provide this service for about three months. Additionally, Rachel Riley hosted an informational webinar on May 21 for individuals and organizations that are interested in expanding the training to other regions.

Key Publications with OU Authors

Needham, H. F., B. D. Keim, and D. Sathiaraj, 2015: A review of tropical cyclone-generated storm surges: Global data sources, observations and impacts. *Reviews of Geophysics*, in press.

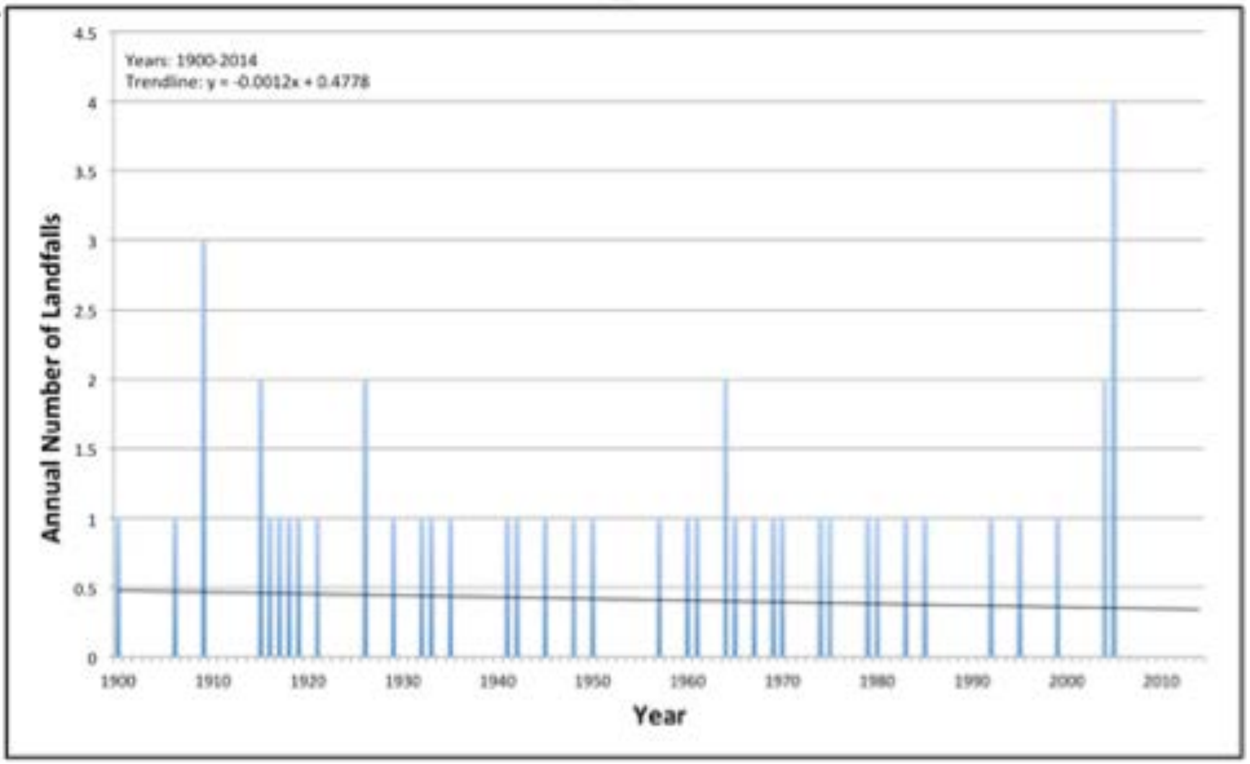
Otkin, J. A., M. Shafer, M. Svoboda, B. Wardlow, M. C. Anderson, C. Hain, and J. Basara, 2015: Facilitating the use of drought early warning information through interactions with agricultural stakeholders. *Bulletin of the American Meteorological Society*, in press. doi:10.1175/BAMS-D-14-00219.1.

Key Non-OU Publications

Ford, T. W., A. D. Rapp, S. M. Quiring, and J. Blake, 2015: Soil moisture–precipitation coupling: Observations from the Oklahoma Mesonet and underlying physical mechanisms. *Hydrology and Earth System Sciences Discussions*, **12**, 3205-3243. doi:10.5194/hessd-12-3205-2015.

Lewis, A. B., and B. D. Keim, 2015: A hybrid procedure for classifying synoptic weather types for Louisiana. *International Journal of Climatology*, in press.

Powell, E. J., and B. D. Keim**,** 2015: Trends in daily temperature and precipitation extremes for the southeastern United States: 1948-2012. *Journal of Climate,* **28**, 1592-1612. doi:http://dx.doi.org/10.1175/JCLI-D-14-00410.1



Trend in annual major hurricane landfall counts along the U.S. Gulf Coast.

Example of the smartphone app.

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

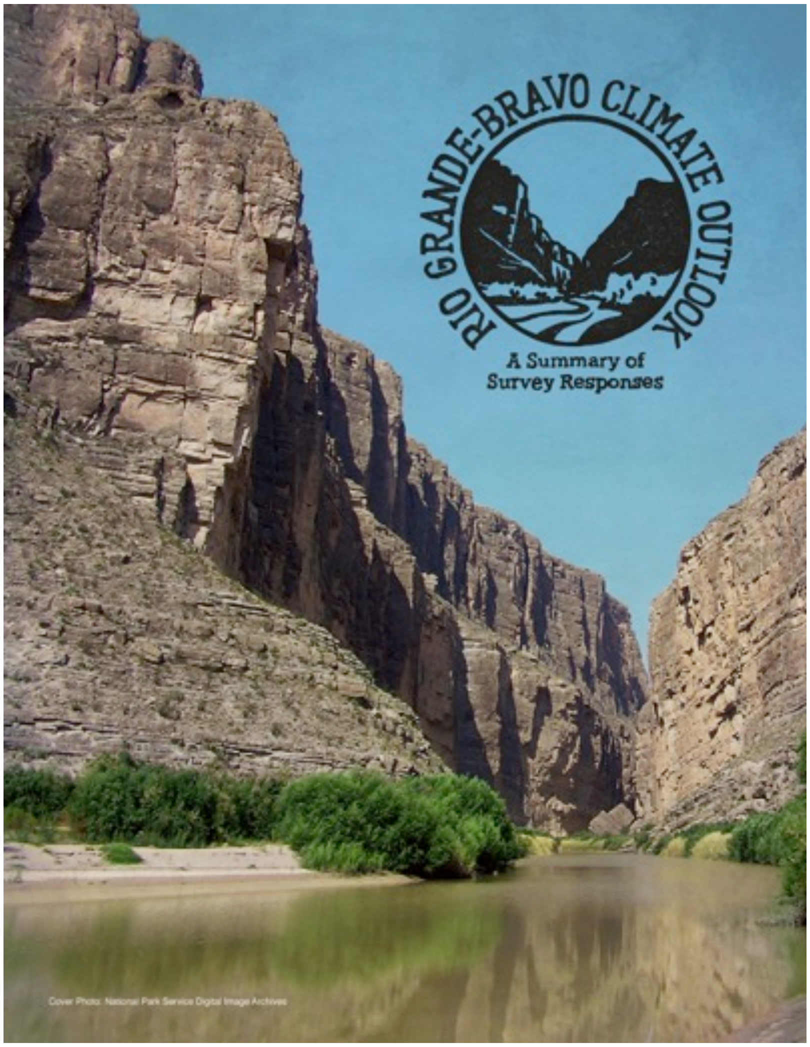
The Rio Grande/Bravo River Basin (RGB) of the United States and Mexico, is exposed to tornadoes, severe storms, hurricanes, winter storms, wildfire, and drought. The combination of these weather and climate-related hazards has resulted in impacts, such as wildfire, crop loss, water supply reduction, and flooding, with exceedingly high economic costs ($13 billion, in 2011 alone). In order to contribute to increased bi-national 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

A survey was conducted to solicit information on the utility of the information contained in the RGB Climate Outlook and preferences for layout and delivery mechanisms. The survey was distributed in August 2014 to 161 people who were identified through various interactions by the two NOAA RISA Teams, State Climatologists, and NOAA partners. The survey was provided in both English and Spanish. The survey included demographic information that described the characteristics of the population served by the respondent's organization, use of climate information, document layout, and preferred formats for distribution. The survey found that the most frequently-used sources of weather and climate information were the U.S. National Weather Service (95%), NOAA's Climate Prediction Center (79%), the North American Drought Monitor (72%) and Television, radio and newspapers (72%). Mexican sources were used infrequently, perhaps attributable to a small sample size from Mexican colleagues but also may be indicative of a reliance upon U.S.-produced information on both sides of the border. Drought and water supply information was seen as most important, especially given the intense and long-lasting drought affecting the region at the time the survey was conducted. Climate projections, seasonal variability, and forecasting-related topics such as the North American Monsoon, El Nino outlooks, and tropical storm information were also mentioned frequently. Full results (not peer-reviewed) are

reported in M. Shafer and G. Garfin, 2014, which can be seen at http://www.southernclimate.org/documents/Rio_Grande-Bravo_Outlook_Survey_Results_-_FINAL.pdf].

The bulletin and other climate information, tools and scenarios were discussed at a workshop in El Paso, Texas on September 10-11, 2014, co-hosted by the International Boundary Water Commission. The workshop included discussions of climate, hydrology, and ecology of the region, with a special focus on the Big Bend reach of the river. Workshop participants were introduced to scenario planning techniques used by the National Park Service and other agencies that included factors both within and outside the control of resource managers, including variations in timing and magnitude of the North American Monsoon.



Cover image from the Rio Grande/Bravo Outlook survey report, highlighting the landscape and importance of water to the vitality and ecology of the region.

CIMMS Task III Project – Drought Risk Management for the United States

Mark Shafer (OCS at OU), and Michael Hayes, Mark Svoboda, Cody Knutson, Tsegaye Tadesse, Deborah Bathke, and Brian Fuchs (National Drought Mitigation Center)

NOAA Technical Lead: Chad McNutt (NOAA NIDIS 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

Objectives

The overall goal of the project is to improve drought risk management across the United States. To accomplish this goal, the project builds upon partnerships between the Southern Climate Impacts Planning Program (SCIPP), National Drought Mitigation Center (NDMC), and National Integrated Drought Information System (NIDIS). The project will develop new tools and procedures and test them in the Southern Plains Drought Early Warning System being developed by NIDIS. Specific objectives of the project include: (1) Improving and expanding drought monitoring activities; (2) Engaging the NIDIS Preparedness Community Technical Working Group activities; (3) Examining drought planning assistance; (4) Continued development of Regional Drought Early Warning System assistance; (5) Conducting a regional drought event assessment; and (6) Communication and dissemination activities.

Accomplishments

Objective 1: Scoping of a prototype mobile app for the iPhone will include an ability for app users to report drought conditions, in addition to providing access to commonly-used drought information. Scoping work included distribution of a survey to the U.S. Drought Monitor list to prioritize products and features.

Objective 2: Planning for development of a national Early Preparedness Communities (EPC) workshop, tentatively scheduled for February 2016 in Austin, TX, got underway. Prior to the workshop, project team members are collaborating with the U.S. Army Corps of Engineers on hosting two drought/flood tournaments (one in Iowa and one in Texas). The Texas workshop is scheduled for September 17.

Objective 3: A survey of local (county-level) offices in the six-state SCIPP region was distributed to identify their needs for drought-related information and their connection to larger-scale drought monitoring, planning and management efforts. Survey results are currently being analyzed to identify gaps in information, research, and communication.

Objective 4: NIDIS has undergone some internal reorganization and is evaluating all Regional Drought Early Warning System (RDEWS) projects. Once their evaluation is complete, they will provide guidance to the project team for scoping a phased work plan and long-term mission.

Objective 5: A drought event assessment (led by NDMC) has been drafted and is undergoing final editing.

Objective 6: Regional webinars and meetings, hosted by SCIPP, have been on hold as excessive rains affected the region, consequently reducing public demand for drought information. Planning for future webinar topics and other methods of disseminating drought information are ongoing.

Photo from the Crosstimbers Marina at Skiatook Lake, Oklahoma, on 26 January 2015. The lake was 17.11 feet below normal. It has since fully recovered to normal conservation level. Photo courtesy Bill Lawrence, Tulsa, Oklahoma.

CIMMS Task III Project – Life and Death Decisions: An Integrative Approach to Extreme Weather

Workshop Organizing Committee: Lans Rothfusz (NSSL); Kelvin Droegemeier (OU Vice President for Research and OU School of Meteorology); Jennifer Henderson (Virginia Tech); Jennifer Sprague (NOAA Office of the Chief of Staff); Kimberly Klockow (UCAR Post-Doctoral Research Scientist and Policy Advisor at NOAA/OAR/OWAQ); Danielle Nagele (NOAA Office of Program Planning and Integration); Kodi Monroe (CIMMS at OU); Alicia Knoedler (OU Associate Vice President for Research); and John Ferree (NWS Severe Storms Services Leader)

NOAA Technical Lead: John Cortinas (NOAA/OWAQ)

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

Funding Type: CIMMS Task III

Objectives

Despite substantial advances in technology and our understanding of the atmosphere, it has become clear in recent years that extreme weather (e.g., tornadoes, hurricanes, flash floods, straight-line winds, blizzards, hail storms) – though a manifestation of the atmosphere and hydrosphere – fundamentally represents a social and behavioral science challenge to society. Experience shows that physical science, engineering and technology *alone* cannot prevent hundreds of people from dying each year due to extreme weather events, or mitigate the substantial deleterious impacts on built infrastructure and the economy.

Making progress toward the bold goal of dramatically and consistently decreasing mortality from extreme weather requires -- in addition to advances in physical science, engineering and technology -- solutions to deep, fundamental questions that engage multiple disciplines, including those in the social, behavioral and economic sciences (SBES). Recognition of the importance of the social sciences in particular has increased substantially during the past decade, as evidenced, among other things, by the WAS*IS initiative, several sessions on related topics at recent Annual Meetings of the American Meteorological Society, by the American Meteorological Society journal titled *Weather, Climate and Society*, and in two Weather Ready Nation (hereafter WRN) workshops. In the latter, a comprehensive list of key research questions was developed, numerous excellent recommendations were offered regarding the creation of research centers, funding programs, and educational activities, and strategies for improving operational forecasts and warnings were offered.

Building upon the important activities noted above, collaborators from the University of Oklahoma and several NOAA organizations organized an invitation-only workshop, held in Norman, OK on 18-20 May, 2015, to bring together scholars whose work is highly relevant to the rigorous and credible inclusion of SBES research in the context of

extreme weather, and to broaden and deepen existing research collaboration networks. The formal title of the workshop was: **"Living with Extreme Weather: A Workshop to Integrate Understanding and Improve Societal Response,"** the goals of which included the following:

- Identify existing bodies of knowledge from relevant domains that can contribute to the current state of knowledge regarding predicting extreme weather, formulating and communicating to the public threat information, and understanding and predicting public response;
- Develop foundational research questions, both within and across disciplines, along with strategies for addressing them, so as to make substantial advances toward dealing with extreme weather;
- Lay the groundwork for bringing to life-saving operational practices the results of these new research collaborations.

Underpinning these goals was a number of framing questions, including the following:

- What are the greatest challenges in formulating and communicating extreme weather threat information to the public (e.g., information aversion)? What new approaches might be most useful for making progress to address those challenges and what research is needed to explore them?
- What are the greatest challenges in mitigating loss of life due to extreme weather and how do they relate to demographics, previous personal experiences, information source, confirmation bias, and trust?
- What strategies are best suited for stimulating and sustaining multi-disciplinary collaboration and how should such interaction be organized?
- What research frameworks are needed to experimentally conduct and evaluate research on workshop topics, and how can they effectuate a smooth and rapid transfer of research outcomes to operational practice?

And finally, the following outcomes were established not specific to the workshop itself but rather as part of an ongoing engagement with the broadened community of scholars.

- Identification of disciplines that can contribute to research problems in extreme weather that, to date, have not been well integrated into solving these problems;
- Identification of perspectives and methodological approaches that can contribute to reformulating the severe weather warning process and evaluating its success;
- Development of fundamental, cross-cutting research questions and recommendations for multi-agency programs to support the study of these questions and assess their outcomes in operational experimentation.

As noted above, the Living with Extreme Weather Workshop (hereafter LWEW) benefitted greatly from but also built upon previous activities such as Weather and Society * Integrated Studies (WAS*IS) of the National Center for Atmospheric Research

(NCAR) and two NOAA-led WRN meetings. In so doing, it sought to add specific and new value to previous planning by:

- Strategically engaging professional societies and other organizations to draw upon a broad array of SBES scholars from across the nation, many of whom were unaware of the relevance of their research to the extreme weather challenge, the WRN initiative, or of the strong emphasis on SBES by the atmospheric sciences community;
- Identifying and applying best practices, particularly from the literature, for effectuating inter-disciplinary collaborations and research in teams, emphasizing specific mechanisms for building common vocabularies, seeing research challenges from vastly different yet complementary and mutually beneficial viewpoints, and applying research methodologies and tools across disciplinary boundaries in powerfully novel ways;
- Building awareness of and gaining access to highly valuable data sets for research, particularly from surveys but also from physical event data bases as well as physical and social/behavioral models;
- Creating formal frameworks, particularly via the use of technology, for building and continuously maintaining relationships and collaborations across the community, and identifying, promoting, and presenting opportunities to pursue specific research projects and become engaged in translation research and operational evaluation; and
- Leveraging new developments and focusing mechanisms, such as FACETs (Forecasting a Continuum of Environmental Threats), which is a NOAA priority and is built upon the premise of a fully integrated physical/social/behavioral sciences framework.

In light of the rather daunting goals of the workshop, considerable effort was expended to create an interesting, engaging, and novel structure by a) devising an agenda (see at the end of this project report) informed, in part, by a pre-workshop survey given to all participants to discern particular interests and scholarly strengths of the participants and automatically draw disciplines together by presenting issues and challenges in an integrative manner; b) providing background information in advance, in the form of topical brief videos as well as supporting documents, on key topics of relevance to all attendees (see http://www.youtube.com/playlist?list=PLowCkjeYmJBSREJAJidfb_XXBwCr7tufo and http://extremeweather.ou.edu/#resources) so as to minimize on-site presentations and maximize the time available for personal interactions; c) providing extensive time on site for networking; d) providing immersive learning opportunities via participation in mock operational forecasting activities; e) using real-time tools, such as a Sketchbook, for participants to post their thoughts, ideas, suggestions, references, etc.; and f) using thematic break-out groups in which participants considered practical issues and focused on creating frameworks for studying them in a scholarly manner. The workshop agenda, shown below, reflects these elements and was quite effective. Some modifications were made as the workshop proceeded to take full advantage of new ideas as they arose.

Of course, holding a weather-themed workshop in Oklahoma during the height of tornado season afforded the possibility of participants experiencing severe weather first hand, and indeed, an event did occur the evening of Tuesday, May 19. Tornadic storms developed west of Norman and threatened to move into the area near the end of the day. A real time feed to local television stations was established in the meeting venue, providing participants with an extraordinary ability to witness, in real time, how extreme weather information is conveyed via the media. The impact on those from outside Oklahoma, and from disciplines other than meteorology, was quite powerful. In fact, we leveraged this opportunity, while waiting for the weather to subside, to create the "final exam" given to all participants.

Accomplishments

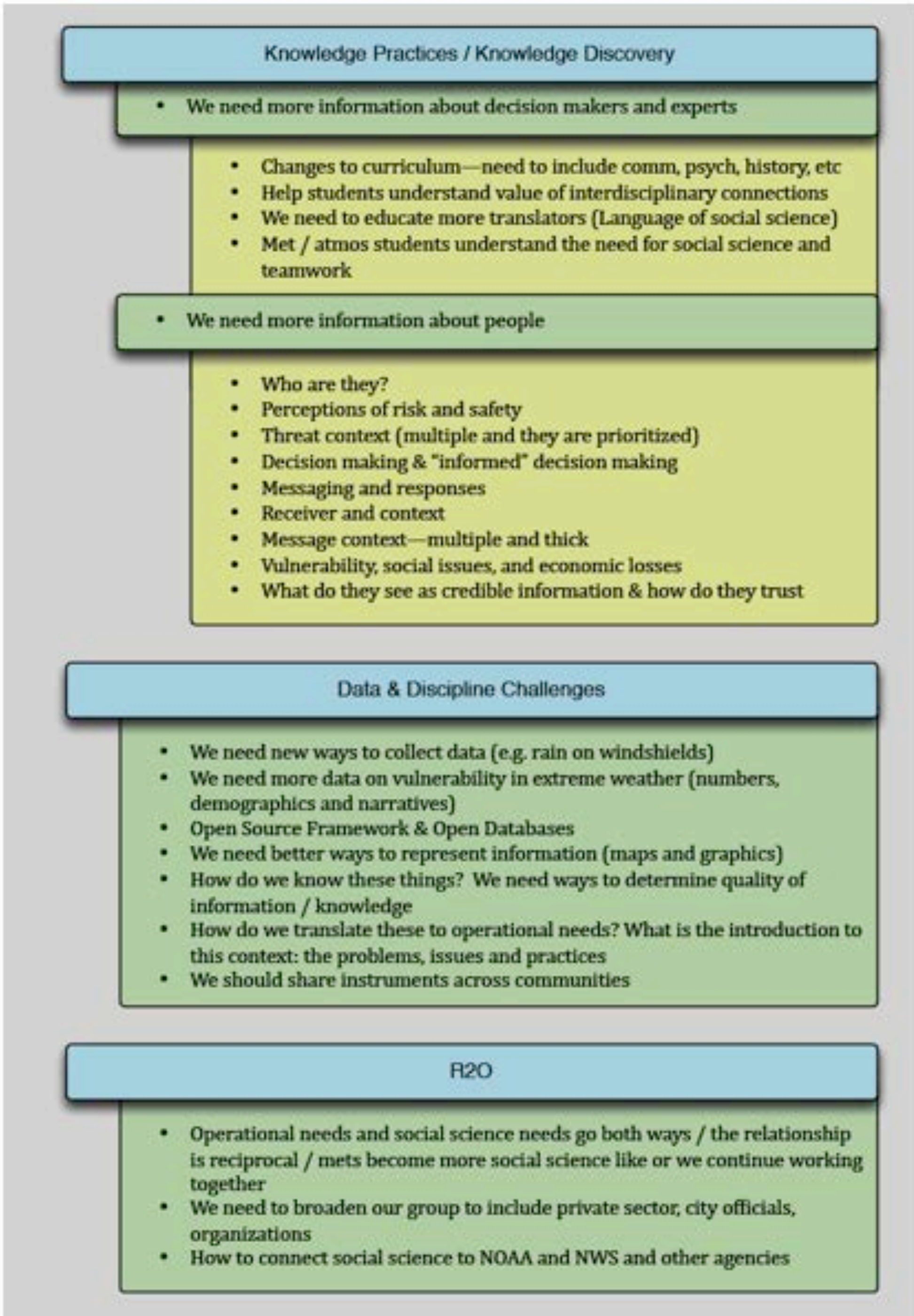
A total of 84 individuals attended the workshop (which includes the Organizing Committee), consisting of scholars from 26 states (27% from EPSCoR jurisdictions and 29% from Oklahoma). Sixty participants were from outside of Oklahoma, which was an important workshop goal, and 54% were female. Approximately 70% represented SBES disciplines, with the remainder coming from atmospheric and related physical sciences, engineering and technology – another important goal. Specific disciplinary representation is shown below in Table 1.

Disciplinary representation of workshop attendees.

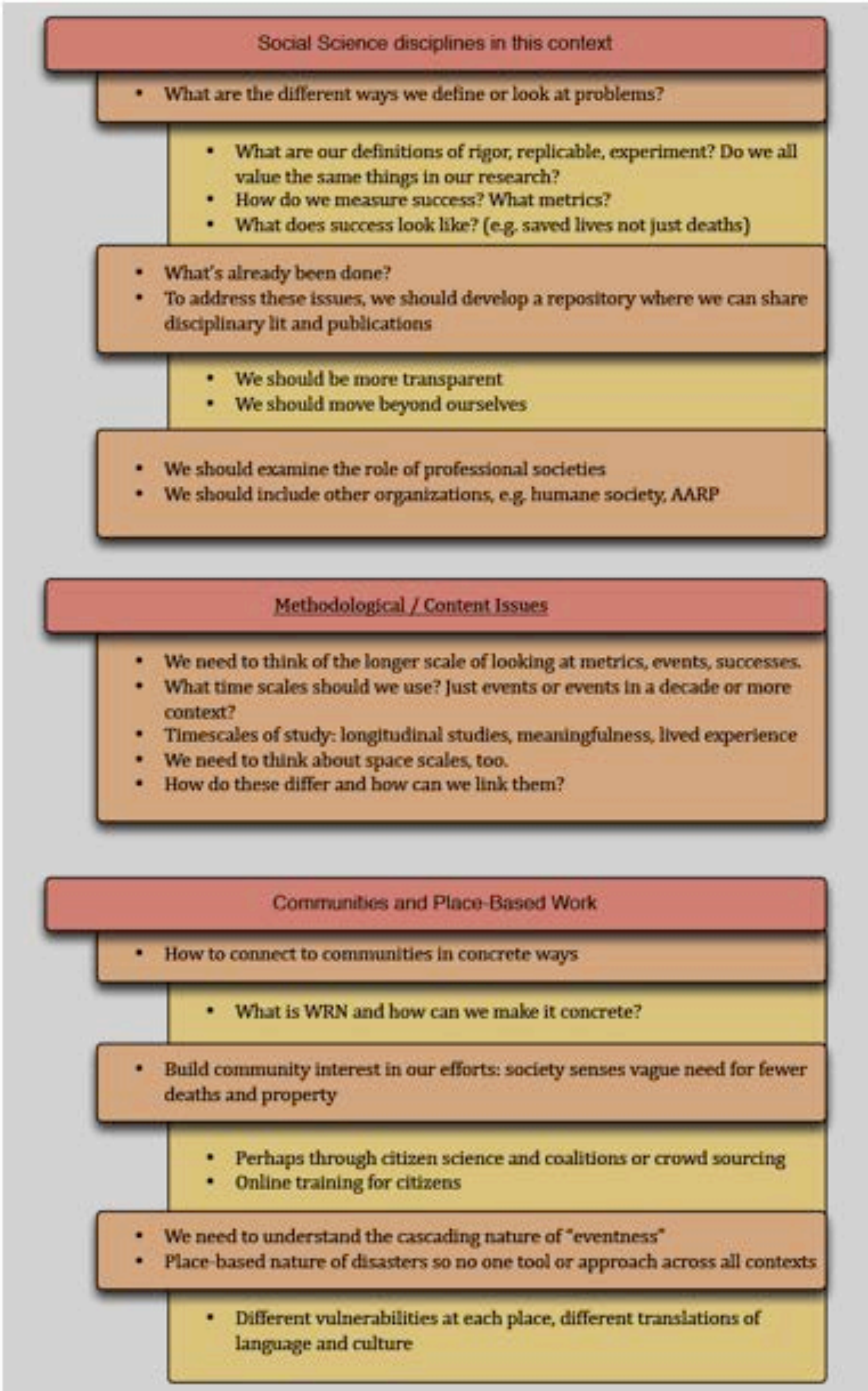
Discipline	**Number of Attendees**
Meteorology/Atmospheric Science (research, operations)	19
Geography (demography, epidemiology, hazards, decision sci)	13
Communication (health, risk)	10
Psychology/Cognitive Psychology/Human Factors	9
Sociology (hazards, risk, disasters, response, uncertainty)	7
Political Science/Public Policy	6
Anthropology (health, disasters)	5
Economics	5
Civil/Industrial/Systems Engineering	3
History/History of Science	2
Health/Environmental Health	2
Philosophy and Ethics	1
Emergency Management	1
Adult Education	1
TOTAL	**84**

Although the preponderance of attendees had not previously attended a WRN workshop or a WAS*IS activity, some were aware of their existence. The several breakout sessions, and the final plenary, produced a wide variety of thoughtful comments and recommendations that coalesced around three "content" topics as follows (see figure immediately below): a) Knowledge Practices and Discovery; b) Data

and Disciplinary Challenges; c) Research to Operations Transition, as well as three related “approaches” as follows (see second figure below): d) SBES Disciplines in Context; e) Methodological and Context Issues; and f) Communities and Place-Based Work. Details are provided in the final project report to NOAA.



Outline of the three “content” topics from the workshop.



Outline of the three "approach topics from the workshop.

One overriding outcome emerged from the workshop that serves as a keystone recommendation in the final project report to NOAA. Specifically, although strides have been made during the past several years, as noted previously, on topics related to integrating social sciences and weather and using research outcomes to inform or enhance operational practice, less progress than desired has been made on specific recommendations emerging from the two WRN workshops, and on the WRN road map overall. Reflecting that observation, a recurring theme within the LWEW workshop was the need for a structured framework or facilitation mechanism to coordinate the many activities needed to realize the component of the WRN vision involving social sciences (and here expanded to include SBES broadly defined). Such a mechanism, echoing a recommendation from the first WRN workshop report but structured somewhat differently, is seen as essential for bringing together multiple stakeholders in an effective manner but also to purposefully build community, create common vocabularies, and provide resources to facilitate interaction in ways that presently are not available. In other words, a construct is needed that speaks not only to *what* needs to be done, but also very specifically to *how* and *by whom*.

To this end, the LWEW organizers are creating a special "community" within NOAA's Virtual Laboratory (VLab) environment to foster networking and collaboration. Many of the recommendations from the LWEW participants are being incorporated into this web-based service, including the creation of a repository of relevant work, a networking portal, and several other devices to grow the community, including providing assistance in the evaluation of solicitations as well as in the development of grant proposals. This VLab service is being developed and supported by NSSL.

Living With Extreme Weather Workshop Agenda
Monday, May 18 to Wednesday, May 20, 2015

Sunday, May 17
Participants arrive

5:30 - 7:00 Pre-registration at hotel
6:00 - 8:00 Reception at NCED Route 66 Lounge

Monday, May 18

Bus departs NCED at 7:15 for NWC

Networking Continental Breakfast: 7:30-8:30 am (At NWC)

Day 1: The Problems, The Process, The Plan and Performing Together!

I. Welcome, Introductions, Objectives and Goals: [Who, What/Why, & How]
8:30 - 8:50 Welcome to the workshop!
8:50 - 9:30 Introductions: Participants Characteristics

II. Extreme Events from Multiple Perspectives: The Inherent Interdisciplinarity of Problems in Hazards Resiliency

9:30 - 10:30 Panel Discussion of Multidisciplinary Work & Challenges
10:30 - 11:00 Caffeinated Networking & Transition
11:00 - 12:00 Breakout Groups: Discuss Videos in Context of Workshop Goals

Catered Lunch in NWC atrium: 12:00 - 1:30

Optional excursions:

12:00-12:45 Immersive Learning: You're the Forecaster (Room 4820)
OR
NWC Tour (Meet at Science on a Sphere)
12:45-1:30 Immersive Learning: You're the Forecaster (Room 4820)
OR
NWC Tour (Meet at Science on a Sphere)

III. Demonstration of Successful Interdisciplinary Projects in Extreme Weather via the CCC Framework

1:30 - 2:00 What does it take to achieve success in C, C or C? (Room 1313)
2:00 - 2:30 Common perceptions of multidisciplinary challenges / barriers

2:30 - 3:00 Caffeinated Networking & Transition

3:00 - 4:00 Breakout groups: Applying the CCC to research problems in natural hazards (See card in packet for room numbers)
4:00 - 5:00 Large group report out with Q&A (Room 1313)

5:30 - 7:00 Dinner w/ Guest Speakers (NWC Atrium)

Bus Departs NWC at 7:15 for NCED

Tuesday, May 19

Bus departs NCED at 7:45 for NWC

Networking Continental Breakfast: 8:00-8:30 am (At NWC)

Day 2: Research Needs and Strategies

8:30 - 9:15 Review of Previous Weather Ready Nation (WRN) Workshop Outcomes (Room 1313)

9:15 - 10:30 Breakout Groups to discuss research problems in Hazards Research (assigned rooms)

10:30 - 10:50 Caffeinated Networking & Transition

10:50 - 11:50 Breakout Groups Continue discussions on addressing problems in Hazards Research (same rooms as 9:15 session)

Lunch: 12:00 - 1:30

Optional excursions:
12:00-12:45 Immersive Learning: You're the Forecaster (Room 4820)
OR
NWC Tour (Meet at Science on a Sphere)

12:45-1:30 Immersive Learning: You're the Forecaster (Room 4820)
OR
NWC Tour (Meet at Science on a Sphere)

1:30 - 2:30 Resources and Funding Opportunities Relevant to Hazards Research
(Room 1313)

2:30 - 2:50 Coffee Break and Transition Time

2:50 - 4:20 Breakout Groups Discussion Initial Thoughts About a Roadmap and Recommendations to Agencies (same room as morning breakout sessions)

4:30 - 5:30 Full Group Report-out about Research Problems and Roadmap Recommendations
(Room 1313)

Bus departs NWC at 6:00 for NCED
Dinner: On Your Own
Wednesday, May 20

Bus departs NCED at 7:45 for NWC

Networking Continental Breakfast: 8:00-8:30 am (At NWC)

Day 3. Moving Forward: Recommendations for a Strategic Approach to Extreme Wx

8:30-9:15 Wrap-Up: Where We are Now (Room 1313)
9:15-9:30 Caffeinated Networking
9:30-11:00 Group Discussion of Where to Go From Here (Room 1313)

11:00 Workshop Ends. Boxed lunch provided.

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, and Department of Commerce leadership, and 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 peer-reviewed journal articles determined to be significant by NSSL leadership. NSSL/CIMMS reported 10 significant papers in FY2015.
- Reported publication numbers for Quarterly Education performance taskers

2. Legislative Affairs – Steve Koch and Lans Rothfusz (NSSL), Susan Cobb (CIMMS at NSSL), and Randy Peppler (CIMMS at OU)

- 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
- **Cooperative Institute Directors Advocacy on The Hill** – every March the CI Directors spend two days on Capitol Hill advocating for the research and outreach priorities of NOAA overall and for their individual cooperative institutes.

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, 17 NSSL OAR Hot Items were authored in FY2015.

- **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 FY2015, **4** 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 updated or produced in FY2015.

5. Publicize NSSL and CIMMS Research and Projects through Social Media – Susan Cobb (CIMMS at NSSL)

- NSSL's and CIMMS' 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.

6. NSSL/CIMMS Outreach emails – Susan Cobb (CIMMS at NSSL)

- The public submits questions to NSSL via the NSSL Outreach email account. In FY2015, 60 emails and two written letters were answered.

7. Other Outreach – Susan Cobb (CIMMS at NSSL)

- Worked with Time For Kids on weather content

WDTD Outreach

Alyssa Bates, Jill Hardy, Eric Jacobsen, Mason Rowell, Chris Spannagle, Matt Teraldsen, and Andrew Wood (CIMMS at WDTD)

CIMMS staff at WDTD 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:

- Working support "shifts" at the NWS Norman Weather Forecast Office during severe weather events;

- Participating in the planning and presentation of the National Weather Festival in November; and
- Volunteering with other National Weather Center organizations during the Norman United Way Day of Caring.

Other outreach activities involving CIMMS staff at WDTD included:

- Developing short, grade-level meteorology activities and presenting them to elementary school students;
- Talking to undergraduate students about careers in meteorology; and
- Visiting elementary and middle school career days to discuss the daily job duties of meteorologists.

Photo shows the Norman Weather Forecast Office during a severe weather event in the spring of 2015. CIMMS scientists at WDTD coordinate with forecast office staff to observe severe weather operations. During these support "shifts", CIMMS scientists will support the warning forecasters by locating potential severe weather reports (via phone, streaming chaser video, or social media) and passing the information along to the office staff. CIMMS personnel (along with WDTD instructors) can observe warning operations from the table reserved for the media (seen in the foreground of photograph with a CIMMS scientist observing).

Appendix A

AWARDS AND HONORS

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

- **CIMMS Scientists** were key contributors to the NOAA 2015 Silver Medal for the "successful transition of the Multi-Radar, Multi-Sensor system into operations to provide critical radar-based products to forecast weather hazards." Contributors (present and recent past) include (alphabetical order): Ami Arthur, Alyssa Bates, Jeff Brogden, Kristin Calhoun, Steven Cocks, Karen Cooper, Matthew Elliott, Heather Grams, Jill Hardy, Eric Jacobsen, Brian Kaney, Darrel Kingfield, Valliappa Lakshmanan, Carrie Langston, Kevin Manross, Steven Martinaitis, Tiffany Meyer, Dale Morris, Kiel Ortega, Youcun Qi, Heather Reeves, Travis Smith, Chris Spannagle, Gregory Stumpf, Lin Tang, Matt Taraldsen, Robert Toomey, Yadong Wang, and Andy Wood

- **Andrew Wood** (CIMMS at WDTD) was recognized for the 2015 Dean's Award for Outstanding Service for "his exceptional support of severe weather education and outreach to the National Weather Service (NWS), NOAA, and key partners of the Weather-Ready Nation initiative"

- **Corey Potvin** (CIMMS at NSSL) was nominated for 2015 Presidential Early Career Award for Scientists and Engineers (PECASE)

- **Zachary Flamig** (CIMMS at NSSL and OU School of Meteorology) was selected as the 3rd Place Winner – Poster Presentation Category – in the AMS *Joint EIPT-R2O Conferences* Student Competition at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "HWT-Hydro: Evaluation of Experimental Forecast and Nowcast Tools"

- **Robert "Race" Clark** (CIMMS at NSSL and OU School of Meteorology) was as the 3rd Place Winner – Oral Presentation Category – in the AMS *Joint EIPT-R2O Conferences* Student Competition at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "The Inaugural Hazardous Weather Testbed – Hydrology (HWT-Hydro) Experiment"

- **Elizabeth Mintmire Argyle** (CIMMS at NSSL and OU School of Industrial and Systems Engineering) was a Student Presentation Award Winner (oral presentation) in the AMS *10th Symposium on Societal Applications* at the 2015 AMS Annual Meeting in Phoenix, AZ (January 2015) for "Forecaster 'Best Practices' During Operations in the Hazardous Weather Testbed Hydrology Experiment 2014."

- **Burkely Twiest** (CIMMS at NSSL and OU School of Meteorology) was a Student Presentation First Place Award Winner (oral presentation) in AMS *27th Conference*

on Weather Analysis and Forecasting in Chicago, IL (29 June–3 July 2015) for "Using the High-Resolution NSSL-WRF Ensemble to Provide Hazard Guidance"

- **Eswar Iyer** (CIMMS at NSSL and OU School of Meteorology) was a Student Presentation Second Place Award Winner (oral presentation) in the AMS 23rd Conference on Numerical Weather Prediction in Chicago, IL (29 June–3 July 2015) for "Comparison of 36-60 Hour Precipitation Forecasts from Convection-Allowing and Convection-Parameterizing Ensembles"

- **James Kurdzo** (ARRC at OU and OU School of Meteorology) won the Tommy C. Craighead Award for Best Paper in Radar Meteorology – *School of Meteorology (2014-2015)*, 2nd Place Oral Presentation – *AMS Severe Local Storms Conference (2014)* – 2nd Place Oral Presentation – *AMS Conference on Environmental Information Processing Technologies (2015),* 2nd Place Oral Presentation – *AMS Conference on Research to Operations (2015)*

- **Nicholas Gasperoni** (OU School of Meteorology) won the 2015 Douglas Lilly Best Ph.D. Publication Award from the OU School of Meteorology, and won Best Student Oral Presentation at the IOAS-AOLS Conference at the AMS Annual Meeting, January 2015.

- Two papers with CIMMS authors were designated "Significant Papers" by NSSL – these include, (1) Sudesh Boodoo, David Hudak, **Alexander Ryzhkov**, **Pengfei Zhang**, Norman Donaldson, David Sills, and Janti Reid, "Quantitative Precipitation Estimation from a C-Band Dual-Polarized Radar for the 8 July 2013 Flood in Toronto, Canada", *Journal of Hydrometeorology* and (2) **Dustan Wheatley, Kent Knopfmeier, Thomas Jones, and Gerald Creager**, "Storm-Scale Data Assimilation and Ensemble Forecasting with the NSSL Experimental Warn-on-Forecast System, Part 1: Radar Data Experiments", *Weather and Forecasting*

- **Caleb Fulton** (ARRC and ECE at OU) was presented a DARPA Young Faculty Award to support further research into "Risk Mitigation for Large-Scale, Low-Cost, Highly Digital Phased Array Systems" for general digital beamforming systems, the proposal for which benefited substantially from work done under the support of the NSSL for this grant

- **Guifu Zhang and Robert Palmer** (ARRC at OU) **and Richard Doviak and Dusan Zrnic** (NSSL): A Patent #8988274 of "Cylindrical Polarimetric Phased Array Radar" awarded by U.S. Patent Office, 24 March 2015

- **Guifu Zhang** (ARRC at OU), **Dusan Zrnic** (NSSL), and **Lesya Borowska** (ARRC at OU): "Joint Signal Processing for High Efficiency in MPAR Design and Development", OU Intellectual Property Disclosure (#15NOR003), 14 July 2014

Appendix B

PUBLICATION SUMMARY*

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2007-08	2008-09	2009-10	2010-11	2007-08	2008-09	2009-10	2010-11	2007-08	2008-09	2009-10	2010-11
Peer Reviewed	55	52	32	28	16	13	25	22	37	45	40	44

	CIMMS Lead Author				NOAA Lead Author				Other Lead Author			
	2011-12	2012-13	2013-14	2014-15	2011-12	2012-13	2013-14	2014-15	2011-12	2012-13	2013-14	2014-15
Peer Reviewed	31	32	57	60	13	8	9	7	35	45	44	40

**Publication numbers are approximate.*

Appendix C

PERSONNEL SUMMARY – NOAA FUNDED RESEARCH ONLY

Category	**Number**	**B.S.**	**M.S.**	**Ph.D.**
Research Scientist	71	3	33	35
Visiting Scientist	5	1	3	1
Postdoctoral Fellow	8			6
Research Support Staff	17	6	11	
Administrative	4	2	2	
Total (>50% support)	**105**	**12**	**49**	**44**
Undergraduate Students	23			
Graduate Students (current degree)	39	4	35	
Employees that receive <50% NOAA Funding (not including students)	**32**	**2**	**3**	**25**
Located at Lab	NWSTC-4, NSSL-82, ROC-7, SPC-4, WDTD-15, OUN-1			
Obtained NOAA employment within the last year	**6**			

Appendix D

COMPILATION OF CIMMS-RELATED PUBLICATION 2014-15

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*

Bluestein, H. B., J. C. Snyder, and J. B. Houser, 2015: A multi-scale overview of the El Reno, Oklahoma, tornadic supercell of 31 May 2013. *Weather and Forecasting*, **30**, 525-552.

Boodoo, S., D. Hudak, A. Ryzhkov, P. Zhang, N. Donaldson, D. Sills, and J. Reid, 2015: Quantitative precipitation estimation from a C-Band dual-polarized radar for the July 08 2013 flood in Toronto, Canada. *Journal of Hydrometeorology*, **16**, 2027-2044.

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Bowden, K. A., P. L. Heinselman, D. M. Kingfield, and R. P. Thomas, 2015: Impacts of phased-array radar data on forecaster performance during severe hail and wind events. *Weather and Forecasting*, **30**, 389-404.

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**, 1229-1237.

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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.

Crandall, K. L., P. S. Market, A. R. Lupo, L. P. McCoy, R. J. Tillott, and J. J. Abraham, 2015: The application of diabatic heating in Q-vectors for the study of a North American cyclone event. *Advances in Meteorology*, Article ID 269709, in press.

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.

Curtis, C., M. Yeary, and J. Lake, 2015: Adaptive beamforming to mitigate ground clutter on the National Weather Radar Testbed phased array radar. Accepted by *IEEE Transactions on Geoscience & Remote Sensing*.

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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)

Final Report: June 2015 (Executive Summary only)

Renee A. McPherson, PI, and Rick P. Thomas, PI (University of Oklahoma); Kimberly E. Klockow, PI (UCAR)

NOAA's National Weather Service (NWS) forecasters and the broadcast media commonly use maps to communicate tornado risk to the U.S. public; however, little research has been conducted to explore the effects of tornado warning map content and design on risk perceptions and decision-making. The NOAA-funded study NA12OAR4590118 is an important contribution to knowledge in this area, examining the ways modern-day tornado warning maps are interpreted and then comparing those interpretations to those evoked by potential future technologies. In particular, this research examined the decision-shaping properties of longer lead-times as depicted on a map (i.e., larger risk spaces), inquired about what happens when people find themselves inside or outside of tornado warning polygons of various lengths, and explored the effects of rendering explicit on a map the probability that a given thunderstorm will produce a tornado at points downstream.

Our work has generated several key findings of relevance to NOAA. First, the research supports a growing body of literature that suggests that providing estimates of forecast uncertainty may provide significant benefits to end-users. The work also demonstrates that it's beneficial for forecasters to communicate times when they are more certain that a tornado exists through simple verbal statements; this practice could be implemented now, without waiting for programs like Warn-on-Forecast to render those estimates explicit at longer lead-times. Additionally, the project demonstrates that the way forecasters depict spaces of risk influences decision-making. There are complex trade-offs involved in lengthening the lead-time of deterministic warnings. Finally, the research finds that the use of cool colors in risk depictions may lead people to underestimate tornado threat, and we therefore recommend that cool colors not be used in tornado threat graphics.

This research used an experimental approach to systematically study the effects of warning content within a series of maps. While this approach allowed for a straightforward comparative analysis, the ecology of warning communication and

decision-making in the real world is much more complex. We recommend several avenues of research to follow from this study, including deeper and more place-based examinations of response and self-efficacy in situations of tornado threat, more systematic experimental work related to communicating forecast uncertainty, and more real-world case studies of warning comprehension.

SSWR Project: Social and Behavioral Influences on Weather-Driven Decisions (NA12OAR4590119)

Progress Report: September 2014-February 2015

Kenneth J. Galluppi, PI (Arizona State University), Burrell E. Montz, Co-PI (East Carolina University), Jessica Losego, Co-PI (University of North Carolina), Rachel E. Riley, Co-PI (University of Oklahoma) James Correia, Jr. (CIMMS at SPC)

The goal of the Social and Behavioral Influences on Weather-Driven Decisions (SBI) project is to develop an understanding, characterization, and prioritization of the major social and behavioral influences on weather-driven emergency management (EM) decision-making to protect life and property, and to make recommendations to the National Weather Service on how to minimize negative influences in their products and services and accentuate the positive.

Our team from Arizona State University, East Carolina University, the University of North Carolina, and the University of Oklahoma explores the major influences on EM decisions in complex social networks and collaborates with National Weather Service entities including the Storm Prediction Center, Central Region Headquarters, and the Tulsa WFO. We use efficient agile approaches to highlight significant issues that inhibit the understanding of risk and the employment of good risk management practices. This project is organized around the National Research Council's Risk Paradigm that connects hazards to personal and institutional risk management. Influences manifest themselves in a disruption of the risk connections.

Activities 9/1/14-2/28/15

Our activities centered around two main emphases: (1) Understanding the role that confidence plays in decisions and (2) testing messaging with large venue managers in Oklahoma. With respect to the first, we undertook analyses of the surveys shown in the table below.

Survey Topic	Examples of issues covered	Responses to date	Date launched
Demographics	A separate survey providing information on characteristics of the respondents such as age, tenure, education, location, and training. Subsequent surveys are linked to this baseline survey allowing for analysis of how responses differ with different individual	1519	5 May 14

	characteristics, while preserving respondents anonymity		
Confidence	Probes how EMs define confidence, what helps build their confidence, and the role of forecaster confidence in their decision-making.	1301	5 May 14
Messaging Effectiveness	Addresses use, awareness, and understanding of NWS products	806	25 June 14
Training	Addresses effectiveness, types and relevance of training as well as availability	704	26 June 14
Timing	Asks about effects of lead times, causes of time pressure and the role of time pressure in decision-making	672	2 July 14
Media	Asks about EMs use of media, specifically TV meteorologists and their interactions	519	9 Sept 14

The findings and their implications are presented in the table below.

Survey Topic	Findings
Confidence	Inadequate situational understanding or awareness can lead to a lowering of confidence in making decisions – which then requires a search for more information to confirm or modify one's understanding. At the same time, knowing the forecaster's confidence in the forecast (as opposed to just the probability of occurrence), is critical to developing the EMs' confidence. In turn, confidence is balanced with what is believed which comes from training and experiences, but also from what one is told from a trusted source.
Messaging Effectiveness	Where messages are not clear or are inconsistent, they are not effective because confidence is lowered and valuable time can be consumed seeking additional information to build that confidence. The results of the surveys do not lead to specific conclusions or recommendations about how to best cast messages to be more directly applicable to EM needs, but rather suggest that additional research is required. Similarly, the fact that almost two-thirds of EMs filter the information received from the NWS before forwarding it to others requires additional research. There are numerous questions to be addressed around these topics.
Training	Emergency managers identified three crucial areas in which current trainings do not meet their needs or reflect the complexities of their positions: the relevance of the training's content to their operations; a recognition of their position not only as decision-makers but also information brokers for other entities; and the role of building comfort between individuals and organizations through training. These areas demonstrate the necessity not only for a reconsideration of weather training, but a broader rethinking of the relationship between EMs and the weather enterprise as a whole.
Timing	For an EM, lead time is relative. The necessary lead time varies with required tasks of the EM, with the potential impacts of the event and, most importantly, with the EM's understanding of a given situation. The greater each of these, the more lead time is needed. As a result, one size does not fit all. Different emergency support functions have different responsibilities that require different amounts of time. Even within an emergency support category, different events or different characteristics of the same type of event may require different lead times. Clearly, there is no easy answer to how much lead time is needed.
Media	These results are currently being analyzed

The second major activity involved undertaking a messaging experiment with emergency managers of large venues to understand how both messages and the dissemination of the messages affects their actions and decisions. These included: an airport, schools, universities, industrial park, large retail, sports arena, large indoor multipurpose arena, and large and small emergency operations in the Tulsa, OK area. These venues have both operational decisions and dissemination needs and the officials are responsible for the safety of tens of thousands of lives and very expensive properties. Our findings indicate that officials from these entities have identified what localized time and location forecast information means for their operational consideration in light of personal understanding of provided weather forecasts and lead-time information. They have defined their needs for clear, concise and consistent information that they can use and pass along with additional information they generate relating to actions for the public to take. While this study is still in its infancy, participants are thinking beyond the traditional emergency notifications to explore what actionable information the public needs to understand about the weather and what to do to protect themselves given a venue layout that they may or may not be familiar with. A weather scenario was able to be understood through combined messaging to add context related to the six elements. Adding context to messages was performed by all participants and not limited to the NWS. This clearly showed in collaboration, safety officials could better interpret and disseminate decisions and weather outcomes. In this prototyping experiment, the evidence showed clearly that EM understanding and decision-making is greatly improved through collaborative messaging: pertinent information was more readily gathered and consisted of the 6 critical elements. Collaborative understanding required elements to be provided and interpreted by both the NWS forecaster and the operational decision makers, and not the county EM alone.

Presentations

1. Galluppi, K., S.F. Piltz, K. Nuckles, B.E. Montz, J. Correia, and R. Riley. Improving Weather and Emergency Management Messaging: The Tulsa Weather Message Experiment. Annual Meeting of the American Meteorological Society, Phoenix, Arizona. January, 2015.
2. Montz, B.E., K. Galluppi, J.L. Losego, J. Correia Jr., and R. Riley, Social and Behavioral Influences (SBI) on Decision-making by Emergency Managers. Annual Meeting of the American Meteorological Society, Phoenix, Arizona. January, 2015.
3. Galluppi, K., L.C. Kurtz, and B. Montz. Weather Training for Emergency Managers: A Perspective from the EM Community. Annual Meeting of the American Meteorological Society, Phoenix, Arizona. January, 2015.
4. Montz, B., K. Galluppi, J. Losego, J. Correia, and R. Riley. Social and Behavioral Influences (SBI) on Weather-Driven Decisions. NOAA Science Days, Silver Spring, MD. September 2014.
5. Montz, B.E., K. Galluppi, J. Losego, J. Correia, R. Riley. 2015. Effective Communication Within the Integrated Warning Team. Webinar, IWT Workshop Wilmington, NC. February 2015.
6. Montz, B.E., K. Galluppi, J. Losego, J. Correia, R. Riley. 2015. Effective Communication Within the Integrated Warning Team. IWT Workshop, Greenville, NC. January 2015.

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:
- All milestones for this task were completed, except the workshops, the reasons for which were described in previous reports.
- We expanded our work on understanding the influences on decision making, particularly confidence. Results are still being analyzed

Task 5. Repeat process used for severe weather for a tropical weather use case to verify influences.

- 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.
- Completed surveys and messaging experiments

Upcoming Activities (April 1, 2015-August 31, 2015)

- Analyze survey results, both within and between surveys
- Write draft project report; write papers for publication

SSWR Project: Utilization of Real-Time Social Media Data in Severe Weather Events: Evaluating the Prospects of Social Media Data Use for Severe Weather Forecasting, Communication, and Post-Event Assessments (NA12OAR4590120)

Final Report: March 2015 (Executive Summary only)

Carol L. Silva, PI; Joseph Ripberger; Hank C. Jenkins-Smith, Co-PI; Jack Friedman; Paul Spicer, Co-PI; and Peter J. Lamb, Co-PI (University of Oklahoma)

According to a recent report by the Department of Homeland Security, "social media and collaborative technologies have become critical components of emergency preparedness, response, and recovery" (2013). These technologies are critical because they provide a centralized mechanism for two-way communication before, during, and after disasters that allows federal/state/local officials, emergency managers, the media, and affected communities to disseminate and receive information about a hazard in near real-time. Recognizing the potential utility of these technologies, the National Weather Service (NWS) recently began experimenting with the use of social media to educate the public and share critical information about weather, water, and climate issues as part of its effort to build a Weather-Ready Nation. As yet, however, we know relatively little about who participates in the exchange of weather, water, and climate information that occurs on social media platforms and how that exchange of information evolves throughout the course of extreme weather and water events.

In this report, we begin to fill this void by answering three basic, yet important, research questions about social media usage before, during, and after one type of extreme weather event—tornadoes:

1. Who uses social media to get information about severe weather and how has this evolved over time?
2. What do NWS forecasters and weather scientists think about social media and how has it changed the way they approach their jobs?
3. How does social media usage evolve throughout the course of a severe weather event?

In Chapters 2 and 3, we use data from regional surveys of U.S. residents who live in tornado prone regions of the country to investigate the extent to which residents who live in these regions are using social media to collect and disseminate information about severe weather. The first survey was fielded in 2012 and the second in 2013. Among our key findings were the following:

- Relative to traditional sources of severe weather information (such as television and radio), public usage of information from social media about severe weather is rather low.
- Despite these relatively low rates of use, public reliance on information from social media about severe weather appears to be growing over time, whereas public usage of traditional sources *may* be declining over time.
- Public utilization of social media sources to collect information about severe

weather varies rather significantly across individuals and demographic groups.

- Younger people are more likely than older people to use information about severe weather that comes from a social media source.
- To a lesser extent, the same is true of women and minority groups—women and members of minority groups are more likely than men and members of non-minority groups to use social media to obtain information about severe weather.

In Chapters 4 and 5, we shift away from a focus on the public and instead focus on NWS forecasters and weather scientists. More specifically, we use data from in- depth qualitative interviews of 44 forecasters and 5 weather scientists to address our second research question—what do forecasters and weather scientists think about social media and how has it changed the way they approach their jobs? Our interviews reveal a number of important insights, including:

- Forecasters and weather scientists are—for the most part—willing and eager to share information with the public via social media sources.
- In general, however, forecasters and weather scientists are less willing and eager to use information (i.e., weather reports) provided by the public via social media sources than they are to share information with the public via social media sources.
- This lack of enthusiasm towards weather reports on social media stems from an underlying skepticism about the quality of information that social media users are capable of and willing to provide—some forecasters and weather scientists believe that social media users are "good intentioned" but not sufficiently trained to provide useful reports; others are worried that social media users may provide intentionally misleading reports that—if used— would jeopardize the quality of information that forecasters are able to provide to the public.

In Chapter 6, we begin to investigate the extent to which this skepticism is justified by looking for a meaningful information "signal" in the social media "noise." We do so by systematically comparing weather signals to social media signals, by collecting and analyzing millions of severe weather messages (tweets) that were published on Twitter between April 24th and June 20th, 2014. Our analyses of these data show that:

- There is a severe weather signal in the social media noise, suggesting that relevant, credible, and/or valid information about severe weather is present in social media posts over the course of severe weather events.
- Nevertheless, substantial noise remains, even on extreme weather days when communication about severe weather is most important.

In Chapters 7, 8, 9, and 10 we provide a more comprehensive look at the relationship between the signal and the noise by commencing a "close-up" study of the messages published on Twitter before, during, and after a specific event – the 2013 Newcastle-Moore-South Oklahoma City tornado. In this study, we systematically identify the kinds of users who published these messages, where they were when they published them,

what they said, and – if the message contained information of some sort – we evaluate the quality of this information. We then explore the extent to which these attributes of social media posts changed over the course of the severe weather event.

In Chapter 7, our study of social media users reveals that:

- Individual Twitter users were responsible for the majority of messages containing the word “tornado” that were published on Twitter before, during, and after the event; organizations, by comparison, published a relatively small portion of the messages.
- Before the event occurred, organizations were a bit more active than average whereas individuals were a bit less active than average; during and after the event, this relationship reversed – individuals were more active than normal and organizations were less active.
- The overwhelming majority of messages published before, during, and after the event were published by users that were not affiliated, by way of self-identification, with the weather enterprise.

In Chapter 8, our analysis of where these users were when they published their messages shows that:

- A very small fraction of the severe weather messages that Twitter users published before, during, and after the event included geographic information that utilized Twitter’s geolocation feature.
- There was no discernable bias in the type of users who chose to include this geographic information.
- The modal location of Twitter users changed over the course of the event – in the days leading up to the tornado, the majority of messages came from areas of the country that were affected by severe weather on those days; as the storm approached and produced the tornado, the majority of messages came from users that were located in the regions of the country that were expecting/experiencing it; in the hours and days after the tornado occurred, messages began to appear throughout the region, across the country, and around the world.

In Chapter 9, our analysis of what Twitter users were sharing on social media throughout the course of the event indicates that:

- The majority of the messages contained some sort of “objective” information about the event, or tornadoes in general; most messages contained general information about the event, information about how to help the victims, and/or information about the storm as it approached.
- A smaller portion of the messages contained a personal or “subjective” expression of some sort; most of these messages expressed a general comment, feeling, or opinion about tornadoes or support/encouragement for the victims of the tornado; the remaining messages in this category included first

person accounts of what the authors were doing/experiencing as the event unfolded.
- The content of Twitter messages evolved throughout the course of the event; alert messages, for example, were published rather frequently in the hours and minutes leading up to the storm, whereas information about how to help the victims started to appear more frequently in the minutes, hours, and days that followed the event.

In Chapter 10, our assessment of the *quality* of information contained in messages that were published before, during, and after the 2013 Newcastle-Moore-South Oklahoma City tornado suggests that:

- The information contained in the Twitter messages that were published over the course of the event was relatively high in quality; the vast majority of messages that contained verifiable information were accurate and the majority of messages that contained actionable information were timely.
- Like user type, location, and message content, information quality varied throughout the course of the event; information quality peaked in the days, hours, and minutes leading up to the event, but declined in the aftermath of the event.

In Chapter 11, we conclude the report with a brief discussion about next steps – how do we further develop and expand upon the insights gleaned from this early research on social media and severe weather? We offer a number of concrete proposals for future research, including:

- Continue to field scientific (random and/or representative) surveys designed to systematically measure public reception of, reliance on, and trust in severe weather information from a variety of traditional and “new” media sources, including social media – is reliance on social media continuing to grow relative to other sources of severe weather information? Or, has the market for social media information plateaued?
- Work with forecasters and weather scientists to systematically evaluate the quality of severe weather reports on social media – how often do members of the public publish verifiable weather reports on social media and, more importantly, how accurate are these reports when they are published?
- Move beyond the 2013 Newcastle-Moore-South Oklahoma City tornado to study the evolution of social media usage before, during, and after other tornadoes and other types of severe weather – are our findings generalizable to other tornado (and other severe weather) events? Are the patterns evident in this analysis consistent across time, space, and weather phenomena?

This report provides a systematic point of departure for developing an empirically grounded understanding of the roles played by social media in severe weather events. In the pages that follow we provide an assessment of the roles that social media currently play that may contribute to building a Weather-Ready Nation. It is important to note that our findings are taken from a specific period of time, whereas the world of

severe weather forecasting, communication, response, and recovery is dynamic and evolving. Thus, in the interest of continuing to develop a Weather- Ready Nation that is resilient in the face of increasing vulnerability to extreme weather and water events, we must continue to study and monitor the changes in technical, natural, and social systems that can facilitate community resilience.

Social media is one such change in the technical system that – in a relatively short period of time – has significantly altered the way in which communication about extreme weather and water events occurs in the social system. In the eyes of many, this change has, to date, facilitated a net increase in community resilience. In the eyes of others, this change could, in the near future, obstruct resilience by making it all too easy for untrained members of the public to send and receive low quality or deceptive information that confuses weather decision makers and other members of the public who rely on that information to make highly consequential, protective action decisions. While the research provided in this report provides some reassurance that roles played by social media are more helpful than hurtful, more and continued research is urgently needed as the NWS continues to experiment with and begins to implement social media in forecasting and warning efforts.

RISA Project: Climate Training for Native American Tribes (NA13OAR4310208)

Progress Report: June 2014-May 2015

Rachel Riley, PI (SCIPP/University of Oklahoma), Mark Shafer, Co-PI (SCIPP/University of Oklahoma) Wayne Kellogg, Co-PI (Chickasaw Nation), Alek Krautmann (SCIPP/University of Oklahoma), April Taylor and Kim Merryman (Chickasaw Nation and South Central Climate Science Center), Irenea Lodangco (SCIPP Post-Doc), and Katy Christian (SCIPP Undergraduate Assistant)

Stakeholder Partners: The Chickasaw Nation: April Taylor, Kim Merryman and Wayne Kellogg. Please note that the proposal for this project was written prior to Taylor being employed by the Chickasaw Nation and SC-CSC. Kellogg is a project Co-PI, but once Taylor 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). Kim Merryman joined the project team in June 2014. During the performance period Merryman played an important role in communicating with workshops participants, keeping track of evaluations, and providing other logistical support. Taylor continued to build relationships with tribal members that SCIPP had started before the SC-CSC was established. Taylor also provided presentation material on past climate reconstruction and climate proxies. Taylor's knowledge of the local areas and cultures was critical to the success of the workshops.

Drought/NIDIS Interaction: Although this project was not designed to focus specifically on drought, it was one of the many hazards covered in the workshop materials. Drought monitoring and planning was also covered in-depth as the special topic on Day 2 at two

of the four workshops in Wyandotte and Durant, Oklahoma. We know from prior work and engagement during the workshops that drought is a hazard that is of greatest concern for many of the tribes with whom we have interacted. Finally, some of the ongoing interaction with the tribes noted near the end of the Accomplishments section will likely involve looking at drought indices and histories.

In terms of NIDIS interaction, direct interaction with NIDIS was not planned for this project. However, co-PI Mark Shafer is on the NIDIS Implementation Team and was closely involved in these workshops. Two other Implementation Team members, Michael Hayes and Doug Kluck, participated in the informational webinar (described in the Accomplishments section below) that was held on May 21, 2015. Finally, we collaborated with several Implementation Team members and others to submit a session proposal for the 2015 National Adaptation Forum in St. Louis, Missouri. Unfortunately, our session was not chosen.

Accomplishments

Workshop Preparation (June-August, 2014): Workshop planning was in full swing by June 2014. The project team met on a bi-weekly basis. Merryman and Taylor continued in their role of logistical support and helping Krautmann and Riley with points of contact at the various workshop locations. Taylor also put together a presentation on climate proxies and the paleoclimate record. Krautmann built many of the presentation slides and used some of the material from slides that were developed as part of a SARP Climate Training 101 grant that co-PI Shafer had developed several years prior (the SARP slides can be found here: http://www.mesonet.org/index.php/earthstorm/page/climate_101_workshops). Riley developed a Climate Tools & Data handout and an accompanying presentation. SCIPP Undergraduate Assistant Katy Christian supported the project by printing the workshop materials, putting together binders, and binding the National Climate Assessment material that was provided to the workshop participants.

Hosting Workshops (August-September, 2014): Workshops were held on the following dates at the following locations:

- August 14-15: Wyandotte, OK (Hosted by Eastern Shawnee Tribe)
- August 27-28: Fort Cobb, OK (Hosted at Caddo-Kiowa Technology Center)
- September 10-11: Durant, OK (Hosted by Choctaw Nation)
- September 18-19: Stroud, OK (Hosted by Sac & Fox Nation)

The workshop locations were chosen based on a variety of factors including local host interest, transportation feasibility for workshop participants, and space considerations. No workshops were hosted in Texas because the three Texas tribes are spatially dispersed. However, three individuals from one Texas tribe, Kickapoo Traditional, participated in the Durant workshop. Below is a summary of attendance at each workshop:

Workshop	# of Tribes Represented	# of Tribal Participants	# of Total Participants
Wyandotte	7	14	15
Fort Cobb	5	9	16
Durant	3	8	9
Stroud	3	4	7
Total	18	35	47

Note: The total participant count does not include the project team members, some of whom were present at all of the workshops.

The agenda consisted of:

Day 1

8:30a – 9:00a	Coffee and check-in
9:00a - 9:15a	*Welcome, Pre-Questionnaire*
9:15a - 9:45a	*Introduction to Climate*
9:45a - 10:45a	*The Basics of Climate*
10:45a - 11:00a	Break
11:00a - 12:00p	*Weather Hazards and Hazard Climatology*
12:00p - 1:00p	Lunch (provided)
1:00p - 1:30p	*Past Climate Reconstruction and Climate Proxies*
1:30p - 2:30p	*Climate Variability and Change*
2:30p - 2:45p	Break
2:45p - 3:30p	*Discussion and Roundtable on the National Climate Assessment, Indigenous Peoples Chapter*
3:30p - 4:15p	*Climate Tools and Data*

Day 2

8:30a - 9:00a	Coffee and check-in
9:00a - 10:00a	*Special Topic*: *Drought Monitoring & Planning, Managing the 2014 Guthrie Fire,* ***or*** *2007 Flooding and Tropical Storm Erin*
10:00a - 10:15a	Break
10:15a - 10:45a	*Introduce Vulnerability Assessment Concept*
10:45a - 11:30a	*Vulnerability Assessment Discussion*
11:30a - 12:30p	Lunch (provided)
12:30p - 1:30p	*Vulnerability Assessment Exercise*
1:30p - 1:45p	*Post-Questionnaire*
1:45p - 2:00p	*Wrap-Up Discussion*

Post Workshop (October 2014-Present): Upon completion of the workshops, the presentation materials were finalized, annotated, and posted on the SCIPP website, www.southernclimate.org as a news story and on the *SCIPP Documents* page. The materials were sent to the participants (all of whom received hard copies during the workshop they attended) and a few other interested parties. We have further increased our interactions through an informational webinar that occurred on May 21st. The webinar brought together a few individuals who are interested in possibly replicating

these workshops in other regions around the country. The purpose of the webinar was to provide information on the process of developing relationships with Oklahoma and Texas tribes and the material that was presented. A small amount of funds remained on the grant upon completion of the stated proposal goals. Subsequently, SCIPP hired a postdoctoral researcher Dr. Irenea Lodangco to produce climate analysis for several tribes. Her appointment runs May 18-August 14, 2015.

National Climate Assessment

We provided hard copies of the *Overview*, *Great Plans*, and *Indigenous Peoples* chapters to the participants at the workshop and sent them electronic copies of the chapters beforehand. During the workshop we presented on summary points from the *Indigenous Peoples* chapter and then had some informal discussion time. During the discussion we asked the following questions:

1. Do you find the *Indigenous Peoples* chapter relevant to your tribal community?
2. What are some of the key points that stand out and which should be given priority?
3. What are some of the things missing from the chapter that should be considered?
4. Does your tribal community have the capacity to plan for climate change and variability?

In general the participants felt that the chapter was somewhat relevant, but geared more toward Alaskan tribes and tribes on reservations. Many of our workshop participants felt that their tribe's health and social services were more developed and that they did not face the same level of poverty and challenges as some of their neighbors in other parts of the country. (Note: A report that was produced from a 2011 intertribal meeting in Oklahoma was included in the NCA process and is cited on the NCA, so the irrelevancy is not due to lack of involvement or knowledge by those involved in the NCA. Rather, as some of the participants noted, it was likely due to the fact that the climate-related challenges are much greater in other regions of the country.) Surprisingly, maybe participants thought their tribal community had capacity to plan for climate change and variability. Additional feedback pertaining to the NCA discussion will be included in the final report.

CSTAR Project: A Partnership to Develop, Conduct, and Evaluate Real-Time 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 (CAPS at OU)

Objectives

The real-time 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:

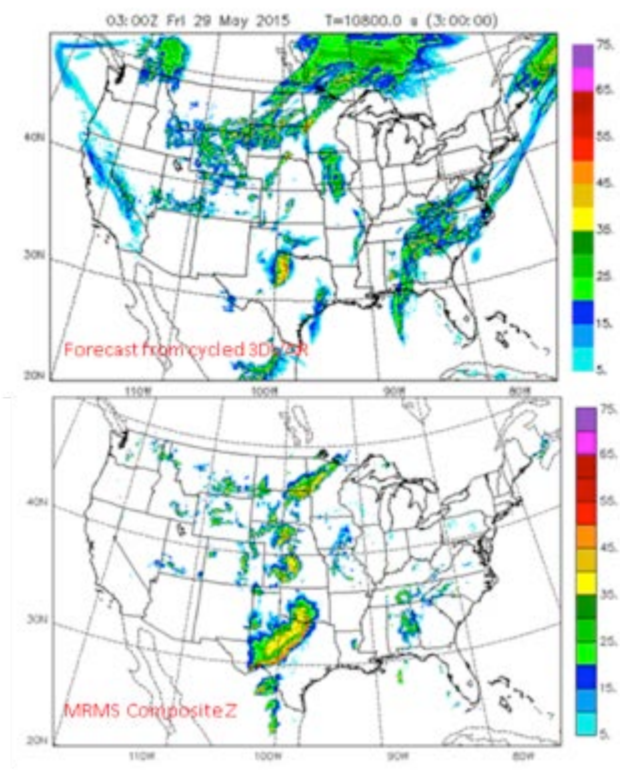
- The value and cost-benefit trade-offs of storm-scale versus coarser-resolution short-range ensembles and even-higher-resolution deterministic forecasts;
- The most suitable perturbation methods for storm-scale ensembles, among breeding, ETKF (ensemble Transform Kalman filter), EnKF, physics perturbations, 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 real-time forecasting and warning.

Accomplishments

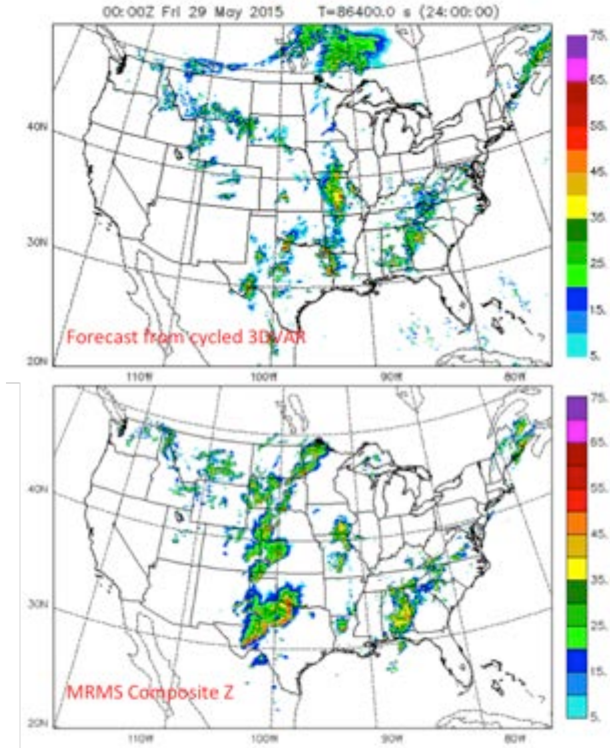
The primary activity in this reporting period is the configuration, code development and test, and the production of storm-scale ensemble forecast system (SSEF) for the 2015 spring season between 20 April and 5 June for the NOAA HWT Spring Forecast Experiment (SFE). Two ensemble suites are configured and run in 2015 SFE: a 20-member SSEF initiated at 0000 UTC with onetime 3DVAR analysis and running 60-h forecasting, and an experimental EnKF-cycled ensemble procedure followed by an 11-member 60-h SSEF starting at 0000 UTC. Experimental demonstration of visualization of convection-allowing NWP storm forecast is also planned.

The CAPS 2015 Storm-Scale Ensemble Forecast (SSEF) started on 20 April through 5 June 2015, encompassing the NOAA HWT 2015 Spring Forecast Experiment that is officially between 4 May and 5 June. Different from past years, the 2015 SSEF CONUS domain is changed from 4-km to 3-km horizontal grid spacing, resulting in 2.1 times more grid points and covering 18% more area than in the 2014 season. The migration to a 3-km grid spacing makes CAPS SSEF more consistent with the operational HRRR setting. As in previous years, the forecasts are produced Monday through Friday, initialized at 0000 UTC (1900 CDT) each day and made available in early morning for evaluation at HWT. A total of 33 days of complete ensemble forecasts from the 0000 UTC 3DVAR initialized SSEF runs were produced during the experiment period. Using the NSSL 1-km resolution Multi-Radar/Multi-Sensor (MRMS) QPE data as a verification dataset, the SSEF QPF and probabilistic QPF performance are evaluated using various traditional verification metrics in post-season analysis effort.

2015 features the first time in CAPS history to successfully run in real-time the complete workflow for the experimental EnKF cycling and ensemble forecast over the CONUS domain. Sample forecasts and some preliminary results are presented. Focus is on the comparison between the forecasts initiated using EnKF mean and using cycled 3DVAR analysis. The first figure below presents an example 3-h forecast valid at 0300 UTC 29 May 2015. The second figure is for the same case but 24-h forecast. Both shows clear benefit of EnKF mean forecast vs. cycled 3DVAR.



3-h forecast composite reflectivity and MRMS radar mosaic, valid 0300 UTC 29 May 2015.



24-h forecast composite reflectivity and MRMS radar mosaic, valid 0000 UTC 30 May 2015.

SARP Project: Facilitating Adaptive Management Under Conditions of Rapid Drought Onset Using the GOES-Based Evaporative Stress Index (NA13OAR4310122)

Jason Otkin, PI (University of Wisconsin-Madison); Martha Anderson, Co-PI (USDA/ARS); Jeffrey Basara, Co-PI (OU School of Meteorology); and Co-Is Mark Shafer (OCS at OU), and Mark Svoboda and Brian Wardlow (University of Nebraska)

TIME PERIOD ADDRESSED BY REPORT: June 2014 – May 2015

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. 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.

E. Summary of accomplishments and findings

During the past 12 months, two focus group meetings were convened with agricultural stakeholders across the central U.S. to better understand how they could use the drought early warning information provided by the ESI to better prepare for drought development and then improvements were made to the dissemination of the ESI datasets to end users (including USDM authors) based on their feedback. In order to reach a larger audience,

we also hosted a 30-minute webinar describing the ESI methodology and its potential use within the agricultural community. In addition, further insight into the role vegetation and soil moisture anomalies play during the onset of flash drought was gained through detailed analyses of in situ observations from the Oklahoma mesonet. Results from these studies were presented at conferences and in peer reviewed publications. Each of these accomplishments is described in greater detail below.

1. Focus Group Meetings with Stakeholders Across the Central United States

Two focus group meetings were convened in August 2014 with stakeholders in the NIDIS Southern Plains and Missouri River Basin regional drought early warning system pilot regions that were impacted by severe droughts in recent years. The first meeting was held in Norman, OK, and the second convened two days later in Lincoln, NE. All attendees were invited based on their prior interest in drought mitigation, with a total of 30 people with diverse backgrounds attending the meetings. A journal article (Otkin et al. 2015) describing results from these meetings has been accepted for publication in the *Bulletin of the American Meteorological Society*.

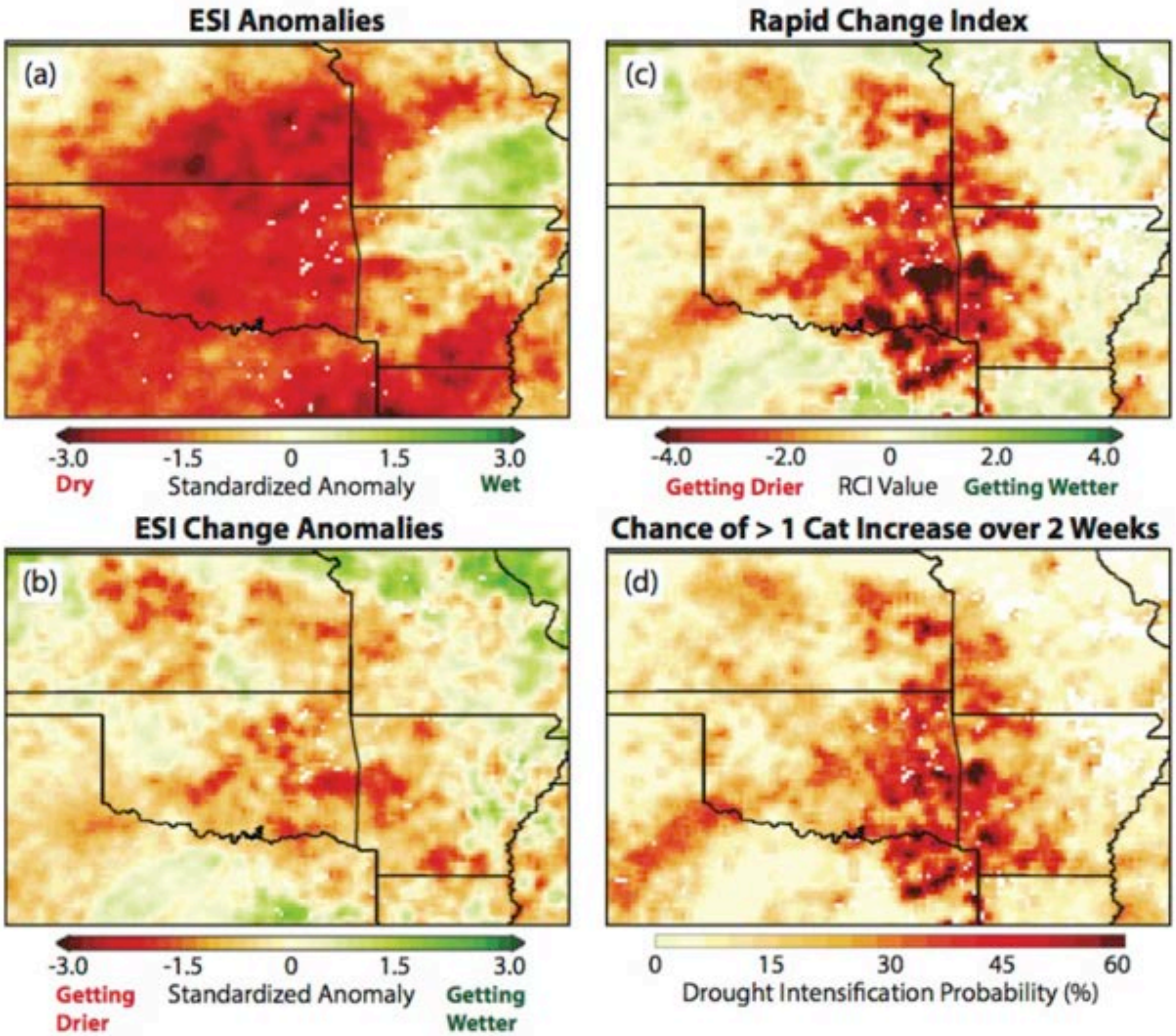
Each focus group meeting included an interactive discussion on the characteristics of flash drought events and their societal impacts, along with several presentations introducing the attendees to the ESI and associated drought monitoring tools, including ESI “change anomalies” that show how rapidly the ESI is changing with time and the RCI depicting the total moisture stress change occurring over longer time periods. Sub-seasonal probabilistic drought intensification forecasts derived from the RCI were also shown. These datasets along with other commonly-used drought metrics were presented to the attendees either as individual domain maps (e.g., first figure below) or as part of a visualization tool referred to as a “plume diagram” (e.g., second figure below) that allows a user to quickly evaluate the evolution of multiple datasets over a specific region without the need to examine potentially dozens of domain maps. The attendees were asked to assess the usefulness of these datasets for drought mitigation efforts through group discussions, analysis of recent flash drought events, and a written questionnaire provided at the end of each meeting.

Overall, most attendees had a favorable opinion of the ESI, RCI, and experimental drought intensification forecasts. The attendees generally preferred to use the ESI and

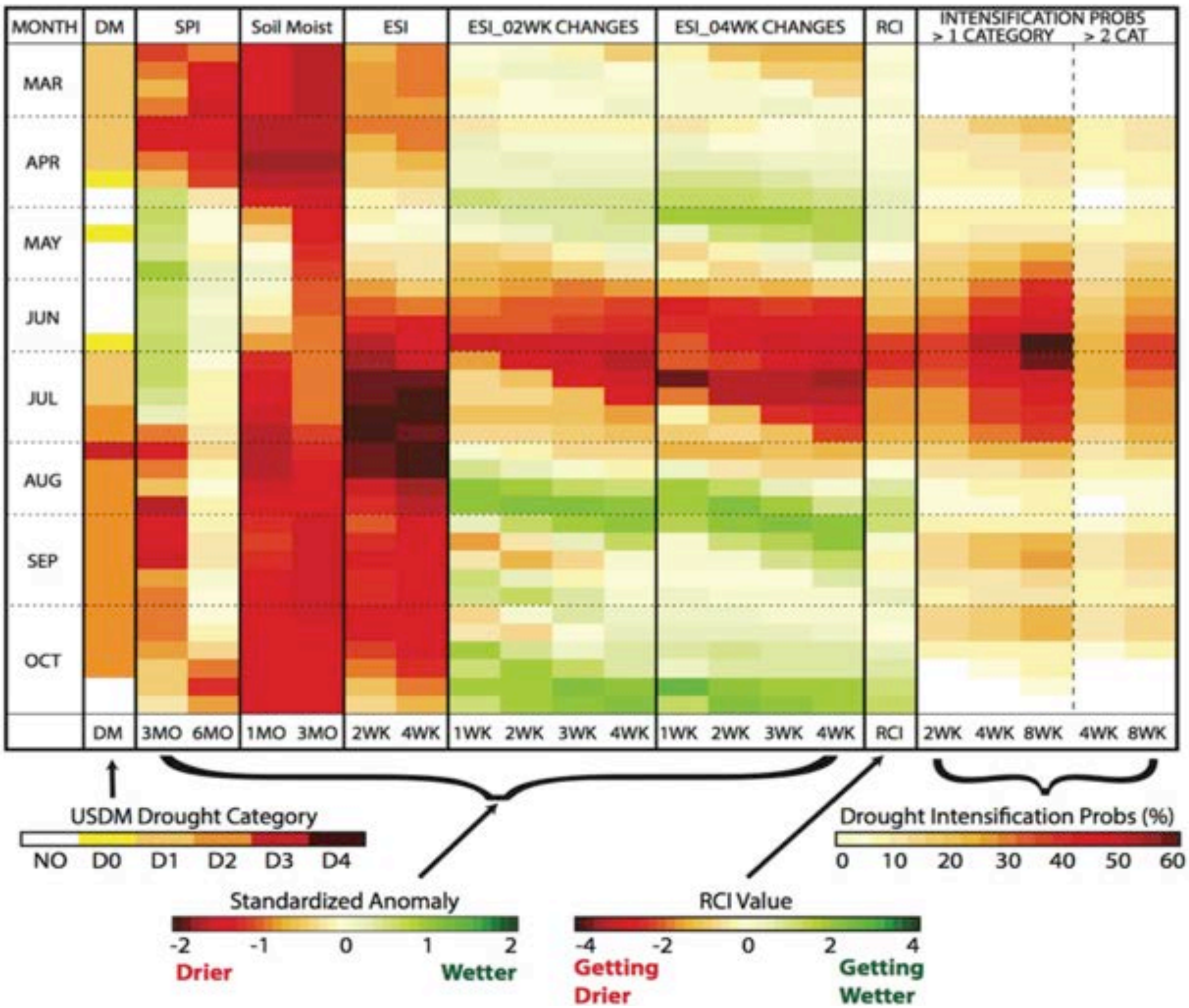
RCI variables in map form (first figure below) when diagnosing current drought conditions. These variables were considered very helpful when used together because the current conditions could be evaluated with the ESI whereas the RCI provides a longer view of how conditions have been changing. The probabilistic drought intensification forecasts allowed the participants to anticipate which regions were most susceptible to drought development, which also influenced their opinion on current drought conditions. Though some concerns were expressed regarding the potential for false alarms, the consensus was that the probabilistic drought forecasts would be useful when making decisions because most farmers and ranchers are accustomed to dealing with uncertainty.

The attendees had a mixed reaction toward the plume diagrams; however, several people commented that their opinion would likely improve after they gain more experience using

them because the visualization method was unfamiliar to them. Many of the attendees appreciated how the columns on the left (ESI, SPI, and soil moisture anomalies) show the current conditions, whereas the columns on the right (ESI change anomalies, RCI, and drought intensification probabilities) provide early warning of drought development. Together, these diagrams provide a concise view of both the current drought status and how things have been changing with time. Overall, the attendee feedback regarding these diagrams was mostly negative at the first meeting, but was mostly positive at the second meeting, with 31% and 80% of the participants expressing a positive opinion in the questionnaire. The higher percentage of positive responses at the second meeting was partially due to the presenters taking more time to explain all of the information included on these complex diagrams because after reading the attendee comments from the first meeting, it was evident that additional time needed to be devoted to explaining how to use them. The more positive comments at the second meeting illustrate the importance of directly engaging stakeholders when developing new tools.



Domain images showing (a) ESI anomalies computed over a 4-week period, (b) standardized ESI change anomalies depicting changes in the ESI during the preceding week, (c) RCI, and (d) the RCI-derived probability of a 1 category increase in the USDM drought severity occurring during the next two weeks. All images are valid on 01 July 2011.



Example "plume diagram" depicting the evolution of the 2012 flash drought event across eastern Oklahoma. The weekly USDM drought analysis is shown in column 1. The Standardized Precipitation Index computed over 3- and 6-month periods is shown in columns 2 and 3, with total column soil moisture anomalies from the North American Land Data Assimilation system computed over 1- and 3- month periods shown in columns 4 and 5. ESI anomalies computed over 2- and 4-week periods are shown in columns 6 and 7. Standardized ESI change anomalies computed by differencing the 2- and 4-week ESI fields over 1, 2, 3, and 4 week time periods are shown in columns 8-15. The Rapid Change Index is shown in column 16, with various drought intensification probabilities computed from the RCI shown in columns 17-21.

The attendees were also asked to describe how access to drought early warning information would potentially affect their decisions. For ranchers, early warning of worsening conditions would allow them to pre-emptively move livestock to different pastures less susceptible to drought or to purchase supplemental feed. Several people noted that forage management is more dynamic than farming, thus, ranchers may realize larger benefits from improved drought early warning. Even so, farmers indicated

that they would still benefit from early warning. For example, knowledge of an increased risk for drought development either locally or across other important farming areas may influence their marketing decisions. It may also help farmers determine if it would be beneficial to plant a cover crop after harvest and which one is most appropriate for the anticipated conditions.

2. *Webinar and Online Drought Impacts Questionnaire*

As part of the Southern Climate Impacts Planning Program's (SCIPP) *Managing Drought in the Southern Plains* webinar series, we hosted a 30-minute webinar in April 2015 that described the methodology used to compute the ESI and associated datasets, discussed their potential use as drought early warning tools within government and the agricultural and natural resources communities, and presented results from the focus group meetings. An online questionnaire soliciting feedback concerning the characteristics of flash drought events and their societal impacts and seeking ways to improve the visualization and dissemination of the ESI was also prepared. The webinar can be accessed at https://www.youtube.com/watch?v=PeLew-DFAuc&feature=youtube_gdata and the questionnaire can be accessed at https://www.surveymonkey.com/r/ESI_Comments.

3. *Webpage and Data Dissemination Modifications*

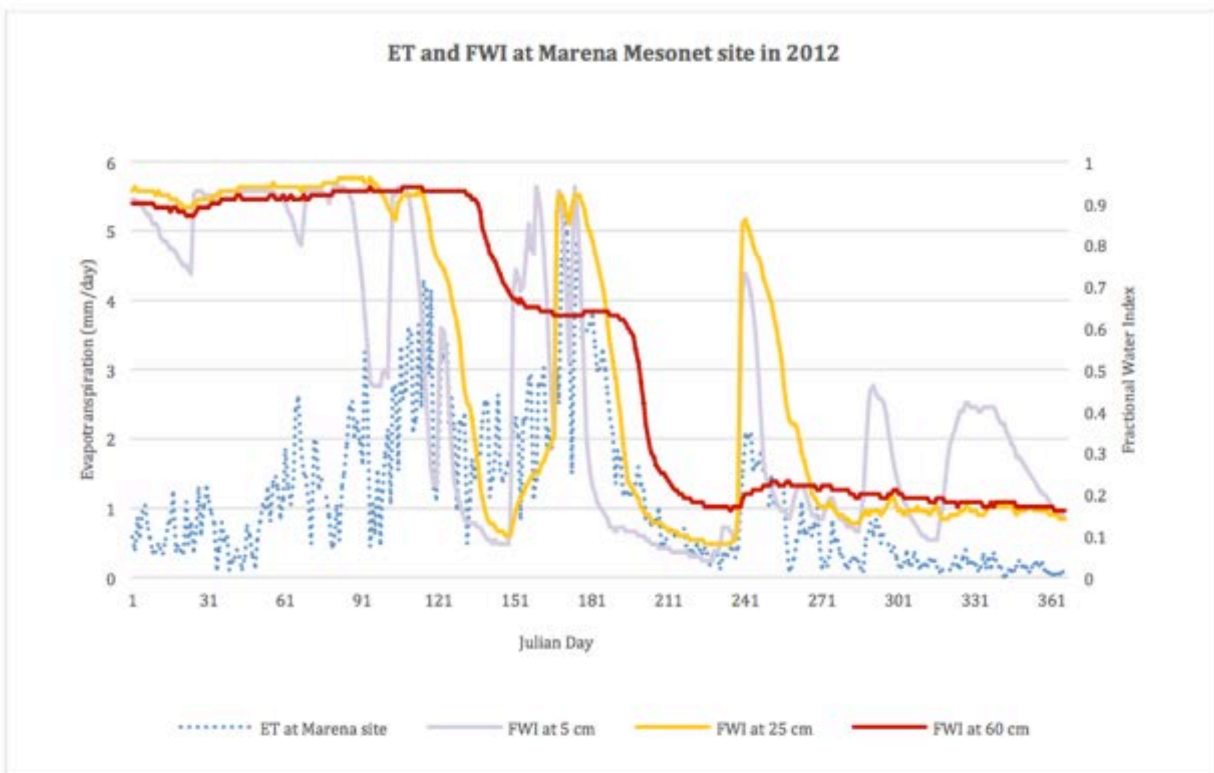
Modifications were made to the ESI webpage (http://hrsl.ba.ars.usda.gov/drought/) based on feedback from the focus group meeting participants, USDM authors, and other people interested in using the ESI as a drought early warning tool or to assess vegetation health conditions. Most of the changes focused on enhancing the utility of the webpage for non- scientists by adding more detailed descriptions that can be used to interpret each image, improving the color bars used to plot the data, and streamlining the webpage by reducing the number of variables displayed on it. Modifications were also made to the ftp server so that USDM authors can directly access geotiff files corresponding to the current date in addition to being able to search for a specific prior date. In response to USDM author questions, we are also exploring ways to improve the representation of the ESI during periods of drought recovery.

4. *Analysis of Flash Drought Development at the Marena, Oklahoma In Situ Sensor Testbed*

This study was performed by an M.S. student at the University of Oklahoma under the supervision of Co-PI Jeffrey Basara. The goal of the project was to provide insight into how physical relationships within the soil-vegetation-atmosphere continuum impact the intensity and development of flash drought events using observations from the Marena Oklahoma In Situ Sensor Testbed (MOISST) during the 2012 flash drought event.

The warmest year on record for the state of Oklahoma occurred during 2012. In response to exceptional warmth during the spring, the growing season began approximately three weeks earlier than normal, with vegetation flourishing due to the availability of sufficient precipitation and soil moisture. Inspection of Gross Primary

Production (GPP) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) revealed large positive anomalies in vegetation biomass (200-400% of normal GPP) during March-May 2012. However, rapid drying of the soil column occurred during May (Fig. 3) as the vegetation extracted water from the soil to maintain overall health and precipitation was below normal. Beneficial rainfall during June 2012 moistened the topsoil, but the soil moisture at deeper depths (e.g., the 60 cm level) was not replenished. As such, when precipitation ceased in July during a time of greatly increasing atmospheric demand, the soil column rapidly dried due to increased evaporation and water extraction by the vegetation. As a result, ET rates rapidly diminished as the vegetation reached the wilting point, with the overall ecosystem collapsing by mid-August. With the reduction in green vegetation and soil moisture, the impacts of a long-term heat wave were accentuated and contributed to flash drought development. These results demonstrate that the soil and vegetation both played a critical role in driving the 2012 flash drought event at this location.



Time series of evapotranspiration (blue line) and Fractional Water Index (FWI) at the 5, 25, and 60 cm levels (gray, yellow, and red lines) during 2012 at the Marena, OK site.

5. Exploring the Relationship Between Drought and the Dry Line over Oklahoma

This study was performed by an M.S. student at the University of Oklahoma under the supervision of Co-PI Jeffrey Basara. The goal of this project was to explore potential relationships between drought, the location of the dry line, and convective precipitation during the 2011 flash drought using data from the Oklahoma Mesonet. During the early

stages of the drought (April-May), the USDM showed that severe drought conditions were present across southwestern Oklahoma, with the remainder of the state experiencing abnormally dry to moderate drought conditions. Significant precipitation fell across eastern Oklahoma during April and May, which relieved drought conditions across that part of the state and helped create a strong west-to-east gradient in soil moisture. Land- atmosphere coupling resulted in the anomalous eastward propagation of the dry line to where the soil moisture gradient was strongest, which impacted convective initiation and precipitation across Oklahoma. Very hot temperatures and abnormally strong surface winds during June resulted in rapid drying of the wet soil over central and eastern Oklahoma. Soil moisture analyses showed that significant drying moved from west to east and initiated along the western edge of the soil moisture gradient. As a result, while drought was present throughout the period across western Oklahoma, flash drought conditions developed over eastern Oklahoma in only a few weeks from the end of June to early July. Furthermore, by the end of the study period most of the state was in exceptional drought and soil moisture conditions were anomalously dry throughout the vertical profile.

Publications

Otkin, J. A., M. C. Anderson, C. Hain, and M. Svoboda, 2015: Using temporal changes in drought indices to generate probabilistic drought intensification forecasts. *Journal of Hydrometeorology*, **16**, 88-105.

Otkin, J. A., M. Shafer, M. Svoboda, B. Wardlow, M. C. Anderson, C. Hain, and J. Basara, 2015: Facilitating the use of drought early warning information through interactions with agricultural stakeholders. *Bulletin of the American Meteorological Society*, in press.

Basara, J. B., J. A. Otkin, and co-authors, 2015: Soil, Atmosphere, and Ecosystem Contributors to Flash Drought Development. To be submitted to *Proceedings of the National Academy of Sciences*.

Flanagan, P. F., J. B. Basara, J. A. Otkin, 2015: Soil Moisture and Near-Surface Atmospheric Evolution Across Oklahoma During the 2011 Drought. To be submitted to *Advances in Meteorology*.

ESI Webpage: http://hrsl.ba.ars.usda.gov/drought/
Webinar: https://www.youtube.com/watch?v=PeLew-DFAuc&feature=youtube_gdata
Online drought questionnaire: https://www.surveymonkey.com/r/ESI_Comments

NWS HFIP: Advancing the Assimilation of Airborne Hurricane Observations Using the GSI-Based Hybrid Ensemble Variational Data Assimilation System for HWRF (NA14NWS4680021)

Xuguang Wang, PI, and Xu Lu (OU School of Meteorology)

Reporting Period: May 2014-July 2015

Figures referenced not included since they were previously transmitted to the Program Manager.

Objectives

The overall objectives of the project are to further extend the capability of the GSI-based EnKF-Var hybrid DA system for operational HWRF; to advance the assimilation of aircraft tropical cyclone (TC) vortex observations and investigate the best data assimilation (DA) configuration to assimilate such data; systematically explore the

impact of aircraft data on the analysis and forecasts of the TCs by HWRF; investigate and document the ability of the extended hybrid DA system in improving TC intensity and track forecasts as compared to the current operational capabilities. The specific accomplishments during this report period are documented below.

Accomplishments

In the last report period, we developed and conducted experiments and detailed diagnostics on the self-consistent, dual-resolution, 6-hourly, GSI-based 3DEnVar hybrid DA system for the entire life cycle of Edouard 2014 assimilating all operational observations. The experiments demonstrated a) the new system improved in particular the MSLP and Vmax forecasts compared to the operational HWRF system due to the alleviation of spin down issue; b) the need of doing dual resolution hybrid over the single resolution; c) the need of using the ensemble relocation capability and vortex initialization procedures especially when TDR data are not available. However, negative impacts of utilizing TDR data were found from two DA cycles with TDR data. During these two DA cycles, the background forecast was going through rapid- changing eyewall replacement and the TDR data were brief and unevenly distributed over the 6-hour window. We hypothesized that a 4DEnVar for 6-hourly DA window or hourly data assimilation would be a solution to solve the issue in this situation. Since 6-hourly 4DEnVar is easy to be implemented in operational HWRF without breaking the 6-hourly assimilation frequency, during this report period, the GSI-based EnKF-Var hybrid DA system for HWRF is further developed with the 4DEnVar capability to explore if the 4D temporal evolution of the error covariances in 4DEnVar can help improve the TDR data assimilation. Figure 1 shows the flow chart of this continuously cycled, self-consistent, dual-resolution hybrid DA system with 4DEnVar capability. The experiments for testing the newly developed 4DEnVar were also conducted for Edouard 2014.

In addition to the efforts of developing and testing the 4DEnVar, in this quarter, we also further extended the 3DEnVar experiments from last quarter by running the experiments using the physics and model resolution (18/6/2km) consistent with the FY15 operational HWRF. The purpose of this experiment is to examine if increased resolution and upgraded physics further improve the performance of HWRF hybrid DA for TC forecast.

1. Further development of GSI-based, end-to-end continuous cycling, self-consistent, dual resolution HWRF hybrid DA system with 4DEnVar capability

The addition of the 4DEnVar capability requires minor modification to the flow chart for the 3DEnVar hybrid data assimilation system. The changes relative to 3DEnVar are marked in yellow. At the beginning of the life of each TC, the system is initialized by GFS ensemble. For example, 40-member HWRF spin-up forecasts on the 27/9 km grids are produced, initialized by the GFS ensemble analyses. In this 4DEnVar hybrid system, these ensemble members are producing forecasts up to 9 hours, and the forecasts valid at +03:00, +04:00, +05:00, +06:00, +07:00, +08:00 and +09:00 will be used to provide ensemble perturbations for the 4DEnVar analysis. In the meantime, a single deterministic HWRF spin up forecast on 27/9/3km grids is produced, initialized by the mean of the GFS ensemble analyses. The forecasts valid from +03:00~+09:00 will also be used to provide background information for the 4DEnVar hybrid data

assimilation at both 9km and 3km grid respectively. At the DA stage, three steps are involved. 1) The 40 member HWRF forecasts at 9km at +06:00 will be used to conduct the EnKF to produce 40-member EnKF analyses at 9km domain. This step is still the same as it is in the 3DEnVar hybrid data assimilation system. 2) The 9km domain will be updated by the GSI hybrid DA ingesting 40 member HWRF ensemble forecasts at 9km resolution. The single deterministic forecast at 3km domain will be also updated by the GSI hybrid DA ingesting 40 member HWRF ensemble forecasts from the 9km domain. Since the assimilation window is 6-hour, 4DEnVar is applied for both the 9km and 3km domain assimilation with background and ensemble perturbations valid from +03:00~+09:00, the 4DEnVar analysis is done at +06:00. 3) The EnKF analyses at 9km domain are re-centered around the hybrid analysis. In order to realize the 4DEnVar, the strategy used in the last report is adopted: the domain movement is directed by the tcvital information and will stay at the same location for model integration during +03:00 to +09:00. After the analyses are produced by the above 3 steps, 4) the hybrid analysis at +06:00 is used to initialize a 9 hour HWRF forecast on 27/9/3km grid, which again is used as the background for the next hybrid analysis. 40 member HWRF forecasts on 27/9 km grids are initialized from the re-centered HWRF EnKF analyses. In the meantime, a 120-h free ensemble forecasts will be produced initialized by the hybrid analyses to meet HWRF’s 5-day forecast need. HWRF’s original vortex following moving strategy is adopted during the free forecasts. The DA and forecast cycles repeat afterwards.

Testing the GSI-based 4DEnVar hybrid data assimilation capability with single observation. GSI based 4DEnVar was implemented for GFS (Wang and Lei 2014). However, the GSI- based 4DEnVar hybrid data assimilation has not been implemented and tested in the regional model. The following experiments were designed to verify the newly extended GSI-based 4DEnVar capability for HWRF.

Similar to Wang and Lei (2014), the observations assimilated in this experiment are at the same location but valid at different times: the start (-03:00), middle (+00:00), and end (+03:00) of the 6 hour data assimilation window. The increments shown in figure 2 are valid at the same analysis time which is the middle of the assimilation window (+00:00). The assimilated observation is a meridional wind at 700hPa. The observation increment is 2m/s. The observation position is marked as a red dot in the figures. In fig. 2a, the wind increment is given at 3 hours earlier than the analysis time. Relative to the observation position, the center of the wind maximum increment is slightly downstream toward the north. This is consistent with the fact that the background wind is blowing north at this position while the analysis time is 3 hours later than the observation time. Fig. 2b shows the wind increments of the assimilation of the meridional-wind observation given at the analysis time (+00:00). As expected, the maximum wind increment center is now co- located at the observation position. In fig. 2c, the observation is valid at +03:00, 3 hours later than the analysis time. With respect to the observation location, the wind increment maximum center is now in the upstream location which is in the southeast of the observation position. This is also consistent with the background wind pattern, which is cyclonic. There is also some negative-positive increment pattern noticed in the eye region for all 3 experiments. They are associated with the update of the position of Edouard due to the assimilation of the single

meridional wind observation. Specifically, the background storm center is a slightly west than the observed storm center. Thus the eastward movement of the storm center makes the wind increase in the original eye center and wind decrease in the updated storm center.

Another single observation experiment was conducted to verify the linear temporal propagation of observation increment in 4DEnVar against that by the full nonlinear model propagation. The assimilated observation is a zonal wind at 700hPa in the blue dot. The observation increment is 3m/s. This observation is valid at the beginning of the assimilation window (-03:00). The observation increment valid at -03:00 is assimilated with 3DEnVar hybrid data assimilation at -03:00 first. Then, two 3-hour forecasts are launched separately. One forecast is initialized from -03:00 with the assimilation of the single observation, the other one is initialized at the same time without the assimilation. The difference between the two model forecasts describes the propagating of the observation increment from -03:00 to +00:00 through nonlinear model integration. Therefore, it can be used as the verification of the increments generated by 4DEnVar and 3DEnVar. The increment of this nonlinear model propagation shows a dipole structure with a positive and negative increment located to the southwest and northeast of the storm eye, respectively. This suggests a northeastward storm position correction in the +00:00 background forecast after the assimilation of a single observation at -03:00. In fig. 3b, the 4DEnVar data assimilation is done on the model forecast at +00:00 with the same wind increment valid at -03:00. The increment from 4DEnVar captures the spatial pattern from the nonlinear model propagation quite well. The dipole structure with the corresponding positive and negative increment is well described by the 4DEnVar analysis at +00:00, suggesting the northeastward correction of the storm center. However, in fig. 3c, with the same wind increment valid at -03:00 and the same background forecast, the 3DEnVar suggests the storm center is corrected southeastward, which is not consistent with the nonlinear model propagation.

<u>The impact of GSI-based 4DEnVar hybrid data assimilation for Edouard assimilating TDR data</u>. After the verification of the capability of the GSI-based 4DEnVar hybrid data assimilation, experiments are done to explore the influence of the 4DEnVar data assimilation. Simulated horizontal and vertical structure of Edouard (2014) for different DA experiments and the corresponding HRD radar composite as the verification were developed. The 3DEnVar analyses showed a spuriously strong wind maximum in the east side of the storm center. During this time period, the storm is going through an eye wall replacement process and the temporal coverage of TDR data is very brief. Compared to the 3DEnVar analysis, the 4DEnVar analyses fit the HRD composite much better. The wind maximum is significantly reduced. This result suggests the benefit of utilizing 4DEnVar over 3DEnVar in this situation.

Intensity forecasts of the last 2 TDR involved cycles where negative impacts of TDR data were found when 3DEnVar was adopted were developed. The intensity forecasts for the 4DEnVar are more consistent with the best track than 3DEnVar especially for the early lead times. This result is consistent with the previous one where the spuriously strong intensity at the analysis time for the 3DEnVar experiment (green) is greatly reduced in the 4DEnVar experiment (blue).

2. The impacts of 18/6/2 km resolution configuration

As discussed early, another effort during this report period is to conduct experiments using the physics and model resolution (18/6/2km) consistent with the FY15 operational HWRF. A flow chart developed is almost identical to the hybrid-27/9/3 from last report except the resolution is higher in each domain.

Hybrid-18/6/2 configuration significantly improved the MSLP and maximum wind forecasts. To summarize, our hybrid-27/9/3 experiments (light blue) show improvements over the FY14 operational HWRF (red). And the hybrid-18/6/2 further improved the hybrid-27/9/3 especially for the intensity forecasts. This result also suggests that our system is robust with configuration changes.

3. Efforts for operational transition

During the last report period, we have finished the primary implementation of our end-to-end self-consistent hybrid DA system into the operational HWRF system in the operational Python and Rocoto scripting environment. During this report period, we have been collaborating with EMC to merge our system into FY16 HWRF. Our efforts also continue on using the end-to-end system to explore the best DA configuration to be implemented for the operational HWRF. The development will not only be tested for FY16 HWRF implementation, but will also be easily applicable for basin scale HWRF for seasons beyond FY16.

Publications

Lu, X., X. Wang, Y. Li, M. Tong, X. Ma, and H. Winterbottom, 2015: GSI-based ensemble-variational hybrid data assimilation for HWRF using airborne radar observations for hurricane initialization and prediction. To be submitted to *Quarterly Journal of the Royal Meteorological Society*.

Lu, X., and X. Wang et al., 2015: GSI-based, cycled, dual resolution hybrid ensemble-variational data assimilation system for HWRF: System description and experiments with Edouard 2014. To be submitted to *Monthly Weather Review*.

Wang X., and T. Lei, 2014: GSI-based four-dimensional ensemble-variational (4DEnsVar) data assimilation: formulation and single resolution experiments with real data for NCEP Global Forecast System. *Monthly Weather Review*, **142**, 3303-3325.

Appendix F

NOAA HURRICANE SANDY COMPETITIVE AWARD RECIPIENT REPORTS

Figures and tables not included since they were previously submitted to NOAA

Advancements in Weather Radar

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA13NWS4830030**
NOAA Sponsor: **Mike Istok**
NOAA Sponsoring Organization: **NWS Office of Science and Technology**
Reporting Period: **April–June 2015**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Accomplishments

Task 8. HCA Improvement: Winter Weather and Hail Size Discrimination

a. Develop a 2D infrastructure for the NSSL prototype of the ORPG HCA and QPE algorithms

Velocity dealiasing was added to the 2D PreProcessor in the simplified 1D form. This allowed us to create the azimuthal shear field output from the 2D PreProcessor. Azimuthal shear is needed to implement the Tornado Debris Signature (TDS) class in the Hydrometeor Classification Algorithm (HCA). HCA was modified to add the TDS class and is now known as HCA-TDS. An analysis of the output from the HCA-TDS revealed limitations due to 1D velocity dealiasing. A decision was made to move to 2D velocity dealiasing and significant progress has been made in adapting that into the 2D PreProcessor.

b. Hail size discrimination

An evaluation of Hail Size Discrimination Algorithm (HSDA), a polarimetric radar algorithm for hail size classification for the operational WSR-88D radars, has been completed. The HSDA uses Z_h, Z_{DR}, and ρ_{hv} within a fuzzy logic scheme to distinguish between small, large and giant hail. Hail size classification is performed at all antenna elevations and different sets of the membership functions for the radar variables depending on the height of the radar resolution volume. The HSDA was validated using reports from the Severe Hazards Analysis and Verification Experiment (SHAVE). SHAVE hail reports are at high spatial resolution making them ideal to evaluate HSDA, which pinpoints locations of hail fall.

In the process of validation, the original version of HSDA described in (Ryzhkov et al. 2013) was modified to mitigate general overestimation of hail size by the original version. The new HSDA reduces the false alarm rate and quantifies hail size more accurately by adjusting membership functions within the fuzzy logic scheme to more

closely match observations, making the Z_{DR} membership functions dependent on Z_h values, and adding an adaptable parameter, ΔZ_{DR}, to adjust the Z_{DR} membership functions to account for possible radar miscalibration and/or forecaster preference for increasing or decreasing warning thresholds for large and giant hail.. The new HSDA also produces more coherent spatial patterns of hail size designations as compared to the original algorithm.

Different scoring methods for the algorithm performance yield different scores with the ones contingent on the results of actual hail reports showing highest scores, as expected. However, since the ground truth information about actual size of hail is commonly not available, we believe that the technique based on the matching of the most common HSDA hail size designation at lowest radar tilt within the 4 km x 4 km area surrounding SHAVE hail report provides the most objective estimation of the algorithm skill. The corresponding probability of detection (POD) is 0.594, false alarm rate (FAR) is 0.136, and the critical success index (CSI) is 0.543.

The HSDA outperforms the traditional single-polarization algorithm (with CSI equal to 0.324) confirming the ability of polarimetric radars to better quantify hail size. Additionally, the HSDA pinpoints locations of hail of different sizes with the storm, whereas the single-polarization algorithm provides only a single hail size estimate per storm.

c. Background classifier for winter precipitation

Work has continued in efforts to provide improved classification of the surface precipitation type. In previous quarters, a new classifier that borrows techniques from spectral bin microphysical parameterization schemes was developed (the Spectral Bin Classifier; SBC) and subjected to preliminary testing. In this quarter, the SBC was subjected to broader testing using a larger dataset.

The program is a one-dimensional spectral-bin algorithm that diagnoses six categories of precipitation: SN, RA, FZRA, PL, RASN, and FZRAPL. The required inputs are the vertical profiles of Tw, RH, and pressure. The algorithm is comprised of three modules: the melting module, the refreezing module, and the automatic classifier for cases of SN, RA RASN, and certain cases of FZRA. Those profiles that are not pre-classified enter either or both of the melting and refreezing modules where the mass liquid-water fraction f_w of each hydrometeor in a spectrum of hydrometeors is calculated at each model level from the cloud top to the surface. The melting and refreezing modules explicitly treat the processes of melting and refreezing but assume no interactions between particles, such as riming or aggregation. In other words, one hydrometeor aloft produces one hydrometeor at the surface.

The SBC is applied to a collection of observed soundings associated with SN, RA, PL, and FZRA. This dataset was created by considering all soundings for winter months (i.e., October-March) from 2002 to 2013 at sounding locations in the eastern and central United States. Only those soundings whose precipitation type does not change during the 40-min window are considered. Additionally, no mixes are included. Lastly, all

soundings are required to ascend to at least 5 km AGL. This yields 649 SN, 545 RA, 422 FZRA, and 125 PL soundings. (There are fewer PL soundings because this form of precipitation is only reported at stations that are augmented by human observers.) The probabilities of detection (POD) are 95.2%, 97.2%, 71.0% and 73.6% for SN, RA, FZRA, and PL, respectively. Though the PODs for FZRA and PL are somewhat lower than for SN and RA, these PODs are about 20% higher than for existing classifiers. A more detailed statistical analysis of the SBC algorithm will be provided in a final report.

d. Surface HCA

As noted in previous reports, a new Winter surface Hydrometeor Classification Algorithm (WsHCA) that is currently under development relies upon a model-based background classification that is later modified, when necessary, by polarimetric radar observations. In turn, much of the radar-based modification depends upon the accurate determination of the location and overall coverage of an overlying "melting layer", the absence of which precludes the occurrence of winter precipitation types such as freezing rain and sleet. Unfortunately, accurate determination of melting layer coverage is a notoriously difficult problem that often leads to both poor hydrometeor classification and, since it depends on HCA results, rainfall estimation.

To illustrate deficiencies in the current HCA, we here present the results from the KVWX (Evansville, Indiana) radar at 170140 UTC on January 5, 2014 as presented by Cocks et al. (2015). Cocks et al. identified 3 winter weather events that presented challenges to the real-time polarimetric rainfall estimation algorithm due to either low or incomplete melting layer coverage over the radar domain. Figure 1 shows the KVWX HCA product that was available to operational forecasters in real-time for that event. As can be seen in Fig.1, the existing HCA produced a large "bulls eye" classification of light rain that was centered over the radar, with unrealistic regions of embedded heavy rain, hail, and graupel. This classification is inconsistent with surface precipitation type observations obtained by the Meteorological Phenomena Identification Near the Ground (mPING) project (not shown) at this time, which largely showed rain to the S-SE of the radar and snow to the N-NE.

Figure 2 shows 170140 UTC 0.50 elevation KVWX radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and melting layer height, as indicated by the HRRR model initialization at 17 UTC, on January 5, 2014 UTC. In contrast to Fig. 1 and in better agreement with the mPING observations, both the radar (Z, Z_{DR}, and ρ_{HV}) data and HRRR output depicted in Fig. 2 suggest the presence of an elevated warm layer over the S-SE part of the radar domain. From Fig. 1, it is clear that the underlying problem with both the precipitation type classification and rainfall estimation for this case can be traced back to the methodology used to determine the melting layer coverage in the existing HCA algorithm wherein 4 to 100 elevation angle data are used to determine the heights of both the top and bottom of the melting layer. When no melting layer is detected or the results are inconsistent due to incomplete coverage (as is the case with the KVLX data at this time), the algorithm resorts to using either the most recent sounding or model height for the melting layer. Those heights, whether determined by radar, sounding, or model, are then "projected outwards" along each

radial to determine the horizontal distance at which each lower elevation scan would intersect that height. This technique assumes horizontal homogeneity of the melting layer across the radar domain, which is more often than not a poor assumption. Clearly, a more robust method to calculate the location of the melting layer over the radar domain is needed (see next section of the report).

e. Hybrid melting layer detection algorithm (HMLDA)

As part of the WsHCA project, we have developed, and continue to refine, a "hybrid" melting layer detection algorithm, referred to HMLDA, that attempts to emphasize the advantages (and de-emphasize the disadvantages) of several melting layer estimation techniques. This includes the use of 1) high (4-100, as used in the existing HCA algorithm) elevation angle data, which can provide highly accurate designations at close distances to the radar but less accurate results at more distant ranges when horizontal homogeneity of the melting layer can not be assumed, 2) low elevation (<40) elevation data, which can provide melting layer designations to more distant ranges but is complicated by the increasing effects of beam broadening with range, and 3) thermodynamic output from numerical models, which can provide evidence (though not a direct measurement) of a melting layer over a much broader domain than is possible with the radar but suffers from decreased accuracy as the time lag between the hourly model analysis and subsequent approximate 5-minute radar volume times increases. In our new methodology, 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 a time-dependent that accounts for the time lag between the model analysis and the radar scan time.

The results of the HMLDA for the KVWX radar at 170140 UTC and using the 17 UTC HRRR analysis is shown in Fig. 3. The low-elevation angle input for the HMLDA results shown here employed a newly developed technique that examines several "interest fields" of polarimetric variables to come up with optimal low-level melting layer detection. The Gaussian weights allow the contribution from the numerical model to increase with greater distance from the radar and decrease as the ΔT between the model analysis time and radar volume time increases. While additional work needs to be done to refine algorithm parameters/weights, it is clear that the results represent a dramatic improvement, when compared to the mPING observations, over the unrealistic "bulls eye" provided by the existing HCA.

f. Tornado debris signature (TDS)

Although Doppler radar radial velocity data can partially resolve some tornadoes, particularly large tornadoes near the radar, most tornadoes are not explicitly resolved owing to inadequate spatiotemporal resolution. In addition, it can be difficult to determine which mesocyclones observed on radar are associated with tornadoes. Since debris lofted by tornadoes has scattering characteristics that are distinct from those of hydrometeors, the additional information provided by polarimetric weather radars can aid in identifying tornado debris; the polarimetric tornadic debris signature (TDS)

provides what is nearly “ground truth” that a tornado is ongoing (or had recently occurred).

A modification to the hydrometeor classification algorithm (HCA) used with the operational Weather Surveillance Radar – 1988 Doppler (WSR-88D) network in the United States to include a TDS category has been completed. The primary purpose of such modification was - c identification of TDS events and reduction of false alarm rates (FAR) where the TDS occurs. The new algorithm is described in the paper by Snyder and Ryzhkov (2015) which has been accepted for publication in the Journal of Applied Meteorology and Climatology. The paper contains numerous examples of automated TDS classification provided for several recent cases observed in the United States.

Swaths of high azimuthal wind shear can be used to identify the paths of mesocyclones associated with supercells (e.g., “rotation tracks”). However, owing largely to sampling inadequacies (e.g., beam height, radar resolution volume size compared to tornado size, etc.), most tornadic supercells sampled by WSR-88Ds are not sampled with sufficient resolution to discriminate the tornado from the larger mesocyclone. Figure 4 compares TDS tracks with rotation tracks obtained through the NSSL OnDemand website for tornado outbreaks that occurred on 17 November 2013 and 28-29 April 2014. Not all tornadoes (marked by red curves in Fig. 4a,c) produced a TDS, but essentially all of the TDS tracks were associated with tornadoes. Most of the observed tornadoes were associated with swaths of high azimuthal wind shear in the rotation tracks as well (where the tornado paths are marked in green in Fig. 4b,d); there is considerable agreement between the TDS tracks and the rotation tracks, though there are several intense rotation tracks not associated with a tornado.

Task 9. Improvements of Polarimetric QPE

a. Determination of the ZDR slope for optimization of the algorithms for attenuation correction and rainfall estimation

A slope of the dependence of differential reflectivity Z_{DR} on radar reflectivity factor Z in rain (Z_{DR} slope) estimated from the polarimetric radar data in real time can be utilized for optimization of the algorithms for attenuation correction and rainfall estimation. The latter one include the algorithms based on specific attenuation A and specific differential phase K_{DP} (R(A) and R(K_{DP}) respectively). A functional description of the automatic semi-operational procedure for estimation of the Z_{DR} slope has been made and is available upon request.

b. QPE in pure rain or rain mixed with hail

Robust estimation of the total span of differential phase $\Delta\Phi_{DP}$ is crucial for radar rainfall estimation using specific attenuation A and specific differential phase K_{DP}. It is also important for fixing corrupted values of K_{DP}. Inaccurate determination of $\Delta\Phi_{DP}$ can cause biases in the estimate of A along the whole radar ray if specific attenuation is computed using the ZPHI methodology. This results in “spiky” appearance of the R(A) field. If K_{DP} is estimated from A or Z, then it also becomes vulnerable to the errors in

the determination of $\Delta\Phi_{DP}$. Recall that K_{DP} retrieved from A or Z is needed in the regions where traditional estimate of K_{DP} is noisy or corrupted as in the areas of light rain, low cross-correlation coefficient, or non-uniform beam filling. Addressing this need, we made a functional descriptions of the most recent versions of the procedure for determination of the span of differential phase and the algorithm for rainfall estimation based on A (R(A)). The algorithm is designed for quantitative precipitation estimation in pure rain and in rain mixed with hail. Both functional descriptions are available upon request.

Task 10. Utilization of Dual-Polarization WSR-88D radars for better Nowcasting / Forecasting of Severe Weather Events

a. ZDR column product

Analyses of the polarimetric radar observations and results of numerical simulations using cloud models with spectral microphysics show a positive spatial relationship between the updraft of convective storms and the Z_{DR} columns associated with those storms. Combining the spectral bin microphysics in a high-resolution numerical model with a polarimetric emulator, we have shown that the location and depth of simulated Z_{DR} columns match quite well with the location and intensity of convective storm updrafts, and changes in the maximum vertical velocity within an updraft tend to be seen after changes in the height of a Z_{DR} column. In general, Z_{DR} columns tend to be dominated by rain early in their lives or at lower altitudes when the column is more mature. The raindrops freeze into hail as they rise in the updraft, so that the upper parts of the Z_{DR} column tend to be dominated by wet hail. Depending upon the particular environment and evolution of the storm, the hail may fall back through the updraft, weakening the updraft and/or masking the Z_{DR} column.

The Z_{DR} column algorithm has been developed that shows potential for providing near-real-time information on the intensity and location of updrafts, at least those associated with strong updrafts. In addition, the Z_{DR} column product has potential uses in radar data assimilation owing to the ability of the Z_{DR} column to provide valuable information (sometimes in the absence of high Z_H) on latent heating rates and hydrometeor distributions via updraft identification. Incomplete radar coverage associated with the VCPs used by the WSR-88D network introduces difficulties in detecting and quantifying Z_{DR} column depth, particularly for weaker updrafts or those at particular ranges from the radar (depending upon VCP and the maximum height of the Z_{DR} column). Z_{DR} column detection could be improved by means of an RHI or by the use of a VCP that provides more complete scanning of atmosphere above the environmental freezing level.

The Z_{DR} column depth can provide useful information about near-term updraft evolution. For example, the ~30 minute evolution of a multicell convective complex over western Florida is shown in Fig. 5; the top row contains Z_H data at 0.50o elevation angle, and the bottom row contains output from the Z_{DR} column algorithm. Looking at

Z_H, it is very difficult to ascertain where the strongest updrafts are located and where one may expect continued development or maintenance. The Z_{DR} column product indicates where subsequent convective development should be expected. Fig. 5 shows that strongest enhancements of Z occur in the areas where strong and deep Z_{DR} columns were detected in the previous radar scans.

Manuscripts Related to the Project during the Reporting Period

Ortega, K., J. Krause, and A. Ryzhkov, 2015: Polarimetric radar characteristics of melting hail. Pat III: Validation of the algorithm for hail size discrimination. To be submitted to *Journal of Applied Meteorology and Climatology*.

Snyder, J., and A. Ryzhkov, 2015: Automated detection of polarimetric tornado debris signatures. Accepted by *Journal of Applied Meteorology and Climatology*.

Snyder, J., A. Ryzhkov, M. Kumjian, J. Picca, and A. Khain, 2015: Developing a Z_{DR} column detection algorithm to examine convective storm updrafts. Submitted to *Weather and Forecasting*.

Develop Improved Predictions of Inland Flooding

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA14OAR4830100**
NOAA Sponsor: **John Cortinas**
NOAA Sponsoring Organization: **OAR Office of Air and Water Quality**
Reporting Period: **April-June 2015**
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

Task 1: Errors that were discovered in the processing for four years have been corrected and re- run. Quality control of the reanalyzed precipitation is being conducted manually and will be finalized by the end of FY15, completing this task.

Task 2: The Hydrometeorological Testbed Experiment (HMT-Hydro) was funded and has enabled the evaluation of forcing from two different methods. A radar extrapolation method called ADSTAT and quantitative precipitation forecasts from the High Resolution Rapid Refresh Model have been implemented into the hydrologic model and are presently being evaluated by 16 National Weather Service Forecasters during a 3-week period of the experiment. Initial feedback indicates very good performance by the FLASH products.

Task 3: The website (http://flash.ou.edu/e) has been released and now shows comparisons of distributed hydrologic model outputs to USGS streamflow observations at each gauge that has defined flood stages. Analyses during the active spring flood season have been conducted, indicating excellent performance during the deadly Houston flooding event and extensive flooding of the Blancos River near San Marcos,

TX. Forecasts from the FLASH system are now being provided to select River Forecast Centers in the NWS in order to begin assessing its value in providing hydrologic information on larger stem rivers in ungauged basins.

Task 4: Virtual machines are being established on local hardware in order to simulate processing at NCEP Central Operations. FLASH is still on schedule to transition to operations in Q2FY16, including the following products: MRMS rainfall to flash flood guidance ratio, MRMS rainfall average recurrence intervals, precipitable water anomaly products, and CREST soil moisture, streamflow, and unit streamflow products.

Task 5: Work stemming from this task has been summarized into two articles. One paper is titled "Shallow landslide prediction through assimilating satellite remote sensing and geospatial datasets into a coupled hydrological-geotechnical framework at regional scale", and has been submitted to the Journal of Hydrology. Another paper is in preparation and will be submitted soon. In addition, model optimization and sensitivity analysis of coupled flood-landslide models to DEM resolution and soil properties were conducted.

Task 6: The latest version of Ensemble Framework For Flash Flood Forecasting (EF5), the core distributed hydrologic model in FLASH, was evaluated on 1837 unregulated USGS-gauged basins over the decade at which the MRMS precipitation estimates were computed. Overall, this dataset is comprised of 88,241 significant flow events. Following filtering of basins dominated by snowmelt and poor radar coverage, the linear and ranked correlation of simulated to observed peak flow was 0.64 and 0.79, respectively. Following this robust, long-term evaluation, we have been concentrating on case studies of record flooding that occurred during this quarter. FLASH performance was evaluated for the Houston and Blancos River events; results have been posted online (http://blog.nssl.noaa.gov/flash/insights/). Beginning on May 23, very heavy rain (6-8") fell in the headwaters of the Blancos River. The overland flooding was captured well by both QPE-to- flash flood guidance ratio and CREST streamflow products. However, the greatest impacts from this event including the evacuation of a jail and rescues occurred well downstream from the causative rainfall on the Blancos River. In this case, only the CREST-based streamflow forecasts were able to properly model these downstream impacts. This case highlights the need for river routing in a flood prediction system. Another 6-8" of rain fell on May 25 over metropolitan Houston, TX. The left panel of Fig. 3 shows that flash flood guidance was exceeded by 120-140%, indicating a possible flash flooding scenario. However, the inclusion of impervious surfaces in the CREST unit streamflow product in the right panel shows that this case was far more serious. Unit streamflow values exceeded 10 cms/km^2 over many areas; these were the largest unit streamflow values that the developers had seen from the model, and 20 fatalities over the city resulted from this event. A NWS forecaster from Reno, NV used the FLASH tools (via webpage) during a flash flooding event and stated the following: "After looking at FLASH page, I feel the information is more valuable than using FFMP as a flash flood warning decision tool as it combines several data sources."

Task 7: During this quarter, research was conducted on the circumstances that lead to fatalities from flash flooding. The NWS Storm Data were used to determine the

frequency, spatial distribution, and timing of fatalities caused by the following circumstances: a) vehicle-related, b) permanent building or residence, c) mobile home, d) outdoors in a recreational context, and e) outside in a neighborhood in close proximity to a stream or river. This work will be used to guide the impact-based categories for forecasts in the near future. The aforementioned study is being prepared and will be submitted for peer-review by the end of Q4FY15.

Task 8: The research team has begun research on a new method to derive flooding thresholds at each grid point based on observed data. If proven successful, this will negate the need to rerun the model suite in retrospect. The thresholds will apply to streamflow forecasts, and they are being derived from Earth observations alone; i.e., they are independent from models. This presents a major breakthrough for prediction in ungauged basins. First, the thresholds are based on observations of geomorphologic variables that are available everywhere. This means that they readily apply to ungauged basins. Second, the thresholds are model-independent. This readily accommodates improving and refining the model structure and parameters without the computationally expensive need to re-run the model for the period-of-record. The hydrologic model reanalysis will be conducted beginning in FY16. Results from the reanalysis will be used for research purposes.

Manuscripts Submitted for Publication

Hardy, J., J. Gourley, P.-E. Kirstetter, Z. Flamig, and Y. Hong, 2015: A method for probabilistic flash flood forecasting. Submitted to *Journal of Hydrology*.

He, X., Y. Hong, H. Vergara, K. Zhang, J.J. Gourley, P.-E. Kirstetter, Y. Zhang, G. Qiao, and C. Liu, 2015: Shallow landslides prediction through assimilating satellite remote sensing and geospatial datasets into a coupled hydrological-geotechnical framework at regional scale. Submitted to *Journal of Hydrology*.

Saharia, M., P.-E. Kirstetter, H. Vergara, J. J. Gourley, and Y. Hong, 2015: Characterization of floods in the United States. Submitted to *Journal of Hydrology*.

Schroeder, A., J. Gourley, J. Hardy, J. Henderson, P. Parhi, V. Rahmani, K. Reed, R. Schumacher, B. Smith, and M. Taraldsen, 2015: The development of a flash flood severity index. Submitted to *Journal of Hydrology*.

Develop and Deliver a MRMS Course for WFO and CWSU Forecasters

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA14NWS4830006**
NOAA Sponsor: **Mark Miller**
NOAA Sponsoring Organization: **NWS Office of Science and Technology (OST), NextGen Program**
Reporting Period: **August 2013-September 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

The primary WDTD deliverable for this project was the Multi-Radar/Multi-Sensor (MRMS) Products Course (http://www.wdtb.noaa.gov/courses/MRMS/index.php). This course was released in October 2014, at the same time as MRMS products were deployed operationally to the NWS. The Products Course is divided into a severe/aviation track and a hydro track. The full course is a combination of the two tracks, and is recommended for all NWS personnel with job responsibilities forecasting and warning in severe, aviation, and hydrologic service sectors. A MRMS Product Reference Guide (http://www.wdtb.noaa.gov/courses/MRMS/ProductGuide/index.php) was also released for quick access to MRMS product documentation.

In order to help guide training content development for these deliverables, CIMMS personnel accompanied WDTD staff to visit two NWS WFOs (Fort Worth, TX and St. Louis, MO) to observe the use of MRMS products during warning operations. They documented warning methodology and best practices related to the MRMS products that were available at the WFO and the products that the forecasters were familiar with using. This information provided valuable insight on how to best deliver MRMS Severe training content that is pertinent to forecasters. While in Fort Worth, TX, they also visited the West Gulf River Forecast Center and discussed the utility and best practices of the NMQ/Q3 products within their office. Blogs about these trips are available on the NOAA Virtual Lab in the MRMS Community.

Additionally, CIMMS personnel attended the NWS Flash Flood Summit in Alabama in September 2014. The purpose of this participation was to ensure that WDTD training is/will be aligned with the shared vision for future flash flood services in the United States. Since MRMS is a tool that is capable of aiding in flash flood warning decision-making, it is important that stakeholders understand it and are prepared to incorporate it into long-term goals within the NWS.

Subject matter experts from the National Severe Storms Laboratory provided technical documentation for each MRMS product. This documentation was the basis of WDTD's MRMS Reference Guides, which is meant to consolidate and adapt the technical information into a form that is suitable for forecasters. CIMMS work included, but was 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. After completing this, CIMMS staff developed and then populated a website for the MRMS Product Reference Guides.

The track-specific lessons in the MRMS Products course were created by CIMMS staff by consolidating and repackaging information from the MRMS Reference Guides into PowerPoint slides, in order to deliver more relevant job-centered training. To aid in the delivery and understanding of the material, CIMMS recorded animations and narrations into the PowerPoint slides using specialized software (i.e., Articulate Presenter).

This project is complete.

Publications

WDTD Multi-Radar/Multi-Sensor (MRMS) Products Course: http://www.wdtb.noaa.gov/courses/MRMS/index.php

WDTD MRMS Product Reference Guide: http://www.wdtb.noaa.gov/courses/MRMS/ProductGuide/index.php

Warning Decision Making and Training

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA13OAR4830230**
NOAA Sponsor: **Mark A. Tew**
NOAA Sponsoring Organization: **Marine and Coastal Weather Services Branch**
Reporting Period: **September 2013-August 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 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 was involved with the development of this PDS. The framework of the PDS focused 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 WDTD 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; and
- 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.

CIMMS staff also developed an optional case review using data from Tropical Storm Debby from 2012. This optional case review allows NWS forecasters to practice applying the environmental threat assessment learning objectives discussed in the course to the Tropical Storm Debby event through a combination of an interactive website and downloadable material.

In addition to the creation of the Tropical Cyclone Tornadoes Course CIMMS scientists tracked course progress of NWS personnel and awarded course certificates of completion to those that completed the course.

Publications

WDTD Tropical Cyclone Tornadoes Course Official Site: http://www.wdtb.noaa.gov/courses/tc-tor/

Improving High-Resolution Tropical Cyclone Prediction Using a Unified GSI-based Hybrid Ensemble-Variational Data Assimilation System for HWRF

Principal Investigator: **Xuguang Wang** (OU School of Meteorology)
NOAA Award: **NA14NWS4830008**
NOAA Sponsor: **Shannon Louie**
NOAA Sponsoring Organization: **NWS Cooperative Institute Program Office**
Reporting Period: **January-December 2014**
Related NOAA Strategic Goal: **Weather-Ready Nation**

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

1. Development of Self-Consistent, GSI-Based Var-EnKF Hybrid Data Assimilation System for HWRF with Continuous Cycling Capabilities

Under the support of this grant, a continuously cycled, self-consistent GSI-based Var-EnKF hybrid data assimilation system for HWRF with moving nests was developed and implemented for HWRF. Experiments were conducted to test this newly established system. The details of the system and experiment results were discussed in quarterly reports. Here we only provide highlights.

a. System Description

The operational HWRF system requires the assimilation system to be able to follow the life cycles of the tropical cyclone and to conduct 120-hour free forecasts. To satisfy operational requirement and also consider the computational resource constraint, a strategy to allow the hybrid DA system to move with the TC is proposed. Accordingly, the hybrid DA system with moving nests capabilities was developed. The current operational HWRF adopts vortex following moving strategy. In the context of hybrid DA where ensemble will be ingested in GSI, such moving strategy induces nontrivial issue because after each member's first guess forecast, the nests of ensemble members will be located differently. Therefore the ensemble of nests is not co-located, which makes the implementation of the hybrid DA difficult. To solve this problem, we implemented a new moving nest strategy in HWRF. In such approach, the nest of each ensemble member will be directed to the same location during HWRF integration. The HWRF code associated with moving nests was modified accordingly. Figure 1 (not shown) shows the triply nested HWRF domain with 3km grid for the innermost movable nest, 9km grid for the intermediate movable nest and 27km for the outer-most fixed domain, following the triple-nest domain configuration of operational HWRF. Figure 2 (not shown) illustrates how the new moving strategy works. An example of 3-member ensemble was used in these figures. d01, d02, d03 denote 3 members with 3km grid adopting the new "moving-all-together" strategy. d01-old, d02-old, d03-old denote the corresponding members adopting the original vortex following strategy in HWRF. d01 and d01-old share the same initial condition, so do d02 and d02-old and d03 and d03-old. Sea Level Pressure (SLP) was plotted. To facilitate evaluating the results, the fields for each pair were plotted in the same color but with different line patterns. This suggests the following: 1) as expected, using the original moving nest strategy, the nests of the 3 members after model integration were centered at different locations. In comparison, using the new moving strategy, the nests of the 3 members were co-located. 2) For the regions where the pairs are co-located, the simulated SLP was very close to each other. For example, for regions where d02 and d02-old are overlapped (green curves), simulated SLP were nearly overlapping with each other. These results suggest the development and implementation of the new moving strategy function properly.

With the new moving strategy developed and implemented, the GSI-based dual resolution Var-EnKF hybrid DA system for HWRF is now extended to have the capability to cycle through the TC with moving nests. Figure 3 shows the flow chart of this new system. A triply nested domain, a 40-member ensemble and 6-hour cycling frequency are used as an example to describe the system below.

At the beginning of the life of each TC, the system is initialized by GFS ensemble. For example, 40-member HWRF spin up forecasts on the 27/9km grids are produced, initialized by the GFS ensemble analyses. These forecasts are used as the background ensemble for the EnKF at the 9km grid. In the mean time, a single deterministic HWRF spin up forecast on 27/9/3km grids is produced, initialized by the mean of the GFS ensemble analyses. This forecast provides background forecast for the hybrid DA. At the DA stage, three steps are involved. 1) The 40 member HWRF forecasts at 9km grid

will be used to conduct the EnKF to produce 40-member EnKF analyses. 2) The single deterministic forecast will be used to perform hybrid DA. Specifically, the 9km grid will be updated by the GSI hybrid DA method ingesting 40 member HWRF ensemble forecasts at 9km grid. The single deterministic forecast at 3km grid will be updated by the GSI hybrid DA method also ingesting 40 member HWRF ensemble forecasts at 9km grid. In other words, the 3km grid will conduct dual resolution hybrid DA, the functionality of which has already been developed and tested as shown in the last report. As discussed in the last report, having the 3km grid ingesting 9km ensemble is motivated by saving computational cost from running a 3km ensemble and by still maintaining the self-consistent HWRF hybrid DA. 3) The high-resolution hybrid analysis in step 2) is expected to provide better analysis. Therefore, the EnKF analyses at the 9km grid are re-centered around the hybrid analysis.

After the analyses are produced by the above 3 steps, the hybrid analysis is used to initialize a short term HWRF forecast on 27/9/3km grid, which again is used as the background of the next hybrid analysis. 40 member HWRF forecasts on 27/9km grids are initialized from the re-centered EnKF analyses. In the mean time, a 40-member 120-h free ensemble forecasts will be produced initialized by the recentered EnKF analyses to meet HWRF’s 5-day forecast need. HWRF’s original vortex following moving strategy is adopted during the free ensemble forecasts. The DA and forecast cycles repeat afterwards. In addition to the “dual resolution” assimilation capability, the system is also further extended with the “single resolution” capability. Different from the dual resolution method where 3km domain ingests 9km ensemble, in the single resolution hybrid DA method, 3km grid will conduct single resolution hybrid DA ingesting its own 3km EnKF ensembles. Such single resolution method is expected to provide more detailed flow-dependent information, consistent with the high-resolution control forecast.

In summary, such extended, self-consistent hybrid DA system for HWRF has the following capabilities, which facilities exploring the optimal configuration for operational implementation under the constraint (e.g. computing resources, timing) specific for operations:

- Flexibility to conduct continuous cycle or partial cycle following the lifecycle of TC
- Flexibility to use different cycling intervals
- Flexibility to use different ensemble members
- Flexibility to change the size of the triply nested domains
- Flexibility to use dual resolution or single resolution hybrid DA
- Flexibility to run 4DEnVar or 3DEnVar hybrid

b. Experiments and Tests

Initial experiments to test the newly extended system were conducted for cases and periods where airborne radar data were available during the 2014 season. Figure 5 (not shown) illustrates the first test that we conducted for Arthur 2013 using the dual resolution system. The root mean square errors of track, MSLP and maximum wind forecasts up to 120 hours were calculated for all airborne radar missions of Arthur. As a reference, the operational HWRF forecast was included. It was found that the

performance of track forecasts from our newly extended self- consistent hybrid DA system was comparable with operational HWRF. However, MSLP and maximum wind forecasts by the new system were better than the operational forecast overall. Specifically, among the 120-h forecast period, the self-consistent hybrid system performed better than the operational HWRF for majority of the forecast lead times. Figure 6 (not shown) show the actual track, MSLP and maximum wind forecasts up to 120 hours. It was found that the overall trend for the MSLP and Maximum wind were better predicted by the self-consistent system. For example, operational HWRF lagged by 12-24 hours to reach the peak intensity while the self- consistent hybrid DA system was more consistent with the trend indicated by the best track data.

Initial experiments to test the newly extended single resolution system were conducted for Isaac 2012 during the periods when airborne radar data were available. Figure 7 (not shown) illustrates the test that we conducted for Isaac. For most of the airborne radar missions for Isaac, single resolution method showed advantages than the dual resolution method. The discussion below used mission 6 as an example. Shown is the track, MSLP and Vmax forecasts out to 120-hour lead times. The performance of the track forecasts from the single resolution experiment is comparable with that of the dual resolution experiment. The advantage of the single resolution hybrid DA method was shown in the MSLP and Vmax forecasts. Specifically, the prediction of the intensification during the first 36 hours by the single resolution hybrid system followed the best track much closely than the dual resolution experiment.

In summary, under the support of this grant, a continuously cycled, self-consistent GSI-based Var-EnKF hybrid data assimilation system for HWRF with moving nests was developed and implemented in the operational HWRF framework. Our experiment results have shown great promises of the new system in improving hurricane track and intensity forecasts.

c. Efforts to Transition the System to Operations

The operational HWRF system's scripting system is changed significantly replacing the shell script with the python script. Significant progress has been made to implement the self- consistent hybrid DA system in the operational HWRF framework following the new python and Rocoto scripting rules developed by EMC.

We have finished the primary steps of merging our self-consistent hybrid DA system into the operational HWRF system. The self-consistent, dual-resolution, GSI-based Var-EnKF hybrid DA system for HWRF with continuous cycling is now run successfully within HWRF's operational python and Rocoto scripting environment with the test case provided by EMC and DTC. The implementation include the following: 1) add the new HWRF moving nest strategy developed by our group; 2) Add the HWRF EnKF which the operational HWRF does not have; 3) add the capability of using cycled HWRF ensemble to provide the ensemble covariance for dual resolution hybrid replacing cold started HWRF ensemble in the current operational HWRF system; 4) Refine dual resolution hybrid capability; 5) integrate the vortex relocation with the hybrid DA system. These efforts represent a significant step of transitioning our research and development

into the operational system.

Papers During the Reporting Period Under Full or Partial Support of this Project

Lu, X., X. Wang, Y. Li, M. Tong, X. Ma and H. Winterbottom, 2015: Assimilation of airborne Doppler radar observations using the unified GSI-based hybrid EnKF-Variational data assimilation system for HWRF. To be submitted to *Quarterly Journal of the Royal Meteorological Society*.

Assimilation of Caribbean Radar Data for NCEP

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA14NWS4830035**
NOAA Sponsor: **Geoff DiMego**
NOAA Sponsoring Organization: **NCEP EMC**
Reporting Period: **April-June 2015**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Accomplishments
We requested approval from the weather offices in the Bahamas, Jamaica, and Cayman Islands to connect a NSSL-provided computer to a communications ports on their radar unit. This computer will perform tasks in a non-interference basis acquiring data files in real time, run software to compress the data files, and transmit back to NSSL for quality checking using a Local Data Manager (LDM) protocol. An additional request for access to the Internet was also included, either using an existing local network or a NSSL-provided satellite Internet system. The request to the participating weather offices proposed a simple data sharing agreement with each site. For the Bahamas and Jamaica, which use licensed proprietary software libraries (EEC EDGE package), we are exploring ways to use onsite libraries in order to convert raw radar data into readable/ingestible files prior to LDM broadcast.

We received technical details of the local network set up at the Cayman Islands National Weather Service office and are finalizing plans to install the necessary communications equipment for receiving real time radar data. The Jamaica Meteorological Service is still considering the request for installation. We have not received any acknowledgment from the Bahamas Department of Meteorology at this time, but are continuing to inquire.

At the request of the U.S. Department of State and NOAA Headquarters, we have suspended communications with the Cuban Meteorological Institute (INSMET) until both governments recognize high-level formal agreements.

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

Principal Investigator: **Kristin Calhoun** (CIMMS at NSSL)
NOAA Award: **NA14OAR4830164**
NOAA Sponsor: **John Cortinas**
NOAA Sponsoring Organization: **OAR Office of Air and Water Quality**
Reporting Period: **April-June 2015**
Related NOAA Strategic Goal: **Weather-Ready Nation Accomplishments**

Accomplishments

Earth Networks has indicated the potential for their total lightning data and "Dangerous Thunderstorm Alerts" (DTA) 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. This project integrates the Earth Networks data and products into the NWS operational software and tests both the feasibility of use in warning operations as well as the impact on warnings issued by NWS forecasters in the Hazardous Weather Testbed (HWT) in Norman, OK.

The Apr-Jun 2015 period focused on final preparations for the HWT live evaluation of the ENI total lightning data and decision-assistance products (including DTAs) as well as the full evaluation itself. Coordination, including multiple teleconferences between NSSL/CIMMS, ESRL/Global Systems Divisions and Earth Networks, for final updates and real-time testing were completed within in the HWT prior to the forecaster evaluations. Additionally, a training module for the visiting forecasters was completed and made available via web access.

The final evaluation of the system and products was completed within the HWT 4 May - 12 June as part of the Experimental Warning Program. During this time period, the project scientists worked with the visiting forecasters to collect feedback through surveys, interviews, and live blogs during warning operations.

Milestones

- Selection of forecasters for 2014 HWT. Status – Completed April 2014
- Development and integration of ENI total lightning and Dangerous Alert System into AWIPS2 for 2014 HWT. Status – Completed 7 July 2014
- Development of displaced real-time cases for 2014 HWT activity. Including processing raw radar, total lightning and DTA system data for individual dates and development of code to run system in displaced real-time within AWIPS2 platform. Status – Completed 16 July 2014
- Develop and review forecaster training for ENI total lightning and DTA system for 2014. Status – Completed 11 July 2014
- Complete first experiment within the HWT. Status – Completed 29 Aug 2014.
- Complete verification statistics of DTA system and NWS warnings for 2013 and 2014. Status – Completed statistics for 2013 & 2014
- Complete year 1 executive summary and draft for journal publication of HWT evaluation. Status – ongoing and on schedule. Analysis began in September

2014 immediately following end of HWT data collection. Summary will be made available prior to 2015 Spring Experiment.

- Share results from year 1 (via conferences and workshops) and make recommendations to enhance data access, processing, and display as needed based on results from year 1 HWT activity. Status – Completed. Presentations at the National Weather Association and American Meteorological Society Annual Meetings, held a team workshop in Boulder, CO, and gave multiple web-based teleconference to sections of the NWS.
- Complete updates to forecasters display of DTAs and decision tools and install within HWT for 2015 Spring Experiment. Status – Completed March 2015
- Selection of forecasters for 2015 HWT. Status – Completed March 2015
- Create training module on lightning products and DTAs that may be utilized for future NWS-wide field implementation. Status – Completed April 2015
- Forecaster evaluation of updated displays and products during real time Spring Experiment of the HWT Status – Completed June 2015.

Improve Availability and Accessibility of NWS Data and Information for NOAA Weather Radio

Principal Investigator: **Randy Peppler** (CIMMS at OU)
NOAA Award: **NA14NWS4830053**
NOAA Sponsor: **Jim Poole**
NOAA Sponsoring Organization: **NWS Training Center**
Reporting Period: **April-June 2015**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Objectives

Develop and train materials related to the NWR/BMH implementation using AWIPS-II.

Accomplishments

The NWS Training Center was tasked with development of two types of BMH training. A residence course, focusing on system configuration, will be held at the National Weather Service Training Center (NWSTC) the week of 24 August 2015. Two weeks prior, the online course for BMH users will be available in the NWS Learning Center. These training efforts will focus on the six sites involved in the Operational Testing and Evaluation (OT&E) period. The OT&E training components will help build a foundation towards deployment training, which will be completed January 2016.

CIMMS scientist Sarah Grana developed residence and distance learning course materials, as well as created job sheets. She has significant proficiency with the BMH system and serves as the on-site technical lead. Sarah provided overall consultation through the project. CIMMS Megan Taylor reviewed the lesson plan for the distance learning course, created online media, web interactions, and the online course web pages. She also consulted on the appearance of other components. Since April, the CIMMS scientists at NWSTC in conjunction with two NWSTC staff members have completed and published the OT&E distance-learning course. In addition, the OT&E residence course materials are completed, pending updates from NWS Headquarters.

Finally, the NWSTC, in conjunction with NWS Headquarters, is preparing for hardware and software installations by the end of July 2015.

Improving the Application of Ground-Clutter Filters in the WSR-88D Using Polarimetric Data

Principal Investigators: **David Warde and Sebastian Torres** (CIMMS at NSSL)
NOAA Award: **NA14NWS4830054**
NOAA Sponsor: **Mike Istok**
NOAA Sponsoring Organization: **NWS Office of Science and Technology**
Reporting Period: **April-June 2015**
Related NOAA Strategic Goal: **Weather-Ready Nation**

Objectives

Develop a scheme to improve the application of ground-clutter filters in the WSR-88D signal processor. The scheme to be developed, Weather Environment Thresholding (WET), is based on the premise that ground clutter returns significantly bias polarimetric-variable estimates at contaminated range gates.

General Project Overview

The nationwide network of WSR-88D radars has been successfully upgraded to dual polarization. These radars now provide a tremendous amount of new information that can be efficiently used for better weather warnings and forecasts in areas prone to natural disasters including coastal regions affected by landfall hurricanes. Research associated with this project contributes toward realizing the many benefits of this significant technological investment. High-quality polarimetric data is imperative for downstream applications such as quantitative precipitation estimates (QPE) and the assimilation into numerical weather models. Work was done towards the development and transfer ground-clutter mitigation improvements to the operational WSR-88D, thus ultimately providing improved polarimetric data to all data consumers. The WSR-88D fleet continues to have data-quality issues associated to ground-clutter contamination. If not effectively mitigated; clutter contaminants can artificially inflate/deflate QPE and can obscure Doppler-velocity signatures of weather. The goal of an effective ground- clutter mitigation scheme is to eliminate contamination from ground-clutter returns while also providing unbiased meteorological estimates. The key to achieving this and to better control the application of ground-clutter filters is to have the capability to recognize the presence and degree of ground-clutter contamination in real-time, which can be realized through the use of polarimetric information.

Accomplishments

Using the unique capability of dual-polarization information to identify weather-dominated regions, we developed the WET algorithm. The combination of WET and CLEAN-AP was shown to improve ground-clutter mitigation using data from a stratiform snow event captured with operational WSR-88D radar. Because these preliminary results are promising, the WET algorithm will be tested in other weather environments using operational WSR-88D data.