Cooperative Institute for Mesoscale Meteorological Studies

Annual Report
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Cover figure – “The WSR-88D Dual Polarization Guide” is an example of the outreach materials CIMMS staff at the Warning Decision Training Branch have developed to assist National Weather Service partners in the integration of dual-polarization radar data into their regular work flow. More on this project can be found on pp. 59-60.
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INTRODUCTION

General Description of CIMMS and its Core Activities

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

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

CIMMS research contributes to the NOAA mission through improvement of the observation, analysis, understanding, and prediction of weather elements and systems and climate anomalies ranging in size from cloud nuclei to multi-state areas. Advances in observational and analytical techniques lead to improved understanding of the evolution and structure of these phenomena. Understanding provides the foundation for more accurate prediction of hazardous weather and anomalous regional climate. Better prediction contributes to improved social and economic welfare. Because small-, meso-, and regional-scale phenomena are also important causes and manifestations of climate, CIMMS research is contributing to improved understanding of the global climate system and regional climate variability and change. CIMMS promotes research collaboration between scientists at OU and NOAA by providing a center where government and academic scientists may work together to learn about and apply their knowledge of mesoscale weather and regional-scale climate processes.
CIMMS is part of the National Weather Center, a unique confederation of federal, state, and OU organizations that work together in partnership to improve understanding of the Earth's atmosphere. Recognized for its collective expertise in severe weather, many of the research and development activities of the Center have served society by improving weather observing and forecasting, and thus have contributed to reductions in loss of life and property.

In addition to CIMMS, National Weather Center organizations include:

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

CIMMS, under the extension agreement, concentrated its research and outreach efforts and resources on the following principal themes: (1) basic convective and mesoscale research, (2) forecast improvements, (3) climatic effects of/controls on mesoscale processes, (4) socioeconomic impacts of mesoscale weather systems and regional-scale climate variations, (5) Doppler weather radar research and development, and (6) climate change monitoring and detection.

This report describes NOAA-funded research and outreach progress made by CIMMS scientists at OU and those assigned to our collaborating NOAA units under the extension agreement NA08OAR4320904 during 1 July 2011 through 30 June 2012. NOAA-funded projects are explicitly identified in project titles. Publications written, awards received, and employee and funding statistics are presented in Appendices.

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

A Memorandum of Understanding between NOAA and OU, last signed in 1995, defined CIMMS organizationally pre-competition. A Council and an Assembly of Fellows governed CIMMS pre-competition. The NOAA Science Advisory Board conducted the most recent review of CIMMS in October 2003. When the NOAA Science Advisory Board took over the responsibility of reviewing CIMMS, the CIMMS Advisory Board ceased to exist. NOAA conducted a nationwide competition of CIMMS in November 2010. OU successfully retained CIMMS and a new Cooperative Agreement took effect on 1 October 2011 for several of its projects.
The CIMMS Council met quarterly to provide advice and recommendations to the Director of CIMMS regarding appointments, procedures, and policies; to review and adopt bylaws; and to periodically review the accomplishments and progress of the technical and scientific programs and projects of the CIMMS.

The Assembly of Fellows met as needed and was 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 to the Fellows, by the CIMMS Council, was normally for a two-year term, and reappointment was possible. Appointments were made for a shorter period of time or on a part-time basis with the concurrence of the appointee and the CIMMS Council. The Fellows reviewed and suggested modifications of bylaws, participated in reviews of CIMMS activities, and elected two of their number to serve on the Council. The Council appointed Fellows.

The Mission and Vision Statements of CIMMS are as follows:

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

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

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

*Executive Summary Listing of Activities during FY2012 Under the Extension Agreement*

**Basic Convective and Mesoscale Research**

The primary goals of this original CIMMS thematic area are to understand cloud and mesoscale dynamics, microphysics and the precipitation process and their relationships to large and small scale forcing, and to develop procedures for assimilation of meteorological data into simulation and prediction models of these processes. The work done here represents a fundamental building block for eventual applied techniques.
During the past year, research was conducted on:

**NSSL Project 3 – Numerical Modeling and Data Assimilation**
- Influence of Mesonet Observations on the Accuracy of Surface Analyses
- Assessment of Operational Forecasts of Heavy Precipitation in the Northern Sierra Nevada Mountains
- A Comparison of Mesoscale Analysis Systems used for Severe Weather Forecasting
- Ensemble Kalman Filter Analyses and Forecasts of a Severe Mesoscale Convective System Observed during BAMEX
- The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes
- The Analyses and Prediction of a Supercell Storm from Assimilating Radar and Satellite Observations using Ensemble Kalman Filter
- Mesoscale Assimilation of Temperature and Humidity Profiles from AIRS Data
- Convective Scale Assimilation of GOES Cloud Property Retrievals
- Mesoscale Assimilation of Simulated Radar Data and Satellite Radiances
- Development and Testing of Forecast Verification/Diagnostics for Warn-on-Forecast and Hazardous Weather Testbed Applications
- Total Lightning Data Assimilation Within the WRF Framework

**NSSL Project 4 – Hydrologic Modeling Research**
- FLASH Demonstration
- Evaluation of Flash Flood Guidance in the United States
- Compare Skill of Coupled Model System Outputs to Operational Forecast Products and Water Level Observations

**Forecast Improvements**

The primary goal of this original thematic area is to accelerate the transfer of research knowledge and skills between the academic and NOAA operational mesoscale meteorological communities to both improve the design and utilization of mesoscale weather observing systems and improve mesoscale weather prediction and warning.

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

**NSSL Project 7 – Synoptic, Mesoscale and Stormscale Processes Associated with Hazardous Weather**
- The Identification of Modeled Thunderstorms Using Object-Based Approaches: Environments and Severe Characteristics
- Real-time 3DVAR Data Assimilation and Forecaster Evaluation for Use in Warning Decisions in the Hazardous Weather Testbed
- Explicit Forecast of Lightning Threats Within the WRF Model Framework
- Storm Tracking and Lightning Cell Clustering Using Geostationary Lightning
Mapping Data for Data Assimilation and Forecast Applications

- The Dependence of QPF on the Choice of Microphysical Parameterization for Lake-Effect Snowstorms
- The Ewiem Nimdie Summer School Series in Ghana

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

- GOES-R Proving Ground
- Verification of Stormscale Ensemble Forecasts and High-Resolution Models
- Social and Behavioral Influences on Weather Driven Decisions
- Forecaster Understanding of Uncertainty

**WDTB Project 12 – Warning Decision-Making Research and Training**

- Advanced Weather Interactive Processing System-2 (AWIPS-2)
- Advanced Warning Operations Course (AWOC)
- Communicating Risks in High-Impact Events
- Distance Learning Operations Course (DLOC)
- Dual-Polarization Radar Training
- Dual-Polarization Radar Outreach and Training for NWS Partners
- Hazardous Weather Testbed: The 2012 Spring Program Participation
- Integrated Warning Team Training
- Radar Data Acquisition Unit (RDA) & Radar Product Generator (RPG) Build Training
- Recognizing High Impact Hydro Events
- Training & Research Toolkit
- Weather Event Simulator-1 (WES-1)
- Weather Event Simulator-2 (WES-2)

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

- Provide Training for the Community Hydrologic Prediction System (CHPS) Adopted by the River Forecast Centers of the National Weather Service

**CIMMS Task III Projects**

- National Sea Grant Climate/Weather Extension Specialist
- Weather Processors Support Task: Right-Sizing NextGen Weather Observation Network
- Improving NOAA Operational Global Numerical Weather Prediction using a Hybrid Variational-Ensemble Kalman Filter Data Assimilation and Ensemble Forecasting System
- Development of Short-Range Realtime 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 CAPS
• Advanced Data Assimilation and Prediction Research for Convective-Scale “Warn-on-Forecast”

**Climatic Effects of/Controls on Mesoscale Processes**

The primary goal of this thematic area is to extend and apply the understanding of mesoscale processes to the problem of climate maintenance and change. This theme also includes investigation of the influence of the large-scale climatic environment on the mesoscale systems that produce growing season rainfall in regions such as central North America and Sub-Saharan Africa.

During the past year, research was conducted on:

**CIMMS Task I Projects**
- Investigation of Large-Scale Atmospheric Moisture Budget and Land Surface Interactions over U.S. Southern Great Plains including for CLASIC (June 2007)
- Weathering the Drought: Building Resilience in the Face of Global Environmental Change

**Socioeconomic Impacts of Mesoscale Weather Systems and Regional Scale Climate Variations**

The primary goal of this thematic area is to estimate the socioeconomic impacts and values of mesoscale weather systems and regional-scale climate variations in central and eastern North America and across the world, to facilitate the mitigation (enhancement) of the adverse (beneficial) impacts. A continuing component of this work makes extensive use of climate scenarios and economic models, and is performed in collaboration with agricultural economists and social scientists. It is also complemented by a research thrust that is addressing a spectrum of weather- and climate-related disaster issues.

During the past year, research was conducted on:

**NSSL Project 8 – Warning Process Evolution and Effective Communication to the Public**
- Ensemble Severe Weather Data Mining
- Evaluating the Efficacy of Call-to-Action and Information Statements
- 24 May 2011 Sheltering Study

**CIMMS Task III Projects**
- Southern Climate Impacts Planning Program (SCIPP)
- RISA Support for Regional Assessment Services at the Southern Climate Impacts Planning Program (SCIPP)
- Warn-on-Forecast and the Social Science Woven into Meteorology (SSWIM) Project
Doppler Weather Radar Research and Development

The primary goal of this thematic area is to accelerate the transfer of knowledge between the meteorological and engineering communities (in academia, and government and private laboratories) to improve the design, usability, and supportability of the NEXRAD WSR-88D Doppler weather radar. Continual enhancements are needed to the system for improving the quality, format, accuracy, resolution, and update rate of the base data, and to keep pace with evolving hardware and software technologies. This work introduces, examines, and analyzes present and future technologies, including phased-array technology, with the goal of meeting the unfulfilled radar needs. This theme also includes a fertile research area for development and improvement of radar algorithms used for forecasting and warning.

During the past year, research was conducted on:

**NSSL Project 1 – Advancements in Weather Radar**
- WSR-88D Improvements
  - Ground Clutter Mitigation
  - Range-and-Velocity Ambiguity Mitigation
  - Coherency-Based Thresholding
  - Noise-Power Estimation
  - Range Oversampling Techniques
  - Floating Radar Product Generation for Display in the AWIPS-2 Environment
- Dual-Polarization Research
  - Validation of Polarimetric Rainfall Measurements Made by Operational WSR-88D Radars
  - Development of the New Polarimetric QPE Algorithm Based on Specific Attenuation
  - Improving Classification of Winter Precipitation Type by Combining Polarimetric Radar Data with Thermodynamic Output from Numerical Prediction Models
  - Validation of a New Winter Surface Hydrometeor Algorithm Using SHAVE and W-PING
  - Investigation of Polarimetric Signatures in Winter Storms
  - Hail Size Discrimination Using Polarimetric WSR-88D Radars
  - Polarimetric Radar Analysis of Severe Convective Storms
  - Investigating Microphysical Processes in Clouds and Precipitation with Explicit Modeling and Polarimetric Radar Data
  - Dual-Polarization QPE Evaluation
  - Improvement of Specific Differential Phase (Kdp)
  - Extending the Capabilities of the Polarimetric WSR-88D Radars
• Phased Array Radar
  • NWRT PAR Multi-Channel Receiver Experiments
  • National Weather Radar Testbed Phased Array Radar Software Upgrades
    o Adaptive Pedestal Control Algorithm
    o Surveillance Scan Capabilities
    o Adaptive Scan Control Infrastructure
    o Real-Time Controller Improvements
    o Distributed Computing Infrastructure Improvements
    o Testing

• Radar Data Management
• Weather Radar Applications Research and Development
  • Rotation Tracks: An Automated Method for Depicting Mesocyclone Paths and Intensities
  • Precipitation Nowcasting
  • Hail Climatology
  • Range-Correction of Azimuthal Shear
  • Tuning AutoNowCaster
  • Incorporating Dual-Pol Algorithms and Processing into WDSS-II
  • Developing a Virtual Globe Display of Weather Information
  • Development and Application of a Satellite-Based Convective Cloud Object Tracking Methodology
  • Multi-Function Phased Array Radar Display and Playback in AWIPS-2

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

CIMMS Task III Projects
• Next Generation Phased Array Technology for Multi-Mission Operations and Advanced Weather Sensing Using Phased Array Technology
  • An Optimized Pulse Compression Waveform for High-Sensitivity Weather Radar Observations
  • Performance Requirements for a Future MPAR System
  • Multi-Function Resource Management
  • Assessing the Impacts of Scanning of Strategies on the Characterization of Storm Processes and Rapidly Evolving Weather Systems
  • Spaceborne QPE (TRMM/GPM) and Implications for MPAR Resource Allocation: Create Synergy between Ground- and Space-Based Weather Radar Precipitation Measurements
  • A Test of Cylindrical Polarimetric Array Configuration Using the Digital Array Radar
  • Calibration for Polarimetric Phased Array Radar
  • Innovative Beam-Steering Reflectarray Antennas
  • Polarimetric Phased Array Weather Radar
  • Development of a Demonstrator CPPAR
• Wind Turbine Radar Clutter Modeling and Adaptive Mitigation Incorporating Laboratory Measurements
• Advanced Detection and Mitigation of Wind Turbine Clutter for the Multi-Mission Phased Array Radar (MPAR) Program

**Climate Change Monitoring and Detection**

The goal of this research theme is to study climate change monitoring and detection in general, and specifically the homogeneity or lack thereof of the historical station records in the U.S. and to use this information to help address the climate change questions.

During the past year, research was conducted on:

**CIMMS Task III Projects**
• Program Support for the Assimilation, Analysis and Dissemination of Pacific Rain Gauge Data: PACRAIN

**Public Affairs and Outreach**

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

**NOAA Weather Partners Outreach**
• Public Outreach
• Communications Outreach

**WDTB Outreach Activities of CIMMS Staff**

**Awards and Honors**

The following awards and honors were bestowed in the past fiscal year:

• **Adam Clark (CIMMS at NSSL)** received an Editor’s Award for the American Meteorological Society journal *Weather and Forecasting*

• **Stephanie Hoekstra (SSWIM at OU)** received an award from the Department of Geography and Environmental Sustainability for Outstanding Publication of the Year, 2012

• **Stephanie Hoekstra and Amy Nichols (both SSWIM at OU)** received the award of Outstanding Presentation at the Student Competition of the 92nd American Meteorological Society Annual Meeting in New Orleans, Louisiana, January 2012

• **Xuguang Wang (OU School of Meteorology)** received the 2012 College of Atmospheric & Geographic Sciences Dean's Award for Excellence in Research and Scholarship
• The oral presentation “Development of Simple Radar Signature Models of Wind Turbine for Knowledge-Aided Wind Turbine Radar Interference Analysis” by Ying Bai, Fanxing Kong, Yan Zhang, and Robert Palmer (all ARRC at OU) was given the Award of Commendable Oral Presentation at the Student Competition of the American Meteorological Society's 92nd Annual Meeting in New Orleans, Louisiana, January 2012

• The oral presentation “Wind Turbine Clutter Mitigation for Weather Radar by Adaptive Processing” by Fanxing Kong, Robert Palmer, Yan Zhang, and Ying Bai (all ARRC at OU) was awarded Second Place in the Engineering category at the Student Research Performance Day, University of Oklahoma, March 2012

• CIMMS Scientists at NSSL Valliappa Lakshmanan (Leader), Jeffrey Brogden, Kimberly Elmore, Charles Kerr, Travis Smith, Lulin Song, Gregory Stumpf, Robert Toomey, and Thomas Vaughan, along with NSSL Scientists Kurt Hondl, Robert Rabin, and Jian Zhang, received the 2012 Innovator Award from the OU Office of Technology Development. The citation includes the following statement: This groundbreaking (WDSS-II) software is used worldwide to help predict weather phenomena including hail, precipitation, mesocyclones, and tornadoes. Used by private companies, research labs, National and International governments across the globe, this technology provides users across the world with the information needed to make property and life-saving decisions in the event of hazardous weather.

• CIMMS Scientists at NSSL Carrie Langston, Ami Arthur, Brian Kaney, Heather Moser, and Youcun Ci, along with NSSL Scientists Kenneth Howard, Jian Zhang, J.J. Gourley, and Steven Vasiloff, were awarded the 2011 U.S. Department of Commerce Bronze Medal “for the design and implementation of a seamless gridded system for multi-sensor-derived precipitation estimation over the continental U.S.”
Distribution of NOAA Funding by CIMMS Task and by Research Theme

NOAA Funding by Task FY12

Task I: $333,116, 3%
Task III: $2,384,877, 26%
Task II: $6,824,297, 77%

NOAA Funding by Theme FY12

Theme 5: 45%
Theme 4: 2%
Theme 2: 3%
Theme 6: 3%
Theme 1: <50%
CIMMS Council and Fellows Membership and Meeting Dates

No meetings were held during the part of the fiscal year that included the competition of CIMMS. Two Council (now called the Executive Board) meetings were held after the institution of the new Cooperative Agreement, on 26 October 2011 and 21 May 2012. No Assembly of Fellows meetings took place.

CIMMS Council membership during FY2012 was:

- Dr. Peter Lamb (Chair), George Lynn Cross Research Professor of Meteorology, OU, and Director, CIMMS
- Dr. Robert Palmer, Professor and Tommy C. Craighead Chair, School of Meteorology, OU, and Director, Atmospheric Radar Research Center (ARRC), OU (Provost designated)
- Dr. Jerry Crain, Professor and Director, School of Electrical and Computer Engineering, OU (Provost designated)
- Dr. Baxter Vieux, Presidential Professor of Civil Engineering and Environmental Sciences, OU (Provost designated)
- Dr. David Stensrud, Chief, Forecast Research and Development Division, NSSL, and Affiliate Professor of Meteorology, OU (OAR designated)
- Mr. Kevin Kelleher, Deputy Director, NSSL (OAR designated)
- Dr. Russ Schneider, Director, SPC (NWS designated)
- Mr. Richard Murnan, Radar Operations Center Applications Branch (NWS designated)
- Dr. Michael Biggerstaff, Associate Professor of Meteorology, OU (Elected from CIMMS Assembly of Fellows)
- Mr. Doug Forsyth, Chief, Radar Research & Development Division, NSSL (Elected from CIMMS Assembly of Fellows)
- Dr. Steven Koch, Director, NSSL (ex-officio member)
- Mr. Ed Mahoney, Director, WDTB (ex-officio member)
- Mr. Richard Vogt, Director, ROC (ex-officio member)
- Mr. Mike Foster, Meteorologist-in-Charge, Norman NWS WFO (ex-officio member)
- Dr. Tom Karl, Director, NCDC (ex officio member)
- Dr. David Parsons, Director, OU School of Meteorology, Mark and Kandi McCasland Professor of Meteorology (ex-officio member)
- Dr. Berrien Moore III, Dean, OU College of Atmospheric and Geographic Sciences, OU Vice President for Weather and Climate Programs, Director of National Weather Center, and Chesapeake Energy Professor of Meteorology (ex-officio member)

Assembly of Fellows membership for 16 August 2009 through 15 August 2011 was (Fellows membership for the period beyond 15 August 2011 is pending approval by the OU Provost):

- Dr. Jeffrey B. Basara, Director of Research, OCS, and Adjunct Associate Professor of Meteorology, OU
- Dr. William H. Beasley, Professor of Meteorology, OU
- Dr. Michael I. Biggerstaff, Associate Professor of Meteorology, OU
- Dr. Howard B. Bluestein, George Lynn Cross Research Professor of Meteorology, OU
- Dr. Keith Brewster, Senior Scientist and Associate Director, CAPS, OU
- Dr. Harold E. Brooks, Research Meteorologist and Team Leader, Mesoscale Applications Group, NSSL, and Adjunct Professor of Meteorology, OU
- Dr. Frederick H. Carr, McCasland Chair Professor of Meteorology and Director, School of Meteorology, OU, and Associate Director, CAPS
- Dr. Phillip Chilson, Associate Professor of Meteorology, OU
- Dr. Michael Coniglio, Research Scientist, NSSL
- Dr. Gerald E. Crain, Professor of Electrical and Computer Engineering, OU
- Dr. Kenneth C. Crawford, Regents’ Emeritus Professor of Meteorology, OU
- Dr. Timothy D. Crum, NWS Radar Focal Point, ROC
- Dr. Michael W. Douglas, Research Meteorologist, Mesoscale Applications Group and Models and Assimilation Team, NSSL
- Dr. Richard J. Doviak, Senior Engineer, Doppler Radar and Remote Sensing Research Group, NSSL, and Affiliate Professor of Meteorology and of Electrical and Computer Engineering, OU
Dr. Kelvin K. Droegemeier, Vice President for Research and Regents’ Professor, OU
Dr. Claude E. Duchon, Emeritus Professor of Meteorology, OU
Dr. Imke Durre, Scientist, NCDC
Dr. David R. Easterling, Scientist, NCDC
Dr. Evegeni Fedorovich, Professor of Meteorology, OU
Mr. Douglas E. Forsyth, Chief, Radar Research & Development Division, NSSL
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, Meteorologist, NSSL
Mr. Michael Jain, Team Leader, Software Engineering and Technology Improvement, NSSL
Dr. David P. Jorgensen, Chief, Warning Research & Development Division, NSSL
Dr. David Karoly, Federation Fellow, University of Melbourne, Australia, and Affiliated Professor of Meteorology, OU
Dr. Petra Klein, Associate Professor of Meteorology, OU
Mr. Kevin E. Kelleher, Deputy Director, NSSL
Dr. James F. Kimpel, Director, Emeritus NSSL, and Emeritus Professor of Meteorology, OU
Mr. Paul Kirkwood, Scientist, NWS Southern Region Headquarters
Dr. Kevin Kloesel, Associate Director, College of Atmospheric and Geographic Sciences; Associate Professor, OU School of Meteorology; and Interim Director, Oklahoma Climatological Survey (OCS), OU
Dr. S. Lakshminarahan, 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, CIMMS Resident Fellow, and Affiliate Professor of Meteorology and of Physics and Astronomy, OU
Mr. Ed Mahoney, Chief, WDTB
Dr. Edward Mansell, Research Scientist, NSSL
Dr. Renee McPherson, Associate Director, Oklahoma Climatological Survey, and Adjunct Associate Professor of Meteorology, OU
Dr. James W. Mjelde, Professor of Agricultural Economics, Texas A&M University
Dr. Mark L. Morrissey, Professor of Meteorology, OU
Dr. Robert D. Palmer, Tommy Craighead Chair and Professor of Meteorology, OU, and Director, ARRC
Dr. Ramkumar Parthasarathy, Associate Professor of Aerospace and Mechanical Engineering, OU
Dr. Thomas C. Peterson, Scientist, NCDC
Dr. Robert Rabin, Research Scientist, NSSL
Mr. John R. Reed, Chief, Radar Engineering Branch, ROC
Dr. Michael B. Richman, E. K. Gaylord Presidential Professor of Meteorology, OU
Dr. W. David Rust, Director, Field Observing Facilities and Services, NSSL, and Affiliate Professor of Meteorology and of Physics and Astronomy, OU
Dr. Russell Schneider, Director, SPC
Dr. David Schultz, Professor of Experimental Meteorology, University of Helsinki, Finland
Dr. Alan M. Shapiro, American Airlines Professor of Meteorology, OU
Dr. James Sluss, Morris R. Pitman Professor and Director, School of Electrical and Computer Engineering, OU
Dr. John T. Snow, Dean, College of Atmospheric and Geographic Sciences, and Professor of Meteorology, OU
Dr. David J. Stensrud, Chief, Forecast Research & Development Division, NSSL, and Affiliate Professor of Meteorology, OU
Dr. Jerry M. Straka, Professor of Meteorology, OU
Dr. Aondover A. Tarhule, Chair and Associate Professor, Department of Geography and Environmental Sustainability, OU
Dr. Susan Van Cooten, Research Meteorologist, NSSL
Dr. Baxter E. Vieux, Brandt Professor and Presidential Professor of Civil Engineering and Environmental Sciences, and Director, Center for Natural Hazards and Disaster Research, OU
Mr. Richard Vogt, Director, ROC
Dr. Xuguang Wang, Assistant Professor of Meteorology, OU
Dr. Louis J. Wicker, Research Meteorologist, Convective Weather Research Group, NSSL, and Affiliate Associate Professor of Meteorology, OU
Dr. Qin Xu, Research Meteorologist, Models and Assimilation Team, NSSL, and Affiliate Professor of Meteorology, OU
Dr. Ming Xue, Director, CAPS, and Professor of Meteorology, OU
• Dr. Mark Yeary, Associate Professor of Electrical and Computer Engineering, OU
• Dr. Tian-You Yu, Associate Professor of Electrical and Computer Engineering, OU
• Dr. May Yuan, Brandt Professor and Edith Kinney Gaylord Presidential Professor of Geoinformatics, and Director, Center for Spatial Analysis, OU
• Mr. Allen Zahrai, Team Leader, Radar Engineering and Development, NSSL
• Dr. Guifu Zhang, Associate Professor of Meteorology, OU
• Dr. Jian Zhang, Research Hydrometeorologist, NSSL
• Dr. Yan Zhang, Assistant Professor of Electrical and Computer Engineering, OU
• 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 Activities**
RESEARCH PERFORMANCE

Theme 1 – Basic Convective and Mesoscale Research

NSSSL Project 3 – Numerical Modeling and Data Assimilation

NOAA Technical Lead:  David Stensrud (NSSSL)

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

Funding Type:  CIMMS Task II

1. Influence of Mesonet Observations on the Accuracy of Surface Analyses

David Stensrud (NSSSL), Kent Knopfmeier (CIMMS at NSSSL)

Objectives

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

Accomplishments

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

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

A manuscript titled “Influence of Mesonet Observations on the Accuracy of Surface Analyses” has been submitted to Weather and Forecasting with authors Knopfmeier and Stensrud, and is currently under review.
2-m dewpoint temperature (°F; see label bar) and 10-m winds valid at 0000 UTC 11 May 2010 from the a) EnKF posterior ensemble-mean analysis and the b) RTMA.
2. Assessment of Operational Forecasts of Heavy Precipitation in the Northern Sierra Nevada Mountains

Heather Reeves (CIMMS at NSSL)

Objectives
Understand the types and causes of errors in operational forecasts of heavy orographic precipitation events.

Accomplishments
In this project, the errors and their sources in operational numerical forecasts of heavy precipitation events along the northern Sierra Nevada Mountains are considered. A six-year climatology of heavy precipitation events is performed. Events are partitioned into two groups: heavy precipitators and extreme precipitators. It is found that despite having a more dynamical environment that is usually well-captured by numerical models, the extreme precipitators have a pronounced dry bias, sometimes underestimating precipitation accumulations by up to 30%. This dry bias is due to an underestimate of humidity incident to the south end of the range. Further inspection shows that this underestimate occurs during the assimilation phase of the model integration. This research was partly conducted for an undergraduate thesis by Ms. Rebekah Banas (Central Michigan University) and was recently presented at the AMS Conference on Mountain Meteorology (20-24 August 2012).

Composites of the 24-h accumulated precipitation from the (a,e) AHPS estimates and (b-d, f-h) NAM forecasts with varying lead times.
3. A Comparison of Mesoscale Analysis Systems used for Severe Weather Forecasting

Dustan Wheatley (CIMMS at NSSL), Michael Coniglio (NSSL)

Objectives
Investigate the potential use of a WRF mesoscale data assimilation system in operational severe storms forecasting.

Accomplishments
This work compares the relative performance of several mesoscale analysis systems with applications to severe weather forecasting by exploring the ability of each to reproduce atmospheric soundings collected during the Verification of the Origins of Rotation in Tornadoes Experiment 2 (VORTEX2). This study added to recently completed work (see listed publication) that also considered the potential use of mesoscale ensemble products in the operational setting.

Model soundings corresponding to the release times and locations of observed sounding were extracted from data sets generated from a mesoscale ensemble forecast system (developed, in part, at NSSL) that uses the Weather Research and Forecasting (WRF model) as its foundation, from the Rapid Update Cycle (RUC) model, and from an hourly product of the SPC, which merges all available surface data with the latest Rapid Update Cycle (RUC) forecast/analysis of upper-air data to create a 3-dimensional description of the current state of the atmosphere. In assessing the performance of each system, environmental characteristics (e.g., CAPE and shear) are examined, as well as other sounding parameters (such as boundary-layer depth and lifting condensation level). Preliminary results show that the mesoscale ensemble forecasts, in many cases, produce smaller errors than the other mesoscale analyses, when calculating such base-state quantities as 2-m surface temperature and dewpoint, as well as sounding parameters.

Early work on this project supported the activities of one undergraduate student (Rebecca Steeves, North Carolina State University), as part of the Research Experiences for Undergraduates (REU) program at the National Weather Center.

Publications
Box plot representation of planetary boundary layer (PBL) height errors (forecast minus observation) calculated from WRF ensemble analyses (WRF00), 1-h WRF ensemble forecasts (WRF01), RUC analyses (RUC01), 1-h RUC forecasts (RUC01), and the SFCOA. The boxes encompass data points between the 25th and 75th percentiles, with the median represented by the horizontal line inside the box. Note that the ends of the whiskers extend only to the 10th and 90th percentiles to diminish the impact of outliers. Filled and open circles show the root mean square difference and mean difference (bias), respectively, between the forecasts and observations.

4. Ensemble Kalman Filter Analyses and Forecasts of a Severe Mesoscale Convective System Observed during BAMEX

Dustan Wheatley (CIMMS at NSSL), Nusrat Yussouf (CIMMS at NSSL), Michael Coniglio (NSSL), David Stensrud (NSSL)

Objectives
Expand upon previous work with a storm-scale ensemble Kalman filter (EnKF), which has been more focused on isolated supercell thunderstorms, by considering any issues that may be unique to meso-convective organization.

Accomplishments
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 and contributed to significant flooding across central Indiana. Single-Doppler observations are assimilated into a 50-member, storm-scale ensemble during the developing stage of the MCS with the ensemble Kalman filter (EnKF) approach encoded in the Data Assimilation Research Testbed (DART). The storm-scale ensemble is constructed from mesoscale EnKF analyses produced from the assimilation of routinely available observations from land and marine stations, rawinsondes, and aircraft, in an attempt to better represent the complex mesoscale environment for this event.

Given the particular sensitivity of the studied system to prior convection (and remnant cold pools), preliminary work has evaluated the impact on EnKF analyses/forecasts of assimilating research quality data—in addition to conventional meteorological observations—from dropsondes and temporally high-resolution surface meteorological sites. In each experiment, the temperature characteristics of simulated cold pools are compared to available observations in order to assess the accuracy of thermodynamic retrievals by the EnKF.

Ensemble mean radar reflectivity (dBZ), 2-m temperature (°C), and 10-m winds at 2300 UTC 4 July 2003, from an experiment that assimilates only radar data (left panel) and another that assimilates both radar and surface data (right panel). The solid dots indicate the difference between observed and ensemble mean 2-m temperature values at available observation locations. Color bars indicate radar reflectivity and 2-m temperature values. Full wind barb is 10 m s⁻¹.
5. The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes

Nusrat Yussouf (CIMMS at NSSL), Ted Mansell (NSSL), Lou Wicker (NSSL), Dustan Wheatley (CIMMS at NSSL), David Stensrud (NSSL)

Objectives
Quantify the impact of assimilating Doppler radar observations on the analyses and prediction of a tornadic supercell thunderstorm, using ensemble Kalman filter (EnKF) data assimilation technique and three different microphysics parameterization schemes.

Accomplishments
A combined mesoscale and storm-scale ensemble data assimilation and prediction system is developed using the Advanced Research Weather Research and Forecasting (WRF-ARW) model and the ensemble adjustment Kalman filter (EAKF) from the Data Assimilation Research Testbed (DART) software for a very short-range ensemble forecast of the 8 May 2003 Oklahoma City tornadic supercell storm. Traditional atmospheric observations are assimilated into a 45-member mesoscale ensemble over a continental U.S. domain at 18 km horizontal grid resolution starting three days prior to the event. A one-way nested 45-member storm-scale ensemble is initialized at 2-km horizontal grid spacing centered on the tornadic event at 2100 UTC on the day of the event. Three radar observation assimilation and forecasts experiments are conducted at storm-scale using a single moment (NFD_SM), a semi-double moment (Thompson) and a full double moment (NVD_DM) bulk microphysics parameterization schemes.

Results indicate that the EAKF initializes the supercell storm into the model with good accuracy after 1-hr long radar observation assimilation window. The ensemble forecasts capture the movement of the main supercell storm, as well as the establishment of a hook echo that matches reasonably well with radar observations. The reflectivity structure of the supercell storm using a double moment microphysics scheme appears to compare better to the observations than that using a single moment scheme. In addition, the ensemble system predicts the probability of the strong low level vorticity track of the tornadic supercell that correlates well with the observed damage track. The rapid 3-min update cycle of the storm-scale ensemble from the radar observations seems to enhance the skill of the ensemble and confidence of the imminent tornado threat. The encouraging results obtained from this study show promise for a short-range probabilistic storm-scale forecast of supercell thunderstorms, which is the main goal of NOAA’s Warn-on-Forecast initiative.

A manuscript entitled “The Ensemble Kalman Filter Analyses and Forecasts of the 8 May 2003 Oklahoma City Tornadic Supercell Storm using Single and Double Moment Microphysics Schemes” was submitted to Monthly Weather Review with authors Yussouf, Mansell, Wicker, Wheatley and Stensrud, and is currently under review.
Neighborhood ensemble probability of vorticity forecasts for the NVD-DM and Thompson experiments exceeding a threshold of 0.003 s$^{-1}$ at 150 m (0.15 km) AGL (1st and 2nd columns) and 0.006 s$^{-1}$ at 1 km AGL (3rd and 4th columns). The forecasts are integrated out to 2300 UTC and are generated from rapid update analyses from 2145 UTC to 2227 UTC. Overlaid in each panel is the NWS observed tornado damage track (black outline) that starts at 2210 UTC and ends at 2238 UTC.
6. The Analyses and Prediction of a Supercell Storm from Assimilating Radar and Satellite Observations using Ensemble Kalman Filter

Nusrat Yussouf (CIMMS at NSSL), Thomas Jones (CIMMS at NSSL)

Objectives
Explore the feasibility of assimilating GOES-East satellite-derived cloud liquid water path (CLWP) observations, in addition to WSR-88D radar observations into a high-resolution model for a very short-range forecasts of 8 May 2003 Oklahoma City tornadic supercell storm using ensemble Kalman filter (EnKF) data assimilation approach.

Accomplishments
This project uses a combined 45-member 18-km horizontal grid spacing mesoscale ensemble, and a 3-km horizontal grid spacing convective-scale ensemble utilizing the Weather Research and Forecasting model (WRF) and Data Assimilation Research Testbed (DART) Ensemble Adjusted Kalman Filter (EAKF) data assimilation scheme. The convective-scale ensemble is initialized from the mesoscale ensemble and four different data assimilation and forecast experiments are conducted at the convective-scale. The first experiment assimilates KTLX radar reflectivity and radial velocity observations (Radar_Only). The second experiment assimilates CLWP observations into the model (Satellite_Only). The third (Radar_Satellite) and fourth (Satellite_Radar) experiments assimilate both radar and satellite observations in two different combinations. One-hour forecasts at 1-min intervals are generated for each of those four experiments.

All experiment initiates a supercell by the end of the 1-hr assimilation window with unique reflectivity and near-storm environment characteristics. Except for the Satellite_Only experiment, all remaining three experiments maintains the supercell 30 minutes into the forecast. However, the Satellite_Radar experiment that assimilates both radar and satellite observations using initial conditions that have previous hour’s satellite data added improves the near storm environment in the analysis and produces the most realistic reflectivity and updraft helicity structures for most forecast times out to 1-hr. The results from the downward shortwave flux forecasts shows that adding satellite observations expands cloud coverage in the northeastern portion of the domain and sharpens the dry line gradient in congruence with observations. Therefore assimilating satellite observations in addition to radar into the convective-scale models may aid in severe weather forecasts.

Partial work from this project supported the activities of one NOAA Hollings Undergraduate Scholar (Matthew Vaughan, Embry-Riddle Aeronautical University) at the National Weather Center.
The reflectivity (color fill, 5 dBZ increment), wind vectors and vertical vorticity (contours from 0.001 to 0.01 at 0.001) at 1-km AGL for the four experiments (first four columns) from the ensemble member that is closest to the ensemble mean at the 2200 UTC analyses. The last analyses at 2200 UTC are shown in the first row and at every 15 min forecasts valid at 2215, 2230, 2245, and 2300 UTC in the 2nd, 3rd, 4th, and 5th row respectively. The last column is the KTLX observed low-level reflectivity closest to the model output time.
7. Mesoscale Assimilation of Temperature and Humidity Profiles from AIRS Data

Thomas Jones (CIMMS at NSSL), David Stensrud (NSSL)

Objectives
Analyze the impacts of assimilating satellite derived temperature and humidity profiles within mesoscale models using an Ensemble Kalman Filter approach.

Accomplishments
Assimilation of AIRS Level 2 temperature and humidity profiles into a U.S. domain WRF-ARW model was tested using a severe weather case study occurring on 10 May 2010. The profiles along with associated uncertainties are assimilated into WRF using an Ensemble Kalman Filter technique with up to 36 members. (Both single and multi-physics options have been tested). Since the AIRS instrument is on a polar orbiting satellite (Aqua), profiles are only available twice per day over any one location. Over the continental U.S. afternoon retrievals generally occur between 1700 and 2100 UTC.

Comparing simulated reflectivity forecasts at 2300 UTC (2 h forecast) from a model run with and without AIRS data with actual WSR-88D reflectivity from KTLX at the same time, we find a good agreement between forecast convection for both models, though there are several important differences as well. The locations of the 30% probability contours for ensemble mean reflectivity greater than 30 dBZ for the NO-AIRS forecast are slightly to the west of the observations, but show a similar spatial pattern otherwise (figure panel a below). However, the overall coverage is somewhat low compared to the reflectivity observations at this time. The AIRS simulated reflectivity forecast shows a similar spatial pattern, but with much higher probabilities associated with the line of convection in central OK (figure panel b below). The higher probabilities of reflectivity greater than 30 dBZ produced by the AIRS model is a result of higher forecast reflectivity values from the individual members as well as less spread in location and intensity of individual cells compared to the NO-AIRS model.

Publications
KTLX WSR-88D radar reflectivity (dBZ) at approximately 2.0 km (AGL) at 2300 UTC showing a line of supercells in central OK. Contours of simulated radar reflectivity probability greater than 30 dBZ over all ensemble members for the NO-AIRS (a) and AIRS (b) runs are overlaid. 50 km range rings from KTLX are shown for reference.

8. Convective Scale Assimilation of GOES Cloud Property Retrievals

Thomas Jones (CIMMS at NSSL), David Stensrud (NSSL), Patrick Minnis (NASA Langley)

Objectives
Study the impacts of assimilating high-resolution satellite derived cloud properties into storm-scale models.

Accomplishments
Assimilating satellite-retrieved cloud properties into storm-scale models has received limited attention despite its potential to provide a wide array of information to a model analysis. Available retrievals include cloud water path (CWP), which represents the amount of cloud water and cloud ice present in an integrated column, and cloud top and cloud base pressures, which represent the top and bottom pressure levels of the cloud layers, respectively. These interrelated data are assimilated into an Advanced Research Weather and Research Forecast (WRF-ARW) model 40-member ensemble with 3-km grid spacing using the Data Assimilation Research Testbed (DART) ensemble Kalman filter. A new CWP forward operator combines the satellite-derived cloud information with similar variables generated by WRF. This approach is tested using a severe weather event on 10 May 2010. One experiment only assimilates conventional (CONV) observations, while the second assimilates the identical conventional observations and the satellite-derived CWP (PATH).
Comparison of the CWP observations at 2045 UTC to CONV and PATH analyses show that PATH has an improved representation of both the magnitude and spatial orientation of CWP compared to CONV. Assimilating CWP acts both to suppress convection in the model where none is present in satellite data and to encourage convection where it is observed. Oklahoma Mesonet observations of downward shortwave flux at 2100 UTC indicate that PATH reduces the root-mean square difference errors in downward shortwave flux by 75 Wm\(^{-2}\) compared to CONV (see figure below). Reduction in model error is generally maximized during the initial 30 min forecast period with the impact of CWP observations decreasing for longer forecast times. A manuscript titled “Evaluation of a forward operator to assimilate cloud water path into WRF-DART” was submitted to *Monthly Weather Review* with authors Jones, Stensrud, Minnis and Palikonda, and is currently under review.

Contour plot of Mesonet SWF at 2100 UTC with corresponding Mesonet locations and wind barbs overlaid (white) with short barbs = 5 m s\(^{-1}\) and long barbs = 10 m s\(^{-1}\) (a). Posterior ensemble mean SWF generated from CONV (b) and PATH (c) at 2100 UTC with Mesonet values overlaid along with model wind barbs (black). The color contrast between Mesonet and model SWF indicates where differences are the greatest.
9. Mesoscale Assimilation of Simulated Radar Data and Satellite Radiances

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

Objectives
Determine the relative impacts of simulated radar and satellite data assimilation into a mesoscale model using a winter-weather event.

Accomplishments
An Observing System Simulation Experiment is used to examine the impact of assimilating water vapor sensitive satellite infrared brightness temperatures (TB) and Doppler radar reflectivity and radial velocity observations on the analysis accuracy of a cool season extratropical cyclone. Assimilation experiments are performed for four different combinations of satellite, radar, and conventional observations using an ensemble Kalman filter assimilation system. Comparison with the high-resolution “truth” simulation indicates that both satellite and radar data assimilation reduce the cloud errors compared to the case in which only conventional observations are assimilated. The satellite observations provided the most impact in the mid- to upper-troposphere, whereas the radar data also improve the cloud field near the surface and aloft due to their greater vertical resolution. Errors in the wind field are also significantly reduced when radar radial velocity observations were assimilated. Comparison of simulated 6.95 µm satellite brightness temperatures for each experiment with those from a truth analysis clear show that assimilating both satellite and radar data improves the representation of the cloud structures (see figure below). Overall, assimilating both satellite and radar data create the most accurate model analysis, which indicates that these observations provide independent and complimentary information and illustrates the potential for these data sets for improving mesoscale model analyses and ensuing forecasts.

A manuscript titled “Assimilation of satellite infrared radiances and Doppler radar observations during a cool season Observing System Simulation Experiment” was submitted to Monthly Weather Review with authors Jones, Otkins, Stensrud and Knopfmeier, and is currently under review.
Simulated GOES-R ABI 6.95 µm TB (K) for the Truth simulation and each experiment at 1200 UTC 24 December.

Adam Clark (CIMMS at NSSL)

Objectives
Development and testing of verification and forecast diagnostic methods that emphasize object-based time-domain approaches.

Accomplishments
Object-based (or feature-based) verification approaches involve defining objects as contiguous groups of points that satisfy some pre-defined criteria (e.g., simulated storms defined as a contiguous group of points with reflectivity ≥ 40 dBZ), and can provide much more meaningful information on forecast errors like displacement, orientation, and intensity, than traditional grid-point based techniques. Until recently, object-based approaches only considered 2-D spatial objects. However, for HWT/Warn-on-Forecast applications, important diagnostics like storm translation speed, duration, track length, and timing, require consideration of a third dimension: time. Thus, objectives for this research include developing object-based time-domain diagnostics (i.e., objects defined as contiguous groups of points in space and time).

A strong relationship (correlation coefficients as high as 0.86) between the total path lengths of simulated rotating storms and the total path lengths of tornadoes was found by applying time-domain diagnostics to members of the Storm-Scale Ensemble Forecast system provided by CAPS to the HWT. Based on this result, visualization of simulated rotating storm tracks was developed and displayed in real-time during the 2012 EFP Spring Forecasting Experiment. A technique based on time-domain diagnostics was used to diagnose attributes from observed rotating storm tracks from the 27 April 2011 tornado outbreak based on 5-minute analyses from a 1.25 km grid-spacing 3DVAR data assimilation system used for the 2010-2012 HWT Experimental Warning Program Real-time 3D Radar Data Assimilation Experiment. In addition, time-domain diagnostics were developed to objectively identify convective initiation in models and observations. These CI-diagnostics were applied in real-time and used as both a forecasting and verification tool during the 2012 Spring Forecasting Experiment.

To expand and accelerate the development of time-domain applications to convection-allowing forecasts, Adam Clark is working with the Developmental Testbed Center through their visitors program to test/implement MODE-TD (Method for Object-based Diagnostic Evaluation – Time Domain) using HWT forecast data.

Publications
Awards
Adam Clark received an Editor’s Award for the journal *Weather and Forecasting*. 

(a) Maximum UH from any SSEF system member initialized 0000 UTC 27 April 2011 for forecast hours 13 to 30 (valid 1200 to 0600 UTC 27-28 April). The red/purple-shading scheme is for UH produced by surface-based storms, while the blue/green shading scheme is for UH produced by elevated and/or high-based storms. Tornado reports (yellow triangles) for the corresponding period are overlaid. 

(b) Exceedance probabilities as a function of total tornado path length computed from the distribution of SSEF member UH path length forecasts. The dark red line is for 27 April, the light red lines are for the 47 other cases in the dataset, and the green line is climatological exceedence probabilities computed from Storm Data for the period 1950 – 2011 (legend provided at top). The dark red triangle marks the actual total tornado path length for 1200 to 0600 UTC 27-28 April. 

(c) Total length of UH objects for each SSEF member using a minimum threshold of 100 m²s⁻². The length of the individual colored bars that comprise each column indicate the length of each UH object for each member. The colors within these bars indicate the maximum value of UH within the corresponding object, with red/pink shades corresponding to objects produced by surface-based storms and green shades to objects produced by elevated and/or high-based storms (color bars provided on right side). The bars in the bottom column similarly indicate path lengths and maximum intensities, but for observed tornadoes where maximum intensities correspond to enhanced-Fujita scale ratings.
11. Total Lightning Data Assimilation Within the WRF Framework

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

Objectives
Develop novel tools designed at assimilating lightning data as a head start to the scheduled launch of the GOES-R in 2015, which will be equipped with the Geostationary Lightning Mapper (GLM) instrument capable of mapping total lightning (CG + intra-cloud) day and night, year-round with a nearly uniform resolution over the Americas ranging between 8 and 12 km.

Accomplishments
To improve forecast of convection, a new assimilation techniques of total lightning data at cloud-resolving scales have been developed within the WRF-ARW model. Lightning data assimilation forced deep, moist precipitating convection to occur in the model using a nudging function for the total lightning data, which locally increases the water vapor mixing ratio (virtual potential temperature) via a computationally inexpensive smooth continuous function using gridded pseudo-GOES-R resolution (9 km) flash rate and simulated graupel mixing ratio as input variables. The assimilation of the total lightning data for only a few hours prior to the analysis time significantly improved the representation of the convection at analysis time and at the 1-hour forecast within the convective permitting/resolving grids (i.e., 3/1 km). This simple, computationally inexpensive assimilation technique has been implemented in the real-time operational WRF/NSSL forecast testbed at: http://www.nssl.noaa.gov/wrf/wrf_ltg/.

Publications
NSSL Project 4 – Hydrologic Modeling Research

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

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

Funding Type: CIMMS Task II

Overall Project Objectives
Assess the skill of NWS operational flash flood guidance (FFG) products and to develop a CONUS-wide system (called FLASH – Flooded Locations and Simulated Hydrographs) of real time flash flood predictions. The skill metrics calculated during the FFG evaluation are used as benchmarks for the skill of FLASH.

Accomplishments

1. FLASH Demonstration

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

The development of the FLASH modeling and prediction system for CONUS has been the primary task of this part of the project. The activities here include data acquisition and processing, modeling framework configuration, and the estimation of distributed a-priori values for the hydrologic model. A prototype of the system currently runs in real-time in the FLASH server in the National Weather Center, which generates warning products available at http://flash.ou.edu (see first figure below).

A priori estimates for the hydrologic model parameters will enable the FLASH system to simulate and make predictions at ungaged locations, and eliminate the need for model calibration. Ongoing research on this aspect has demonstrated that these estimates (see second figure below for examples of a priori parameters) can improve model performance without calibration.
Screen-shot of front page of FLASH website (http://flash.ou.edu) showing real-time gridded warning product for CONUS.

Maps of a priori estimates of four of the hydrologic model parameters.
2. Evaluation of Flash Flood Guidance in the United States

Robert Clark (CIMMS at NSSL), J.J. Gourley (NSSL), Zac Flamig (OU School of Meteorology)

This study, for the first time, quantifies the skill of the NWS’s FFG product over the entire CONUS. From October 2006 through August 2010, flash flooding events forecast by the FFG system were compared to various independent flash flooding observation datasets, including NWS Storm Data and United States Geologic Survey (USGS) stream gauges. FFG skill was also determined for each of the twelve River Forecast Centers (RFCs) that have responsibility for the CONUS. Finally, FFG can be produced using several different methods and so the skill of each of these individual methods was also quantified.

Over the entire CONUS, depending on the exact observation dataset used, FFG had a maximum critical success index (CSI) of 0.20. In the various RFCs, FFG skill had a maximum CSI of 0.43. Legacy methods of generating FFG, dating from the early 1990s, were generally competitive with newer methods developed at individual RFCs after 2003. Specifically, gridded FFG and distributed FFG, deployed after 2005 in some areas, have improved spatial resolution over older FFG systems while maintaining reasonable CSI values. However, flash flood potential index (FFPI) methods used in the western US show little potential for improving flash flood forecasting skill over legacy methods. Preliminary results from this study were included in a poster presentation at the 2012 European Conference on Radar in Meteorology and Hydrology in Toulouse, France. Additionally, these preliminary results have been provided to the NWS Office of Hydrologic Development.

Best skill (CSI) of operational flash flood guidance (1-hr, 3-hr, and 6-hr products) by River Forecast Center area. FFG events evaluated using basin-mean precipitation over all basins gauged by the USGS with contributing drainage areas of less than 1,000 square km. Flash flood events in USGS basins identified as times when stream gauges exceed a given basin’s two-year return period flow.
3. Compare Skill of Coupled Model System Outputs to Operational Forecast Products and Water Level Observations

Zac Flamig (OU School of Meteorology), J.J. Gourley (NSSL), Humberto Vergara-Arrieta (CIMMS at NSSL), Robert Clark (CIMMS at NSSL)

Preliminary evaluation of the system has been conducted using independent datasets such as the Severe Hazards Analysis and Verification Experiment (SHAVE), and NWS flood reports (see figure below). The figure shows the maximum simulated return period that occurred during the duration of a flash flood event in Oklahoma City in June 2010. The simulated results match up well with the flash flood warnings issued by the NWS and SHAVE observations.

**OKC Flash Flood**

*Simulated maximum return period compared to NWS flood report and SHAVE observations for the 14 June 2010 flash flood event in Oklahoma City, Oklahoma.*
Theme 2 – Forecast Improvements

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

NOAA Technical Lead: David Stensrud (NSSL)

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

Funding Type: CIMMS Task II

Overall Project Objectives

Synoptic, mesoscale and storm-scale processes modulate the formation and evolution of severe and hazardous weather. The impacts of hazardous weather can be mitigated significantly if it is forecast with greater accuracy, but progress in this area will require better understanding and prediction of the synoptic, meso, and microscale flows that control when, where and how severe and hazardous weather forms and how it behaves after formation. Better understanding of these processes comes from research related to theory, observations and modeling. Research associated with the project includes field programs designed to collect unique observations on scales ranging from the synoptic to microscales. It also will include numerical modeling and theoretical studies. Better prediction comes from better understanding as well as improved numerical guidance. All of these elements will be combined in the Hazardous Weather Testbed (HWT), which provides a staging ground for field programs, as well as a framework in which new research concepts can be introduced, new numerical modeling strategies can be developed and evaluated, and the operational relevance of these new ideas can be vetted. Improved understanding of the physical processes associated with severe weather is also needed for the Warn-on-Forecast project.

1. The Identification of Modeled Thunderstorms Using Object-Based Approaches: Environments and Severe Characteristics

James Correia Jr. (CIMMS at SPC)

Objectives

Support the Convection Initiation and Severe Weather Desk of the Hazardous Weather Testbed and evaluate the utility of high-resolution ensemble forecast systems for severe storms forecasting by developing diagnostics and visualization for severe storms and their environments using object-based methods.

Accomplishments

Support activities include preparing for ingest and plotting of convective initiation products generated by NSSL for use in N-AWIPS. Object-based techniques were developed and applied to identify storm attributes in three distinct ensemble systems using the updraft helicity parameter. These were used during forecasting to assess
ensemble skill in the timing of severe weather regimes. Other parameters such as hail were explored using the same technique but were not as successful.

**Publications**

The NSSL WRF model climatology depicting storm frequency (in log10 space) of all environments (0-6 km shear vs. CAPE derived Wmax; shaded with maximum frequency of 2.7) compared with those storms that have Hourly Maximum Updraft Helicity > 25 m2s-2 (contours, values of 1 and 2). 3.5 years of data are used accounting for 1,041,000 storms. Note the increase in shear in two distinct regions (small Wmax and large shear, large Wmax and large shear), representative of winter and spring storms.
2. Real-time 3DVAR Data Assimilation and Forecaster Evaluation for Use in Warning Decisions in the Hazardous Weather Testbed

Kristin Calhoun (CIMMS at NSSL), Travis Smith (CIMMS at NSSL), Jidong Gao (NSSL), Darrel Kingfield (CIMMS at NSSL), David Stensrud (NSSL)

Objectives
Include a weather-adaptive three-dimensional data assimilation (3DVAR) system in the Hazardous Weather Testbed (HWT) Experimental Warning Program (EWP) as a first step in the progress to a Warn-on-Forecast system.

Accomplishments
NWS forecasters were asked to incorporate 3DVAR data in conjunction with single-radar and multi-sensor products in AWIPS-2 as part of their warning-decision process for real-time events across the United States. During the 2011 and 2012 experiments, forecasters examined more than 36 separate events including tornadic supercells, severe squall lines, and multi-cell storms.

The product of the 3DVAR analysis was available to forecasters at 1km horizontal resolution every 5 min, with a 4-5 min latency, incorporating data from the national WSR-88D network and the North American Mesoscale (NAM) model. Four different 200x200 km domains were used to run the 3DVAR program throughout the experiment; the location of each was determined by default via an automated algorithm which moved the domains over regions of peak reflectivity throughout the continental United States, but this process could be over-ridden by forecasters/scientists using a web-map interface to focus on specific storms of interest. Initial products provided to the forecasters included: vertical velocity, synthesized (or mosaic) reflectivity, vertical vorticity, and 3D wind vectors.

Following feedback from early forecaster evaluations, additional products for updraft helicity and storm-top divergence (max-divergence above 8 km) were created during the 2012 experiment. The forecasters found the vertical vorticity, storm-top divergence, and updraft products the most useful for storm interrogation and quickly visualizing storm trends, often using these tools increase the confidence in a warning decision and/or issue the warning slightly earlier. The addition of AWIPS-2 during the 2012 experiment also allowed forecasters to overlay 3D wind vectors, barbs, or streamlines on other 3DVAR or radar products at multiple levels from near the surface to storm-top. The 3DVAR analysis was most consistent and reliable when the storm mode was supercellular, though forecasters were still able to utilize the data in multiple scenarios. The analysis was also better when the storm of interest was in close proximity to one of the assimilated 88-D radars, or data from multiple radars were incorporated in the analysis. The latter was extremely useful to forecasters when helping to fill in the gaps of having to analyze multiple radars separately, especially where storms from one or more radars were in the "purple haze" of the range-folded obscuration. The largest hurdle for realtime use of 3DVAR or similar data assimilation products by forecasters is the data latency, as even 3-5 minutes reduces the utility of the products when new radar
scans are already available. Future additions in the HWT include reducing the data latency, cycling the 3DVAR analysis to improve the estimates for other variables, such as temperature and water vapor, and adding a short term forecast component (0-1 hour) as computational speed increases.

Publications

3. Explicit Forecast of Lightning Threats Within the WRF Model Framework

Alexandre Fierro (CIMMS at NSSL), Donald MacGorman (NSSL), Edward Mansell (NSSL), Conrad Ziegler (NSSL)

Objectives
Implement a new explicit, physics-based lightning prediction model within the WRF model framework as a significant step towards improving high impact weather forecast within convection-resolving models.

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

A new and physically sound charging/discharge model was implemented into the WRF-ARW model and was tested using cloud-scale simulations of Hurricane Rita. The discharge model explicitly solves for the ambient electric field using a multigrid elliptic solver. It features in-cloud inductive/polarization charging and non-inductive microscopic charging coupled with a two-dimensional discharge scheme. Preliminary results show results in good agreement with observations.

Publications

4. Storm Tracking and Lightning Cell Clustering Using Geostationary Lightning Mapping Data for Data Assimilation and Forecast Applications

Kristin Calhoun (CIMMS at NSSL), Donald MacGorman (NSSL), Benjamin Herzog (OU School of Meteorology)

Objectives
Determine thresholds of lightning rates and lightning density that define storm clusters for use by forecasters and in numerical forecast models.

Accomplishments
Lightning data will be available with a higher temporal resolution than that of the radar network once the Geosynchronous Lightning Mapper (GLM) on GOES-R is implemented for operational use. The enhanced temporal resolution of total lightning data and its ability to serve as a proxy for storm intensity may be exploited both to enhance the situational awareness of forecasters in an operational setting and to allow these complementary data to be assimilated into numerical weather prediction models to improve their forecasts. However, there is much work to be done to investigate exactly how lightning activity is relevant to operational forecasters and to determine how lightning activity relates to model state variables. Furthermore, little work has been done examining how lightning varies across different storm types and different climatological regions.

Real-time storm tracking for use in an operational setting has been developed within the Warning Decision Support System-Integrated Information (WDSS-II) and tested using both total lightning data and radar data. Additionally, pseudo-Geostationary Lightning Mapper (pGLM) products have been created from Lightning Mapping Array (LMA) systems in various locales for testing lightning data within the Spring Experiment, GOES-R Proving Ground activities, and various algorithms. The initial focus of this project was determining the criteria for defining a lightning cell or cluster from the pGLM data by comparing clusters tracked using lightning data with clusters determined and tracked using only radar data. Additionally, the tracking techniques developed as part of this project were merged into the National Lightning Jump Algorithm Field Test for the National Weather Service. Work has also begun to develop procedures to integrate an automated storm-typing algorithm (e.g., supercell vs. multicell vs. line) so that the evolving flash rates and lightning densities characteristic of each storm type may be determined and used in weather operations. The results of this project are set to be included in forecaster training and operations within the Hazardous Weather Testbed in 2013.

Publications:
Radar, lightning and identified cells at smallest scale, ideal for use in Lightning Jump Algorithm where individual cells need to be identified and maintained. Left: Merged Reflectivity at lowest altitude and lightning flashes detected from the Kennedy Space Center LDAR. Right: Identified storm clusters using merged WSR-88D Reflectivity at 10C with associated cell ID number. Density of pGLM lightning also shown (number of flashes per minute).

5. The Dependence of QPF on the Choice of Microphysical Parameterization for Lake-Effect Snowstorms

Heather Reeves (CIMMS at NSSL), Dan Dawson (NSSL)

Objectives
Quantify and explain the effects of the choice of microphysical parameterization on lake-effect snow precipitation forecasts.

Accomplishments
Several forecasts of lake-effect snow were assessed to compare how the choice of microphysical parameterization scheme affects the precipitation. Differences in the precipitation distribution were ultimately found to be due to assumptions used in the formula for accretion of rain by snow. Two important applications for the results were found. First, the best forecast was unable to be determined given the spatial distribution of observations. A new technique was developed that allowed us to create synthetic QPEs that may be useful for testing potential locations for future radar additions. Second, the production of graupel was an important control on the precipitation via its faster terminal velocities. Graupel can be distinguished from other frozen hydrometeors in dual-polarized observations. Hence, results support the need for enhanced algorithm development of in-situ precipitation type by dual-polarized radar.

The 1-hr liquid-equivalent accumulated precipitation starting at forecast hour 20 (shaded) and the start (gray dots) and end (black dots) points of hydrometeor trajectories for each of the experiments labeled in each panel. The average residence time for the trajectories is given in the lower right of each panel.
6. The Ewiem Nimdie Summer School Series In Ghana

Abdul Dominguez (CIMMS at NSSL), Michael Douglas (NSSL), Peter Lamb (CIMMS at OU), other collaborators across the U.S. and world

Objectives
Provide an innovative series of summer schools to enable young African scientists to work with their peers in the international community.

Accomplishments
The Ewiem Nimdie summer school is a biennial or triennial event that to date has been hosted in Ghana and focuses on the atmospheric sciences; “Ewiem Nimdie” means “atmospheric science” in the local Ashanti language. The first school was conducted in the summer of 2008, hosted by the Kwame Nkrumah University of Science and Technology (KNUST) located in Kumasi, with the second school taking place at the same institution two years later in July 2010. The schools were designed to help launch the undergraduate meteorology program of KNUST and benefitted from the significant increase in research activity regarding West African weather and climate that has arisen from the African Monsoon Multidisciplinary Analysis (AMMA) program. Both schools lasted two weeks, and included a broad program of lectures, hands-on classes in regional forecasting and climate applications modeling, and a variety of field measurement activities with associated student projects that were presented at the culmination of each school.

From its inception, the summer school program was designed around the concept of integrating undergraduate and new Ph.D. students from all over the globe with research interests in African meteorology and climate. The attendance of African students from across the continent was funded under the budget of each school, with about half originating from within Ghana. European students were mostly from France, Germany, and the United Kingdom, due to the involvement of lecturers from these countries in the school, in addition to a limited number of students from other European countries and North America. This broad engagement produced an environment in which African, European, and American students could not only have access to leading scientists in the field, but also could interact with their peers to form lasting working relationships. These links will serve well in the present highly competitive funding environment, in which an increasing proportion of European Union and North American research support is directed towards multi-continent cooperative actions. The multi-national integration of the students and the wide range of activities gave the schools a unique and exciting atmosphere that we wish to maintain and foster in future similar projects here and elsewhere. In this paper, we report on the salient features of the summer school and its future prospects.

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

NOAA Technical Leads: Russell Schneider (SPC), 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

1. GOES-R Proving Ground

Chris Siewert (CIMMS at SPC), Kristin Calhoun (CIMMS at NSSL)

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.

Accomplishments
The 2012 CIMMS fiscal year marked the fourth year of the GOES-R Proving Ground’s efforts at the SPC and HWT. Multiple conference presentations, including the AMS Annual Meeting, NWA Annual Meeting, EUMETSAT International Satellite Conference, and GOES Users Conference, were made between mid-2011 through early-2012 of the results from the third year of the Proving Ground’s efforts, specifically the results from the 2011 Spring Severe and newly created Summer Fire Weather Experiment. Three recent publications discussed the GOES-R Proving Ground work at the SPC and HWT. SPC forecasters were trained on and provided with multiple experimental GOES-R products that were found to be useful during the 2011 Spring Severe and Summer Fire Weather Experiments during the Winter SPC forecaster training sessions.

The fourth installment of the GOES-R Proving Ground Spring Experiment occurred from mid-May through mid-June 2012, with 28 NWS forecasters and 14 researchers participating in evaluating an assortment of experimental GOES-R products during real-time operational forecasting situations. The GOES-R products were provided for demonstration within both the SPC/NSSL Experimental Forecast Program and the NSSL/NWS Experimental Warning Program. The products demonstrated this year included simulated satellite imagery, GOES-R unique band differences and lightning threat forecasts from the NSSL-WRF, object-based convective initiation nowcasts, cloud-top cooling rates, pseudo-Geostationary Lightning Mapper total lightning flash extent densities, 0-9 hour differential theta-e / precipitable water / CAPE “Nearcast”, and GOES Sounder-derived RGB air mass imagery. All of these products will continue to be delivered to SPC throughout the year for demonstration.
Following the 2011 Spring Experiment a partnership was made to establish a GOES-R Proving Ground effort at the Aviation Weather Center (AWC) in Kansas City, MO, and at the Hydrometeorological Prediction Center (HPC) in Camp Springs, MD. Participation in the GOES-R Proving Ground portion of the newly created AWC summer experiment also occurred in 2011 and 2012. Products and expertise continue to be shared from the Proving Ground effort at the SPC to assist in these efforts.

Publications

GOES Sounder Airmass RGB product from 3 April 2012 prior to the onset of severe convection along a dryline extending from the Oklahoma panhandle into central Texas. An RGB image is a composite of three separate channels or channel differences used to create an image that draws out unique atmospheric features. In this example, the air mass RGB depicts regions of jetstreaks associated with an increase in potential vorticity (red), warm/moist air masses (green) and cool/dry air masses (blue). In addition, the air mass RGB product detects your standard cloud features seen in typical satellite IR imagery. Imagery like this will be common during the GOES-R era.
2. Verification of Stormscale Ensemble Forecasts and High-Resolution Models

Christopher Melick (CIMMS at SPC), James Correia Jr. (CIMMS at SPC)

Objectives
Real-time verification of high-resolution models.

Accomplishments
We developed software to process and display a variety of model and observational information for the 2012 HWT Spring Forecasting experiment. An objective forecast verification was conducted for the first time in near real-time during the experiment. As part of the participants’ daily activities, the idea was to routinely test the value of verification metrics by comparing the scores to subjective impressions. Among the metrics were raw versus smoothed neighborhood techniques used to compute Critical Success Index, False Alarm Rate, Bias, and Fraction Skill Scores for various fields (simulated reflectivity and practically perfect probabilities for severe storm reports).

We also developed object based verification for the with and without radar data assimilation simulations provided by CAPS for the first six hours of model spin up, compared to National Mosaic and Quantitative precipitation estimation (NMQ) composite radar reflectivity. This method was demonstrated in real-time and shown to participants during the daily briefing as a supplement to the subjective data assimilation evaluations conducted as part of the Spring Forecasting experiment.

Web software used to depict the Critical Success Index (CSI) verification scores from all days over the chosen primary severe weather threat area for the NSSL-WRF and NAM 4 km models.
CAPS data assimilation evaluation using storms, verified with NMQ
Search over obs and find “hits” (overlap) in the models

Two histograms reflecting (left) the distribution in time of observed and forecast frequency of storm objects between the model with (blue) and without (red) data assimilation and (right) the relative percentage of hits through 25 days of forecasts.

Rapid transition in the first two hrs (CN)
Spin up first 45 min (C0) but peaks by 2 hrs

Lasting impact thru 6 hours (~5%) but 4 hours is probably more significant

Storm objects >34 dBz (8 pixel contiguous region) with interior max of 44 dBz (2 non-contiguous pixels)

3. Social and Behavioral Influences on Weather Driven Decisions

James Correia Jr. (CIMMS at SPC)

Objectives
Communicate risk and uncertainty with primary partners.

Accomplishments
A grant was submitted to NOAA in collaboration with Ken Galluppi (Arizona State University), Rachel Riley (SCIAPP at OU), and other collaborators focusing on preparedness and effective communication within emergency management involving the suite of SPC products. The goal of this project is to connect the right information to the right people at the right time in the right format. We proposed to use the HWT and forecasts within the Experimental Forecast program to prototype, test, and evaluate products/services that may be of use based on focus group analysis of varying
emergency management communities. This proposal was accepted and work will begin in FY13.

The SPC via the NWC Societal Impacts Program also collaborated with the NWS to be a part of the Customer Satisfaction Survey which can be used to understand who our primary partners are, how well our products meet their needs, and how to better communicate our products and services. The knowledge gained from projects like these should help us with Warn-on-Forecast priorities at time scales longer than warnings while allowing us to meet the needs of longer lead time customers. The vision is to keep WoF developers looking out to more than 6 hours so a seamless prediction environment can be maintained between watches and warnings.

4. Forecaster Understanding of Uncertainty

James Correia Jr. (CIMMS at SPC)

Objectives
Investigate how forecasters conceptualize, understand, and convey uncertainty.

Accomplishments
Dr. Correia partnered with Rachel Riley (SCIPP at OU) to mentor a Research Experience for Undergraduates (REU) student to conduct interviews of HWT participants on both the warning and forecast side for how they conceptualize, understand, and convey uncertainty information in forecasts. The sample size was limited to ten participants and a survey instrument was developed for individual interviews and passed through OU’s Institutional Review Board. The scope of the project involved local and national forecasters and a few researchers to inform a more specific survey instrument for future HWT experiments.

WDTB Project 12 – Warning Decision-Making Research and Training

NOAA Technical Leads: Ed Mahoney, Bradford Grant, Liz Quoetone, Jim LaDue, Mike Magsig, Jami Boettcher (all WDTB)

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

Funding Type: CIMMS Task II

Overall Project Objectives
Increase expertise among NOAA/NWS personnel and their core partners on the integrated elements of the warning process. CIMMS staff conducts 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. **Advanced Weather Interactive Processing System-2 (AWIPS-2)**

   Tiffany Meyer, Aaron Anderson, Dale Morris, Darrel Kingfield, Chris Spannagle, Steven Martinaitis, Andy Wood (all CIMMS at WDTB)

   NOAA’s NWS has embarked on a redevelopment of their Advanced Weather Interactive Processing System (AWIPS) platform. The major focus of this AWIPS Technology Infusion project is the development by Raytheon Technology Services, the AWIPS prime contractor, of AWIPS-2. Initially, AWIPS-2 consists of a conversion of the legacy AWIPS software into a modern services-oriented architecture. Based in JAVA, this new software paradigm features a modular design with loosely-coupled components that communicate using an enterprise service bus and new data storage mechanisms, including the creation and usage of metadata. Two of the consequences of this new architecture are that 1) new processes are required to localize and customize the software for use by individual forecast offices, and 2) small functional changes are introduced under the new platform.

   CIMMS staff at WDTB, in collaboration with other NWS training centers, have designed, developed, and released training materials for AWIPS focal points and forecasters in preparation for the migration to AWIPS-2. The training for AWIPS focal points consists of job sheets, exercises, and recorded presentation training for AlertViz and other derived parameters. The AWIPS-2 Variances Training (for use by all forecasters) can be found both on the Learning Management Center as well as on each of the AWIPS-2 workstations. The variance training instructs the forecasters on the functional changes (variances) from the legacy AWIPS system so they may efficiently utilize the new system in daily operations. The process of developing the aforementioned training also has allowed WDTB to extensively test the new platform, submit trouble tickets on problems found, and to make recommendations for improvement of the software and documentation.

   CIMMS staff at WDTB have developed a real-time ingest of data into an AWIPS-2 platform. Hence, all WDTB staff has the capability of learning the new software environment and discovering any effects AWIPS-2 may have on existing and new training and research initiatives.
2. Advanced Warning Operations Course (AWOC)

Chris Spannagle, Veronica Holtz, Darrel Kingfield, Daphne LaDue, Les Lemon, Steven Martinaitis, Dale Morris, Mohamad Said, Mark Sessing, Andy Wood (all CIMMS at WDTB)

CIMMS personnel were heavily integrated into the development, delivery, and support of WDTB’s Advanced Warning Operations Course (AWOC). AWOC is a blended learning course designed to provide training on advanced warning decision making techniques to every NWS forecaster with warning responsibility (meteorologists and hydrologists). The AWOC was the first initiative to deliver warning decision-making training to all forecasters since the WSR-88D Operations Course of the 1990s, and it does so at a significantly reduced cost. WDTB was awarded the Department of Commerce Silver medal for the initial delivery of AWOC, and CIMMS personnel were critical to the success of AWOC. After the initial AWOC release (which included tracks on Core Operations and Severe Weather), a third track (the AWOC Winter Weather track) was released in June 2006.

In collaboration with WDTB instructors, CIMMS staff updated existing (from FY11) AWOC Core, Severe, and Winter Track material to address new science and better fit with other existing curriculum for new NWS hires. This work included adding a required
Forecast Challenge to the AWOC Severe track that provided the opportunity for students to learn through hands on forecasting. An AWOC Facilitation Workshop was also held in October 2011 to help newly hired, local facilitators better integrate this and other WDTB training. CIMMS personnel also contributed logistical support for all three tracks of AWOC and its management. This support included responses to questions from the field, assistance for local facilitators, provision of certificates of completions to students, and utilizing a semi-automated method of producing statistical progress reports of students and forecast offices using NOAA’s Learning Management System.

The entry page used by AWOC Severe students during the AWOC Severe Forecast Challenge.

3. Communicating Risks in High-Impact Events

Veronica Holtz, Daphne LaDue, Dale Morris, Andy Wood, Chris Spannagle, Les Lemon (all CIMMS at WDTB)

The NWS is moving towards an updated role of decision support its partners as part of the Weather-Ready Nation initiative. The WDTB developed the Communicating Risks in High-Impact Events course to respond to several requirements from recent NWS service assessments and this new initiative. This course addresses the crisis communications cycle and how it applies to NWS decision support activities. This course uses real examples from several weather-dependent events, geographical locations, and stakeholder groups to convey how the NWS can deepen its understanding of its role in decision support. During these recent past events, the NWS offices involved had to quickly learn stakeholders’ needs and processes in the midst of providing decision support.
In addition to crisis communications cycle discussion, this course provides NWS forecasters with tools to learn about stakeholder needs and processes before events occur. Work on the module required a careful survey of various tools that might be adapted for use by physical, rather than social scientists. The module includes introductions to the methods, how the methods work, and suggestions for analysis. Supplementary materials were created for each method that step forecasters through use of the method. As part of the course, forecasters work in teams to apply one of the methods to address their local office’s needs and submit a summary of their work to the WDTB.

This screen shot from the Communicating Risks in High-Impact Events course shows how each tool discussed in the training might be useful to forecaster operations.

4. Distance Learning Operations Course (DLOC)

Mark Sessing, Les Lemon, Steven Martinaitis, Dale Morris, Andy Wood, Mohamad Said, Clark Payne, Katherine Willingham, Chris Spannagle, Veronica Holtz, Darrel Kingfield, Aaron Anderson (all CIMMS at WDTB)

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

CIMMS staff members are closely involved with the development of DLOC. The collaborative work includes applied research on future radar improvements such as dual-polarization and current WSR-88D capabilities to assess severe weather and flash flooding threats. As part of this training, CIMMS personnel work closely with radar engineers and software developers to determine how recent updates to different components of the WSR-88D and AWIPS impact the system as a whole. This work allows CIMMS staff to assist their WDTB collaborators in developing and updating significant portions of DLOC during the past year. Another area where CIMMS scientists play a critical role with DLOC is during the residence component of the course. The collaborative work with WDTB during these classes includes developing lecture materials, exercises, and simulations; delivering presentations; and providing expertise on warning-decision making issues to the class participants.

5. Dual-Polarization Radar Training

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

Beginning in 2011, the entire fleet of WSR-88Ds began a major software and hardware upgrade that greatly expands the capabilities of the system. This upgrade, known as
dual-polarization, will allow each radar to collect data with information about the horizontal and vertical properties of weather (e.g., rain, hail) and non-weather (e.g., insect, ground clutter) targets. As part of this system upgrade, CIMMS staff and WDTB instructors developed training for NWS forecasters on how to use the new system. This training included the Dual-Polarization Radar Principles and Systems Operations, the Dual-Polarization Radar Operations Course, and the Storm of the Month Webinar series. The first two courses were finalized and released early during the fiscal year. The Storm of the Month Webinars began during the current fiscal year and are planned to continue into the future.

These various training courses provide NWS forecasters with a variety of background knowledge, expertise building, and social learning opportunities. CIMMS personnel were integral to the development of this training, serving as either primary authors or supporting the author by developing supporting materials and reviewing the training prior to delivery. CIMMS staff has also provided critical logistic support to NWS forecasters as they have completed this training. CIMMS staff helped track forecast office completion progress, worked with offices that encountered problems, and were vital to ensuring this mandated training was completed well ahead of schedule for the vast majority of NWS forecast office staff around the country. Without the participation of CIMMS staff, the initial and continuing dual-polarization radar training of NWS forecasters would not be the significant success that it has been to date.

Example of the Storm of the Month webinar presented by a forecaster from California. They showed the added value of the upgraded WSR-88D during a small hail event that resulted in accumulating hail, which had direct impacts to their stakeholders.
6. Dual-Polarization Radar Outreach and Training for NWS Partners

Andy Wood, Clark Payne, Veronica Holtz (all CIMMS at WDTB)

In addition to the training of NWS forecasters, CIMMS staff and WDTB instructors developed outreach and on-line training for NWS partners as part of the WSR-88D upgrade to dual-polarization technology. The target audience for this training and other support materials has been emergency managers, media weather broadcasters, and forecasters in America’s Weather Enterprise to help these NWS partners more effectively incorporate these new data into their decision-making.

On-line training for both non-NWS meteorologists and non-meteorologists (produced previously for the dual-polarization upgrade beta-test) has been updated and finalized for the launch of the fleet-wide upgrade in September 2011. CIMMS scientists have participated in conference and short course presentations, provided training content to NWS staff to aid in their local dual-polarization radar outreach efforts, and provided other reference materials to support NWS partners in their application of dual-polarization technology. CIMMS staff plan on participating in similar activities in the future as opportunities present themselves.
“The WSR-88D Dual Polarization Guide” is an example of the outreach materials CIMMS staff at WDTB have developed to assist NWS partners in the integration of dual-polarization radar data into their regular work flow.

Clark Payne, Mark Sessing, Steven Martinaitis (all CIMMS at WDTB)

The Experimental Warning Program (EWP) 2012 lasted from 7 May 2012 to 15 June 2012 with the exception of the week of Memorial Day. The goal of the project was to test and evaluate new applications, techniques, and products to support NWS forecast office severe convective weather warning operations. Three primary projects geared toward NWS forecast office applications this year included: 1) evaluation of the three-dimensional variational (3DVAR) multi-radar real-time data assimilation fields being developed for the Warn-On-Forecast initiative; 2) evaluation of multiple CONUS Geostationary Operational Environmental Satellite-R Series (GOES-R) convective applications (including pseudo-geostationary lightning mapper products); and 3) evaluation of model performance and forecast utility of the OUN Weather Research and Forecasting (WRF) model.

WDTB CIMMS staff assisted the weekly participants with developing a PowerPoint presentation that was offered via webinar to all NWS units across the country, as well as facilitating those webinars. WDTB staff was expected to attend the daily weather briefings as well as stay until the end of each day’s shift to assist the participants with screen captures and write-ups for the webinar presentation.

Screen capture of the OUNWRF forecast model valid at 2130 UTC, 21 May 2012. Included in the image are examples of 1 km AGL Simulated Reflectivity (top left) and Maximum Surface Hourly Wind Speed (bottom left).
8. Integrated Warning Team Training

Dale Morris, Daphne LaDue (both CIMMS at WDTB)

At the 2010 National Hurricane Conference in Orlando FL, WDTB and an interdisciplinary team of NWS forecasters, broadcast media, emergency managers, and Sea Grant personnel facilitated a role-playing scenario of a landfalling tropical system in North Carolina. The scenario consisted of three separate and synchronized displaced real-time simulations of operations by an emergency operations center (EOC), a television station, and a NWS forecast office during the tropical event. Functioning as members of the integrated warning team, fifty participants played roles outside of their areas of expertise to learn the importance of improved team situation awareness and communications during tropical events. The scenario was facilitated by two broadcasters, two emergency managers, four people in the NWS room, a technical support person, and four additional people who ensured the groups were synchronized and performed other facilitation tasks. A scenario leader guided each of the three groups with assistance from several subject matter experts. The leader kept the individual simulations on schedule while the subject matter experts operated role-specific software and taught the group while keeping operations as realistic as possible.

The actions and communications between the rooms of the live scenario were captured to use as the basis of a distance-learning version of the scenario. Four distance modules designed for forecasters to play the emergency manager role were prepared, including: 1) a twenty-minute lesson introducing the integrated warning team and the simulations; 2) a twenty-minute self-paced overview of the general responsibilities of emergency managers; 3) a forty-five-minute lesson introducing the jurisdiction where the scenario occurs and summarizing local emergency management operations in the days preceding the event; and 4) a forty-five-minute web-based simulation where forecasters play the role of an emergency manager while being guided by a coach.
Sample weather display for the displaced real-time (DRT) simulation for the emergency manager role. This is a web-based simulation and each data product is refreshed automatically at the appropriate time, using WDTB/CIMMS-developed simulation technology. This display is based on a system emergency managers in North Carolina actually use through the NC-FIRST program.

9. Radar Data Acquisition Unit (RDA) & Radar Product Generator (RPG) Build Training

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

In FY12, outside of the ongoing dual-polarization technology upgrade, minor upgrades were made to the WSR-88D Radar Data Acquisition Unit (RDA) and Radar Product Generator (RPG) software. This latest software upgrade (Build 13.0) restores some algorithms unavailable after the dual-polarization technology upgrade and updates other existing algorithms. CIMMS personnel have worked closely with WDTB instructors and ROC staff to develop training for NWS forecasters that also is available for NWS partners.
An example slide from the RDA Build 13.0 Training presentation shows how the Clutter Mitigation Decision (CMD) algorithm has been updated to incorporate dual-polarization radar base data.

10. Recognizing High Impact Hydro Events

Steven Martinaitis (CIMMS at WDTB)

Findings from the “Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, 1-4 May 2010” NWS Service Assessment resulted in WDTB developing training on flash flood forecasting. In particular, this service assessment identified a need for training on the use of pattern recognition, short-range ensemble data, and standardized anomalies in the forecasting process in identifying high-impact rainfall and flooding events. CIMMS staff collaborated with WDTB instructors and subject matter experts to develop and deliver training on the use of ensembles and standardized anomalies with synoptic-scale patterns to address the recognition of extreme rainfall events.

The content was delivered via two online modules and a series of instructor-led webinars. This was complimented by a two case exercises based on record rainfall and flood events. These exercises utilized job sheets that allow participants to analyze AWIPS-generated model data along with ensemble, anomaly, and QPF products.
through an online interface. Emphasis was placed on identifying and gaining confidence in recognizing synoptic-scale extreme rainfall patterns.

This screen capture shows the 42-hour 850 mb moisture flux and moisture flux anomaly forecast for the 0000 UTC 6 September 2011 GEFS model. This large-scale flash flood event in PA/NY from the remnants of Tropical Cyclone Lee passed over the area.
11. Training & Research Toolkit

Mohamad Said, Chris Spannagle, Darrel Kingfield (all CIMMS at WDTB)

The warning decision-making process is multi-faceted. It often is assisted, or improved, by analysis tools or other data analysis techniques. CIMMS scientists have developed applications train forecasters to apply these new tools and techniques in an operational and research setting. These applications, part of the WDTB Research and Training (WRAT) Lab toolkit, have been successfully used for the past few years as part of various training efforts. CIMMS staff developed this advanced, automated platform to provide meteorological simulations to a lab classroom using multiple servers and twenty-five workstations in an efficient and flexible manner. This tool has performed an important role in configuration, development, and delivery of various training workshops, such as the NWS DLOC and NWS AWOC Facilitation Workshop. This toolkit has made the setting and configuration of the lab easier and more flexible after every major release of the AWIPS/Weather Event Simulator (WES).

Current and future work on the WRAT Lab toolkit focuses on the NWS transition from AWIPS-1 to AWIPS-2 software and hardware. CIMMS scientists are working closely with WDTB instructors to update the toolkit applications to the new software and hardware paradigm introduced with AWIPS-2 for FY13 versions of WDTB in-residence training.

12. Weather Event Simulator-1 (WES-1)

Katherine Willingham, Darrel Kingfield, Mohamad Said, Dale Morris (all CIMMS at WDTB)

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

The WES architecture continues to remain in step with AWIPS releases. WES 9.7 was released during FY12 to maintain this paradigm. This updated applied various fixes for AWIPS software components, including WarnGen, the Four-Dimensional Storm Interrogator (FSI), the Graphical Forecast Editor (GFE), and various D-2D display tools. Improvements were also made optimize processing overhead when converting radar data to displayed real-time (DRT) format. CIMMS staff also provided extensive support to NWS forecast offices in the installation and troubleshooting of this most recent software release, as well as responding to technical questions users had.
This screenshot shows an example of the Weather Event Simulator 9.7 primary interface.

13. Weather Event Simulator-2 (WES-2)

Dale Morris, Darrel Kingfield, Mohamad Said, Aaron Anderson, Tiffany Meyer (all CIMMS at WDTB)

The new AWIPS-2 software architecture being developed and deployed in all NWS forecast offices results in the obsolescence of the existing Weather Event Simulator (WES-1). A need exists to preserve existing simulation functionality provided by WES-1 and support the NWS Directive 20-101 requirement for every forecaster to complete two simulations prior to each significant weather season. As a result, the WDTB has designed and is developing the WES-2 Bridge, based on the AWIPS-2 platform. This design will also serve as a prototype method of incorporating training functionality into the “baseline” AWIPS-2 system. To support this development and to ensure compatibility in the structure of archived data, significant collaboration occurred between CIMMS personnel, WDTB instructors, the NWS Office of Science & Technology, and the AWIPS-2 contractor.

WDTB has tested incremental WES-2 Bridge functionality, including the ability to synchronize simulations on separate machines for an emerging distributed simulation
requirement. The WES-2 Bridge development also features a case converter so that existing AWIPS-1 format case data will be viewable in the WES-2 Bridge/AWIPS-2 system; otherwise most previously collected AWIPS-1 data would be unusable. The case converter allows training and research activities based on the AWIPS-1 storage paradigm to continue in the new system. The WES-2 Bridge also features a completely redesigned and streamlined method of presenting non-AWIPS information (spotter reports, video, etc.) during a simulation (formerly called WESSL – the WES Scripting Language). Exploiting messaging and geospatial capabilities of the AWIPS-2 infrastructure, the updated WESSL provides a method to control the simulation plus the ability to engage forecasters with feedback as they complete simulations. The release of WES-2 Bridge to NWS WFOs is anticipated in 2013, pending AWIPS-2 development and deployment activities.

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

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

Megan Taylor (CIMMS at NWSTC), Teresa Murphy (NWSTC), Hattie Williams (NWSTC), Jeff Zeltwanger (NWSTC), Justin Schultz (CIMMS at NWSTC), Dave Cokely (NWSTC), Randy Schupach (NWSTC), Randy Rieman (NWS Hydrologic Support Branch – HSB), Lora Mueller (NWS HSB), Mark Glaudemans (NWS HSB)

NOAA Technical Leads: Scott Tessmer (NWSTC), Teresa Murphy (NWSTC)

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

Funding Type: CIMMS Task II

Objectives
Provide training for the Community Hydrologic Prediction System (CHPS) that has been adopted by the River Forecast Centers of the National Weather Service.

Accomplishments
The CIMMS research associate assigned to CHPS training at NWSTC works on various course development and training tasks.

Development to date has included finishing the last pieces needed for the course CHPS Simulation Configuration Training and creating and completing the CHPS System Manager course. To undertake and complete a course like CHPS System Manager, steps include gathering general information, putting together an outline (called the High Level Design Document), gathering specific information to put into an HTML draft document (called Detail Design Document), sending out the document for review by CHPS Subject Matter Experts (SMEs), building an HTML course, creating media
presentations, and finally creating quizzes and assessments. The whole process takes 3 to 5 months to complete dependent upon feedback and software/hardware issues. With three training modules released to date, the following also are in the project plan (in order of desired completion): Advanced Configuration, User Training Basics, Calibration, User Training Advanced, and Simulation Mod 2. We have started the steps involved in creating Advanced Configuration Training.

Skill development training also was provided to the CIMMS staff at NWSTC to help them complete tasks associated with their projects. Since CHPS is a Linux based system, the first NWSTC-based training course provided was called Linux Essentials. The next was Adobe Dreamweaver training at Johnson County Community College. This course trained us on how to convert documents to an HTML format, the procedure used at the Training Center for creating training courses. Training trips also included the Missouri-Basin River Forecast Center, Pleasant Hill NWS Forecast Office, Arkansas-Red River Forecast Center, and a trip is scheduled for the end of July 2012 to NWS Headquarters in Silver Spring, Maryland. The NWSTC also provides for all contractors and employees to take distance-learning courses via the Commerce Learning Center. CIMMS staff has taken hydrologic based courses to help in the development of CHPS training, including Hydrologic Program Management training.

![Screenshot of CHPS Interactive Forecast Display Window](image)
Screenshot of CHPS System Manager Training course. See the whole course at http://www.nwstc.noaa.gov/CHPS/sysman.

Screenshot of DOC Learning Center site where CHPS training is published and additional courses are available for CIMMS staff to take.
CIMMS Task III Project – National Sea Grant Climate/Weather Extension Specialist

Suzanne Van Cooten (NWS-Slidell), Kodi Monroe (CIMMS at NSSL), Heather Moser (CIMMS at NSSL), Peter Lamb (CIMMS at OU), Kevin Kelleher (NSSL)

NOAA Technical Lead: Leon Cammen (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

Funding Type: CIMMS Task III (NOAA Sea Grant)

Objectives
Connect National Sea Grant research and outreach programs with NOAA’s NSSL and other NWC organizations; lead the Coastal and Inland Flooding Observation and Warning (CI-FLOW) research project to improve hydrologic information for coastal watersheds.

Accomplishments
The Sea Grant Climate/Weather Extension Specialist at CIMMS/NSSL leads NOAA’s CI-FLOW project and actively participates in NSSL’s hydrometeorological research activities. During the 2011 Atlantic hurricane season, the CI-FLOW collaborators completed the first real-time simulations of total water level for Hurricane Irene, a landfalling hurricane in North Carolina. QPE produced by the NSSL Q2 system provided input data to the National Weather Service (NWS) Hydrologic Lab-Research Distributed Hydrologic Model (HL-RDHM). At four points on the Tar-Pamlico and the Neuse Rivers, discharge information served as upstream boundary conditions for the ADvanced CIRCulation (ADCIRC) hydrodynamic model to incorporate freshwater contributions into coastal water level simulations. The CI-FLOW coupled model system ran in real time every six hours. Real-time simulations of coastal water levels for Hurricane Irene were available on the CI-FLOW web site (https://secure.nssl.noaa.gov/projects/ciflow/), the NOAA nowCOAST web site (http://nowcoast.noaa.gov/ciflow/), and the Coastal Emergency Risks Assessment web site (http://nc-cera.renci.org/cgi-cera-nc/cera-nc.cgi). The Raleigh and Newport/Morehead City NWS Weather Forecast Offices shared CI-FLOW information during Hurricane Irene with critical decision-makers in briefings and conference calls. Delayed surveys of deployed gauge locations resulted in a preliminary assessment of the performance of CI-FLOW total water level simulations during Hurricane Irene with limited verification data, which was presented in webinars hosted by the National Weather Center and the NWS Office of Hydrologic Development. Following the release of the additional gauge data, a more thorough assessment of the performance of the CI-FLOW system was conducted and submitted for peer-reviewed publication.
The two weeks prior to the landfall of Hurricane Irene, CI-FLOW researchers developed and implemented a 128-member ensemble for the HL-RDHM. The 128-member ensemble runs once every six hours providing a 6-hour model state update and a 12-day period for forecasting (5 days previous and 7-day forecast). The members of the ensemble were created using varied model parameter sets (multi-scale, single-scale, single event, and a priori calibration) and a combination of multipliers on rainfall and channel routing. In FY12, the output from all ensemble members for each forecast point was displayed on the CI-FLOW web site. Real-time simulations of coastal water levels for the 2012 Atlantic hurricane season are available on the CI-FLOW, NOAA nowCOAST, and Coastal Emergency Risks Assessment web sites.

In FY12, project members were involved in a number of outreach and education activities. They hosted two volunteer emergency managers from Victoria, Australia studying best practices for flash flood warning systems and public education. A CI-FLOW training session was conducted with forecasters from the Newport/Morehead City NWS Forecast Office to familiarize users with the Coastal Emergency Risks Assessment web site. The Climate/Weather Extension Specialist collaborated with a Coastal Processes Specialist at Woods Hole Sea Grant and Cape Cod Cooperative Extension to produce a Marine Extension Bulletin on coastal erosion caused by hurricanes and nor’easters. Woods Hole Sea Grant distributed 500 copies of the Marine Extension Bulletin to coastal residents in Massachusetts. In collaboration with South Carolina Sea Grant, the content of the CI-FLOW public web site (http://www.nssl.noaa.gov/ciflow) is being rewritten to make it more suitable for general public audiences. In addition, project staff members are actively involved in NOAA’s Storm Surge Roadmap.

Publications


CI-FLOW predicted water levels above sea level (ft) issued at 1500 UTC 27 August 2011 (approximately at time of hurricane landfall) overlain with Hurricane Irene’s track in coastal eastern North Carolina. Maximum predicted water levels occurring on the western side of the barrier islands of 6–8 feet compared within ± 1 foot of the observations. Highest predicted inundation amounts occur in the Neuse and Tar River outlets to the Pamlico Sound.

**CIMMS Task III Project – Weather Processors Support Task: Right-Sizing NextGen Weather Observation Network**

Jerry Brotzge (CAPS at OU), Frederick Carr (OU School of Meteorology), Nick Gasperoni (OU School of Meteorology and CAPS at OU), G. Kutty Mohan Kumar (CAPS at OU), Xuguang Wang (OU School of Meteorology), Ming Xue (CAPS at OU)

**NOAA Technical Lead:** Kevin Kelleher (NSSL)

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

**Funding Type:** CIMMS Task III (U.S. DOT/FAA through NSSL)
**Objectives**
Develop a multi-year plan for NextGen for developing, testing, and demonstrating an optimal design for the collection and processing of information from the sensor observation networks located within terminal airspace; develop a means for quantifying the real-time impact of individual observing systems on mesoscale analyses and forecasts – such a tool will allow for the strategic deployment, and assimilation of, specific sensing systems for yielding the best analyses and forecasts possible.

**Accomplishments**
The primary deliverable from this work was writing the Super Density Operations (SDO) Integration Plan, which outlined a process by which current terminal weather observing networks may be consolidated to allow for a more versatile, “plug-and-play” configuration. One goal of NextGen is to combine the functionality of FAA surface sensors into a single Reduce Weather Impact (RWI) solution set in contrast to current system architecture that inhibits new sensor integration and expansion. This report was delivered to the FAA on 15 November 2010. A second deliverable from this project was the initial development of a diagnostic tool to quantify the value of individual observations to the sensitivity of a given analysis or forecast at the meso- and storm-scales. This tool is being developed using an Ensemble Kalman Filter (EnKF) system and will be applied in real-time. Excellent progress has been made, and work will be continued through non-FAA support.

*Proposed data flow architecture for the collection and processing of weather observations for local SDO terminal operations.*
CIMMS Task III Project – Improving NOAA Operational Global Numerical Weather Prediction using a Hybrid Variational-Ensemble Kalman Filter Data Assimilation and Ensemble Forecasting System

Xuguang Wang (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 (NOAA/OWAQ)

Objectives
The general goal of the project is to improve NOAA operational global numerical weather prediction using a hybrid variational-ensemble Kalman filter data assimilation and ensemble forecasting system. Specific goals for the reporting period were to further conduct sensitivity experiments for the hybrid system and further develop and conduct research for the ensemble 4DVAR (ENS4DVAR) hybrid.

Accomplishments

1. Extensive Tests and Operational Implementation of the Ensemble-3DVAR Hybrid System

The hybrid ensemble Kalman filter (EnKF)-3DVAR data assimilation (3DENSVAR) system was developed based on NCEP GSI (3DVAR) during the last reporting period. In this reporting period, various sensitivity tests were conducted on the 3DENSVAR system. The first figure below shows that various configurations of the hybrid performed better than the GSI. The hybrid system was further tested by running it in parallel with the operational GSI. It was also found that the forecast initialized by the hybrid system was better than the operational global forecasts. The 3DENSVAR hybrid system was implemented operationally at NCEP on 22 May 2012.

2. Extensive Tests of the 4D Ensemble-Variational Hybrid System

The 4D ensemble-variational hybrid system (4DENSVAR) was developed during the last reporting period. During this reporting period, extensive sensitivity tests and verifications of the 4DENSVAR with various configurations and metrics were conducted. The second figure below compares the globally averaged anomaly correlation of the variously configured 4DENSVAR with the 3DVAR hybrid and the GSI. The experiments were conducted over a 5-week period in summer 2010. The verification was against the ECMWF analyses. Forecasts from both the 3DVAR hybrid and 4DENSVAR were more skillful than those from GSI. Forecasts from 4DENSVAR were consistently more skillful than that of 3DVAR hybrid. For ENS4DVAR, using hourly ensembles within the 6-hour assimilation window performed better than using 2-hourly ensemble. The balance constraint in GSI improved forecasts of both 3DVAR hybrid and 4DENSVAR.
In addition to verification of general forecasts, verification for hurricane track forecasts was also conducted. The third figure below shows the root mean square errors (rmse) of track forecasts for hurricanes during the 5-week period of summer 2010. Hurricane track forecasts from various configurations of the hybrid were more accurate than the GSI. 4DENSVAR improved the track forecasts further compared to the 3DVAR hybrid. When the balance constraint was applied, 4DENSVAR with more frequent ensembles (hourly ensemble) improved the track forecasts compared to the 3DVAR hybrid. When the balance constraint was not applied, 4DENSVAR even with less frequent ensembles (2-hourly ensemble) improved the track forecasts as compared to the 3DVAR hybrid. Different from general global forecasts, the balance constraint in GSI applied on the hybrid (both 3DVAR hybrid and ENS4DVAR) degraded the hurricane track forecasts. Diagnostics have been conducted to understand the superior performance of the 4DENSVAR over 3DVAR hybrid (not shown). A few papers documenting the research results for both the 3DVAR hybrid and 4DENSVAR are in preparation.

Publications

Awards
Xuguang Wang received the 2012 College of Atmospheric and Geographic Sciences Dean's Award for Excellence in Research and Scholarship.
The averaged fit of the forecasts to the in-situ conventional observations for temperature (left column) and wind (right column) as a function of pressure at 24-hour (a,b), 72-hour (c,d) and 120-hour (e, f) forecast lead time. Solid, dash, dotted, dash-dotted lines are for GSI (3Dvar) (gsi), one-way coupled hybrid with full ensemble covariance (hyb1way), two-way coupled hybrid with full ensemble covariance (hyb2way), and one-way coupled hybrid with equal weights on the static and ensemble covariances (hyb1way.5).
Anomaly correlation of forecasts and ECMWF analysis as a function of forecast lead time during summer month of 2011 for GSI (black solid), 3DVAR hybrid with (green solid) and without balance constraint (green dash), 4D ensemble VAR hybrid with two-hourly ensemble with (red solid) and without balance constraint (red dash), 4D ensemble VAR hybrid with hourly ensemble (blue solid).

Root mean square hurricane track forecast errors during summer month of 2010 as a function of forecast lead time for GSI (black solid), 3DVAR hybrid with (green solid) and without balance constraint (green dash), 4D ensemble VAR hybrid with two-hourly ensemble with (red solid) and without balance constraint (red dash), 4D ensemble VAR hybrid with hourly ensemble (blue solid).
CIMMS Task III Project – Development of Short-Range Realtime Analysis and Forecasting System based on the ARPS for Taiwan Region

Ming Xue, Fanyou Kong, Keith Brewster, Chong-Chi Tong, Michael Hernandez (all CAPS at OU)

NOAA Technical Lead: Fanthune Moeng (NOAA/GSD)

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

Funding Type: CIMMS Task III (NOAA/GSD)

Objectives
Configure, demonstrate, and deploy a real-time forecasting system at convection-allowing resolution (2.5 km), based on ARPS modeling system, for the Central Weather Bureau (CWB) of Taiwan, to obtain accurate 0-3h heavy precipitation forecasts.

Accomplishments
During the reporting period, CAPS had helped CWB to setup, test and implement the realtime ARPS data analysis and forecast system; provided instructions for CWB team to generate 0-4h QPF forecasts; developed, tested, and provided pre-processing programs to analyzing upper air (AIREP, PILOT, SATEM, SATOB, TEMP, TEMPDROP, and TEMPSHIP) and surface (BOUY, MESONET, METAR, SHIP and SYNOP) observation data to CWB to be implemented; performed case studies on one Meiyu case (28 May 2010) and on Typhoon Morakot case (7-8 August 2009) to investigate the impact of surface and upper air observation data assimilation, and the impact and effectiveness of various DA cycling strategies; provided a baseline bias correction program and a QPF verification package to CWB; developed and tested through the Meiyu case study the capability to ingest and assimilate automated weather station (AWS) observation data, with the program code delivered to CWB.

CAPS met all deliverable requirements for the reporting period, including three code deliveries, one annual report due October 2011, one PowerPoint presentation for the semi-annual review, and one PowerPoint presentation for the Meiyu case study investigating the AWS impact. CAPS performance during this reporting period has been accepted in the annual review meeting held in CWB in November 2011 and the semi-annual review meeting held in May 2012 at the NWC.
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, Fanyou Kong, Keith Brewster, Youngsun Jung (all CAPS at OU)

NOAA Technical Leads: Mark DeMaria and Ingrid Guch (NESDIS/STAR)

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

Funding Type: CIMMS Task III (NOAA/NESDIS)

Objectives
Through collaborations, a better understanding of the interaction between cloud microphysics and radiative transfer modeling will be sought so as to provide insights for improving the Community Radiative Transfer Model (CRTM) system, which is part of the operational data assimilation systems at NCEP.

Accomplishments
This project represents collaboration between three institutions: CAPS, CIMSS-Wisconsin, and CIRA-Colorado State. The proposed project employs 4-km storm-scale ensemble forecasts (SSEFs) produced by CAPS for the HWT Spring Experiments. Utilizing national supercomputing resources, synthetic imagery is generated in real-time, for several infrared channels from 10-15 ensemble members, at hourly intervals. Three radiative transfer (RTM) model packages were 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 of Colorado State University. They were used to generate synthetic brightness temperatures for selected Advanced Baseline Imager (ABI) and current GOES infrared channels. Through collaborations, a better understanding of the interaction between cloud microphysics and radiative transfer modeling will be sought so as to provide insights for improving the CRTM system, which is part of the operational data assimilation systems at NCEP. 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.

CAPS installed the NESDIS CRTM package (v2.0.5) on local computers and on NICS Kraken, a Cray XT5 supercomputer used by the CAPS storm-scale ensemble forecasting (SSEF), in late 2011. One CAPS research associate visited NESDIS in January 2012 for two weeks to further learn CRTM. Interface programs were developed in early 2012 that allow CAPS SSEF post-processing programs to call CRTM subroutines to generate synthetic ABI and GOES infrared brightness temperatures and radiances. The programs were tested on Kraken under the realtime SSEF running environment using 2011 CAPS HWT Spring Experiment case data. The figure below
shows example synthetic imagery for all GOES-R ABI infrared channels using April 27, 2011 Alabama super tornado case computed from SSEF member 26 25-h forecast dataset.

The CIMSS team at Wisconsin installed its Successive Order of Interaction (SOI) RTM on NICS Kraken also. The CIRA team at Colorado State worked on updating the CIRA RTM codes with the recent version of CRTM, which has been used to get optical depth and with the implementation of the routines that Jason Otkin of CIMSS provided to obtain number concentrations for each cloud microphysics scheme. TB comparison runs between the CIRA RTM and CRTM were performed.

All three RTMs were run during the 2012 HWT Spring Experiment, generating realtime synthetic brightness temperature and ensemble products for GOES-13 10.7µm for all 28 CAPS SSEF members and made available to HWT participants for evaluation as part of the GOES-R Proving Ground. Feedback from the participants was positive. The following figure shows example products generated in realtime during 2012 NOAA HWT Spring Experiment, using all three RTMs. Full products are also demonstrated on CAPS realtime forecast website (http://www.caps.ou.edu/~fkong/sub_atm/spring12.html).

Synthetic brightness temperature products of GOES-13 10.7µm channel generated from CAPS SSEF 24 h forecast valid at 00 UTC May 31, 2012. (a), (b), and (c) are brightness temperature computed using CRTM, CIMSS, and CIRA RTMs, respectively; (d), (e), and (f) are ensemble mean, probability of brightness temperature below -32°C, and probability of brightness temperature below -52°C, respectively, from the CRTM ensemble.
CIMMS Task III Project – Contribution to Model Development and Enhancement Research Team by CAPS

Ming Xue, Kefeng Zhu, Yujie Pan (all CAPS at OU), Xuguang Wang (OU School of Meteorology)

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)

Objectives
Develop and test an ensemble Kalman filter (EnKF) and GSI-based EnKF/3DVAR hybrid data assimilation system suitable for operational implementation for the Rapid Refresh (RAP) forecasting system; establish radar DA capabilities in the EnKF and hybrid systems and eventually apply the systems to the High Resolution Rapid Refresh (HRRR) system.

Accomplishments
An EnKF system for the RAP grid, with both ensemble forecasts and EnKF analyses performed at 1/3 of the RAP resolution (~40 km grid spacing) has been established. This EnKF system is also used to establish an EnKF/GSI-3DVAR hybrid DA system run currently at the same ~40 km resolution. A dual resolution version where a high-resolution EnKF or hybrid is run at 13 km resolution is also being established. A large number of tests has been conducted to tune and determine the 'best' configurations of the systems, including the covariance localization and inflation schemes and parameters used.

The EnKF system is based on the NCEP operational GSI 3DVAR system and borrows the data processing and observation operators from GSI. Parallel comparison tests are made using EnKF or hybrid and GSI and the performances of the systems are evaluated in terms of short-range forecast for up to 18 hours, by verifying against upper air sounding and surface station observations. Both EnKF and GSI are run at 3 hourly cycles over a 9 days long period from a spring with active convection, and results show that the EnKF outperforms GSI for temperature, relative humidity, and horizontal wind components for forecasts up to the 18 hours of forecast. Extensive tuning including the use of height-dependent localization scales an adaptive inflation improved the EnKF performance. When the EnKF employs multiple physics parameterization schemes, forecast errors in relative humidity and temperature at the upper levels and surface variables are further reduced. Equitable threat scales of precipitation forecasts on the 13 km RAP grid, initialized by 3 hourly EnKF analyses are consistently better than those from GSI analyses. With the EnKF/GSI hybrid, better results are found when a 50% static and 50% flow-dependent background error covariance is used. It’s found that for a 20-member ensemble, the hybrid scheme clearly out-performs the EnKF, while for 40
members, EnKF often out-perform the hybrid scheme (see figure), most likely because of the flexibility with the EnKF in using observation type and spatially varying localization scales while for the hybrid scheme to do so, multiple analysis steps have to be used. Further tests are being done to identify the cause and hopefully improve the hybrid results.

Average RMSEs for the three-hour forecasts of relative humidity, temperature and wind components verified against sounding data for 3-hour continuous cycles over a 9-day period, comparing EnKF and EnKF/GSI hybrid schemes using 20 and 40 ensemble members and with GSI. In general, EnKF with 20 members is the worst, while EnKF with 40 members performs the best. The hybrid scheme with 20-member ensemble is much better than the EnKF with 20 members, due to the inclusion of the static covariance when the ensemble-derived covariance is poor.
CIMMS Task III Project – Advanced Data Assimilation and Prediction Research for Convective-Scale “Warn-on-Forecast”

Ming Xue, Keith Brewster, Youngsun Jung, (all CAPS at OU), Xuguang Wang (OU School of Meteorology)

NOAA Technical Lead: David Stensrud (NSSL)

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

Funding Type: CIMMS Task III (NOAA/NSSL)

Objectives
The main objectives of the CAPS portion of the project include: development and application of convective-scale ensemble data assimilation methods and systems; participation in inter-comparison projects for DA methods on selected cases; and development of capabilities towards real-time radar DA cycling experiments during future HWT spring programs, a potential task for follow-on years.

Accomplishments
Advanced data assimilation (DA) is the essential procedure for obtaining accurate initial conditions for thunderstorm forecasts, which is the key to the Warn-on-Forecast (WoF) vision. As a partner of the WoF project led by NSSL, CAPS focused its efforts on developing, refining and applying ensemble-based data assimilation systems to storm-scale deterministic and probabilistic predictions. Efforts also were made to develop a hybrid ensemble-variational data assimilation system that seeks to combine the strengths of both variational and ensemble methods.

A four-dimensional asynchronous ensemble square root filter (4DEnSRF) algorithm has been developed for WRF and ARPS, and is now implemented in the parallel EnKF framework of CAPS and is being further refined. A paper reporting OSSE results have been accepted (Wang et al. 2012a). The 4DEnSRF system is being applied to a fast-moving tornadic supercell that occurred on 10 May 2010. Preliminary results show clear advantages of the 4DEnSRF algorithm.

Good progress is being made in various data assimilation applications and experiments. The CAPS parallel EnKF system has been enhanced to include all conventional observations used by ADAS and ARPS 3DVAR, and the correctness of their assimilation on parallel platforms has been verified. The efficiency of the system has been further improved by careful load balancing for data from large radar networks. This EnKF system has been applied to two VORTEX2 cases: the 10 May 2010 Oklahoma-Kansas tornado outbreak and 5 Jung 2009 Goshen County, WY, tornadic supercell. The performance of the system for assimilating multi-scale observations over a mesoscale domain with a storm-scale nest is being investigated for the 10 May 2010 case.
Progress has also been made with the ARPS 3DVAR system. A paper on the impact of including a diagnostic pressure equation constraint (DPEC) within the 3DVAR on the analysis and forecast of convective storms is recently accepted for publication (Ge et al. 2012). Variational assimilation of radar reflectivity has been incorporated into the ARPS 3DVAR system, which also paves the way for assimilating reflectivity in a hybrid system.

A serial version of the Local Ensemble Transform Kalman Filter (LETKF) has been implemented within the CAPS EnKF framework, and its performance is found to be comparable to that of ARPS EnSRF. A parallel implementation is under way.

Publications
Ge, G., J. Gao, M. Xue, and K.K. Droegemeier, 2012: Diagnostic pressure equation as a weak constraint in a storm-scale three dimensional variational radar data assimilation system. *Journal of Atmospheric and Oceanic Technology*, Accepted.


Wang, S., M. Xue, and J. Min, 2012: A four-dimensional asynchronous ensemble square-root filter (4DEnSRF) and tests with simulated radar data. *Quarterly Journal of the Royal Meteorological Society*, Accepted.

Theme 3 – Climatic Effects of/Controls on Mesoscale Processes

CIMMS Task I Project – Investigation of Large-Scale Atmospheric Moisture Budget and Land Surface Interactions over U.S. Southern Great Plains including for CLASIC (June 2007)

Peter Lamb (CIMMS at OU), Diane Portis (CIMMS at OU), Abraham Zangvil (Ben-Gurion University of the Negev, Israel)

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
Evaluation of Southern Great Plains atmospheric moisture budget and surface interactions as background for the Cloud and Land Surface Interaction Campaign (CLASIC).

Accomplishments
Southern Great Plains’ atmospheric moisture budget and surface interactions are evaluated for contrasting May-June periods (1998, 2002, 2006, 2007), as background for CLASIC of (wet) June 7-30, 2007. Budget components (flux divergence, MFD; storage change, dPW; inflow, IF/A) are estimated from North American Regional Reanalysis data. Precipitation (P) is calculated from NCEP daily gridded data, evapotranspiration (E) is obtained as moisture budget equation residual, and the recycling ratio (P_E/P) is estimated using a new equation. Regional averages are presented for months and five daily P categories.

Monthly budget results show: E and E-P are strongly positively related to P; E-P generally is positive and balanced by positive MFD that results from its horizontal velocity divergence component (HD, positive) exceeding its horizontal advection component (HA, negative). An exception is 2007 (CLASIC), when E-P and MFD are negative and supported primarily by negative HA. These overall monthly results characterize low P days (≤ 0.6 mm), including for non-anomalous 2007, but weaken as daily P approaches 4 mm. In contrast, for 4 < P ≤ 8 mm d⁻¹ E-P and MFD are moderately negative and balanced largely by negative HD except in 2007 (negative HA). This overall pattern was accentuated (including for non-anomalous 2007) when daily P > 8 mm. Daily P_E/P ratios are small and of limited range, with P category averages 0.15-0.19. Ratios for 2007 are above average only for daily P ≤ 4 mm. CLASIC wetness principally resulted from distinctive MFD characteristics. Solar radiation, soil moisture, and crop status/yield information document surface interactions.

Publications
CIMMS Task I Project – Weathering the Drought: Building Resilience in the Face of Global Environmental Change

Emily Boyd (University of Reading), Rosalind Cornforth (University of Reading), Peter Lamb (CIMMS at OU), Alan Brouder (Oxfam GB), Aondover Tarhule (OU Department of Geography and Environmental Sustainability), M. Issa Lélé (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
The West African Sahel is currently under threat of food shortages with 19 million people at risk. While there are calls for policy measures to build resilience in the face of ongoing and future crises in the region, resilience remains a contested concept. Yet, people are challenged now across the world with adapting in the face of a global sustainability problem that will lead to recurring and potentially irreversible crises, irrespective of any linkage to global warming or development of a global consensus on tackling greenhouse gas emissions. Given this challenge and that short-term weather and seasonal climate forecasting still have limited skill for West Africa, near real-time monitoring and improved communication channels can make a difference to real peoples’ lives now by helping them learn from crises and prepare for the next set of future events.

We have focused on the case of the Rainwatch project applied to the monitoring of the 2011 West African rainy season, and the resulting severe drought-induced humanitarian impacts that continue in 2012. In the context of weak institutions we identify three defining features for a climate resilient management system, which include: 1) effective monitoring and communication of weather and climate; 2) committed individuals who actively engage in building relations and connect across stakeholders; and 3) sufficient time frames to develop an effective system. At a bare minimum, institutions must put in place practical and tangible innovations to anticipate signals of impending crises. This includes identifying rainfall deficits through long-term monitoring and timely communication of user-relevant information, access to relevant and reliable forecasts, and the ability of stakeholders to act on that information.

Publications
**Theme 4 – Socioeconomic Impacts of Mesoscale Weather Systems and Regional Scale Climate Variations**

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

**NOAA Technical Lead:** David Stensrud (NSSL)

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

**Funding Type:** CIMMS Task II

1. **Ensemble Severe Weather Data Mining**

James Correia, Jr. (CIMMS at SPC)

**Objectives**
Summarize large data sets for severe weather prediction applications.

**Accomplishments**
Three distinct ensembles (two 10-member and one 7-member) of high-resolution convection-allowing model data were statistically summarized and used to generate daily convective outlooks. The statistical summary information involved using object-based methods to identify updraft helicity tracks (essentially rotating storms) in which the characteristics of member, time, location, length, magnitude, and area were recorded. These data were then used to prepare histograms of timing, magnitude, members, and spatial location for quick perusal in the Mondrian Statistical software package. These data were then mapped to a high-resolution grid where probabilities were derived via neighborhood kernel density estimation for two thirds of the CONUS. This dataset, displayed two ways, helped to determine the timing of different threats across the country and guided our selection of the most significant threat area that the severe desk focused on the Experimental Forecast program. In addition, since these updraft helicity objects were treated like storm reports, they were verified against observed tornado and hail reports. Following day verification was explored with the participants when forecasts were evaluated.
An example forecast from 1 June 2012 depicting the AFWA ensemble: bar chart of ensemble membership (upper left), a series of histograms of forecast hour (bottom left), UH path length (bottom middle) and UH magnitude (bottom right), and the forecast probabilities of those simulated storm reports (upper right). The charts have been shaded from lowest to highest UH magnitudes. Although there are strong UH magnitudes, the majority of long track storms tended to be weak. Observed tornadoes in the DC area tended to be short lived and relatively weak, though 20% of modeled tracks in this area were associated with UH greater than 50 m²s⁻², and 10% greater than 75 m²s⁻². These high values have been shown by Clark et al. (2012) to be associated with tornado outbreaks when tracks are long.

2. Evaluating the Efficacy of Call-to-Action and Information Statements

Gabe Garfield (CIMMS at OUN)

Objectives
Understand how forecasters should communicate with the public to encourage proper comprehension of weather information.

Accomplishments
During the reporting period, survey data collected during spring 2011 were analyzed. The survey addresses the efficacy of the so-called “call-to-action” statements (CTAs)
contained with the tornado warning – the text that outlines threats and recommended actions – and other information statements. A sample of the U.S. public (N = 804) considered several hypothetical tornado scenarios. In these, they identified the statements they considered the most likely to inspire action and convey the greatest certainty (real CTAs were included). Results show that the current warning statements can be improved significantly, and are not preferred by the sample. In particular, communicating “dread” risk encourages protective decision responses, comprehensive tornado precaution information is desired, and text emphasis conveys greater urgency – leading to a higher likelihood of protective action.

3. 24 May 2011 Sheltering Study

Gabe Garfield (CIMMS at OUN)

Objectives
Understand how forecasters should communicate with the public to encourage proper comprehension of weather information.

Accomplishments
During the reporting period, patterns of public sheltering during the 24 May 2011 tornado outbreak in Oklahoma were investigated. That day, an unusually large number of citizens took shelter at public buildings – many of which were not shelters – resulting from a large effort by the media and the NWS to warn of the severity of the impending outbreak. Fortunately, no loss of life occurred at these shelters, owing to the fortuitous dissipation of the violent tornadoes outside of the Oklahoma City metropolitan area. Though this situation was unique, it is likely that similar scenarios will unfold when greater lead times – associated with Warn-on-Forecast – are realized.

Thus, work has begun to simulate the potential costs of a violent tornado strike on “non-sheltering” shelters. It is hypothesized that the loss of life may have been more extreme in the case of large advance warning than in the case of current warning lead times. To investigate this, the El Reno EF5 tornado path is being used to simulate a number of potential paths through the Oklahoma City metro area. Hypothetical death tolls will be estimated for both scenarios from mortality rates consistent with historical tornadoes.
CIMMS Task III Project – Southern Climate Impacts Planning Program (SCIPP)

Mark Shafer (OCS at OU), Barry Keim (LSU), Renee Edwards (LSU), Yang Hong (OU Civil Engineering and Environmental Sciences), Peter Lamb (CIMMS at OU), Mark Meo (OU Department of Geography and Environmental Sustainability), Kevin Robbins (LSU), May Yuan (OU Geoinformatics)

Staff and Undergraduate Students: L. Carter (LSU), M. Boone (OU), H. Needham (LSU), R. Riley (OU), C. Lunday (OU), E. Fagan (OU), B. Wesbury (OU), S. Blackburn (OU), J. Bostic (OU), K. Brehe (LSU), G. McManus (OU), B. McPherson (OU), L. Romolo (OU), D. Sathiaraj (LSU), A. Shih (OU), H. Shrivastava (OU)

Graduate Research Assistants: L. Becker (LSU), A. Billiot (LSU), R. Gottlieb (OU), C. Kovacik (OU), L. Liu (OU), A. Trevino (LSU)

NOAA Technical Lead: Caitlin Simpson (CSI/RISA Program Manager, NOAA Climate Program Office)

NOAA Strategic Goal 1 – Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts

Funding Type: CIMMS Task III (NOAA Climate Program Office)

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 the FY12, SCIPP accomplished several reports and research, which capitalized on the major focus points of SCIPP: extreme events and hazards, climate education, and hazard planning.

First, the Oklahoma climate needs assessment, which began in late 2010, was completed in February 2012. The assessment was based on input from decision makers in 23 local, tribal, state, federal, non-profit, and for-profit agencies across Oklahoma in the following sectors: agricultural production, ecosystems, energy, health, society/public safety, transportation, and water resources. The data revealed the most significant climate-related issues that Oklahoma decision makers are currently facing and anticipate they will face in the future, the spatial and temporal scales in which they make decisions, and their need for climate information, education, and decision-support tools. The findings demonstrate that climate had an enormous impact on the sectors in which the decision makers worked.

Next, more than 60 in-person interviews were conducted along the western Gulf of Mexico as part of the Gulf Coast Assessment, including much of the Texas coast (Houston/Galveston region in particular) as well as Louisiana to include representative
interviews along the Texas, Louisiana, and Mississippi coasts. The goal of the Gulf Coast Assessment was very similar to the Oklahoma assessment and focused on climate data needs for coastal stakeholders, perceptions of climate change, and use of climate projections and models. Planners at various community levels represented roughly 16%, and others included agriculture, fishing, permitting, local government, environment, coastal resources, healthcare, and more. As part of the interviews, the SCIPP team provided a series of educational handouts focused on temperature, precipitation, and sea-level rise. Not surprisingly, the research revealed that storm surge and hurricanes are the hazards with the biggest impact on the coast, while sea-level rise is an issue that stakeholders expect to become a bigger threat in the future.

With regard to climate education, SCIPP, in collaboration with Haskell Indian Nations University and the Oklahoma Climatological Survey, and supported in part by the U.S. Global Change Research Program and the National Aeronautics and Space Administration, hosted a meeting on climate variability and change with Oklahoma tribal representatives on 12 December 2011. Oklahoma is home to 39 federally-recognized tribal nations and this meeting provided them with the opportunity to offer input to be included in the 2013 National Climate Assessment (NCA). Of the seventy-three people that participated in the meeting, 42 represented Oklahoma tribes (21 tribal nations were represented). Two participants from a tribe in Texas also attended. Furthermore, three out of the four tribal colleges in Oklahoma were represented. The purpose of the meeting was to 1) enhance and foster dialogue between tribal representatives and climate scientists that was previously initiated through two statewide meetings in which tribal representatives were invited and some attended, 2) educate tribal representatives about climate science and climate change, and 3) develop recommendations for material to be included in the 2013 NCA document.

In direct response to stakeholder requests, storm surge analysis, specifically estimations of storm surge return periods along the U.S. Gulf Coast, were a major research focus. Results indicate the SCIPP Gulf Coast states, Texas, Louisiana and Mississippi, are most vulnerable to storm surge inundation. All of the Mississippi Coast, and portions of the Texas and Louisiana Coasts see 100-year storm surge levels greater than 20 feet. As part of the storm surge research project, a storm surge Internet blog was also maintained. The purpose of the blog was to provide historical context for active hurricane/storm surge events. The SURGEDAT dataset and “Hurricane Hal’s Storm Surge Blog” can be located at http://surge.srcc.lsu.edu.

Lastly, a drought of strong intensity and vast geographical extent gripped the South Central United States throughout 2011 and into 2012. To respond to these severe ongoing conditions, multiple efforts, including webinars and forums, were launched to engage decision-makers from regional to state to local arenas in a conversation about drought. These webinars were held on the 2nd and 4th Thursdays of each month at 11:00 a.m. Central Time, and are ongoing. The content is geared toward a general audience – anyone who has responsibility to manage or assist others in managing drought and its related impacts. Each webinar includes an overview of the current drought assessment and outlook, summary of impacts across the region, and a topic or resource, such as La Niña or wildfire conditions. More than 250 people have signed up
for the webinars, with a typical draw of 60-80 registrants on any individual topic. Several
have indicated that multiple people in their organization participate in the webinar via a
single sign-in, so the number directly participating is likely higher. First and foremost,
this webinar series is a useful way to convey information across a wide region, so that
experts in one state can share their experiences with those in another. We also
recognize that the region is beset by many different types of hazards beyond drought,
such as severe storms, hurricanes, floods, winter storms, and more. Just as we have
learned from the experience with these drought webinars, there is likely an unmet need
for conveying information surrounding these other hazards.

SCIPP continues to expand its method of disseminating extreme events and hazards
information. During FY12, SCIPP created a Facebook page, and a dedicated YouTube
channel. Because social media is becoming an increasing method for information
retrieval, this has become a great outlet to promote climate education, provide important
hazard information, and include real-time extreme event updates.

Publications
Bothwell, J., and M. Yuan, 2012: Apply Concepts of Fluid Kinematics to Represent Continuous Space-
Time Fields in Temporal GIS. Transactions in GIS. Accepted.
Hoekstra, S., K. Klockow, R. Riley, J. Brotzge, H. Brooks, and S. Erickson, 2011: A preliminary look at the
social perspective of warn-on forecast: Preferred tornado warning lead time and the general
public’s perception of weather risks. Weather, Climate and Society, 3, 128-140.
Liu, L., Y. Hong, J.E. Hocker, M.A. Shafer, L.M. Carter, J.J. Gourley, C.N. Bednarczyk, and P. Adhikari,
2012: Analyzing Projected Changes and Trends of Temperature and Precipitation in the Southern
Liu, L., Y. Hong, J.E. Hocker, M.A. Shafer, and C.N. Bednarczyk, 2011: Hydro-climatological Drought
Liu, L., Y. Hong, J. Looper, R. Riley, B. Yong, Z. Zhang, J. Hocker, and M. Shafer, 2011: Climatological

Non-OU Project Publications
Keim, B.D., R. Fontenot, C. Tebaldi, and D. Shankman, 2011: Hydroclimatology of the U.S. Gulf Coast
under Global Climate Change Scenarios. Physical Geography, 32(6): 561–582.
Oklahoma Inter-Tribal Meeting on Climate Variability and Change (12 December 2011) afternoon breakout session. Participants were divided into 10 diverse groups to discuss their views on climate change, climate policy, and the tribal and federal government environmental relationships.

The graphic depicts the height of the 100-year storm surge for 10 segments of the Gulf Coast.
The Managing Drought in the Southern Plains webinar announcement.

CIMMS Task III Project – RISA Support for Regional Assessment Services at the Southern Climate Impacts Planning Program (SCIPP)

Mark Shafer (OCS at OU), Lynne Carter (LSU), Hal Needham (LSU), Rachel Riley (OCS at OU)

NOAA Technical Lead: Caitlin Simpson (CSI/RISA Program Manager, NOAA Climate Program Office)

NOAA Strategic Goal 1 – Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts

Funding Type: CIMMS Task III (NOAA Climate Program Office)

Objectives
Address a vital step in building sustainable relationships with decision-makers across the SCIPP region, and to provide a means to communicate with decision makers and begin to understand their needs in order to execute effective adaptation measurers.

Accomplishments
The Oklahoma Climate Needs Assessment, which began in late 2010, was completed in February 2012. The assessment was based on input from decision makers in 23
local, tribal, state, federal, non-profit, and for-profit agencies across Oklahoma in the following sectors: agricultural production, ecosystems, energy, health, society/public safety, transportation, and water resources. The data revealed the most significant climate-related issues that Oklahoma decision makers are currently facing and anticipate they will face in the future, the spatial and temporal scales in which they make decisions, and their need for climate information, education, and decision-support tools.

The findings demonstrate that climate had an enormous impact on the sectors in which the decision makers worked. The participants stated that flash floods and droughts, ice and snowstorms, water resource issues, and tornadoes create the most significant climate-related issues. Many decision makers use weather and/or climate information on a daily or a weekly basis, and especially during extreme or high impact events. The decision makers said their most significant climate change-related issues will arise from more intense but less frequent rain events because an increased chance of floods and drought is problematic for many agencies.

For the Gulf Coast Needs Assessment, more than 60 in-person interviews have been conducted along the western Gulf of Mexico as part of the Gulf Coast Assessment, including much of the Texas coast (Houston/Galveston region in particular) as well as Louisiana to include representative interviews along the Texas, Louisiana, and Mississippi coasts. The goal of the Gulf Coast Assessment is very similar to the Oklahoma assessment and focuses on climate data needs for coastal stakeholders, perceptions of climate change, and use of climate projections and models. This assessment places a more significant emphasis on place-based analysis than the Oklahoma Assessment, due in large part to the multi-state region of study. Survey participants included representatives of 13 professional sectors, including about 1/3 that were Emergency Management/Homeland Security or Operations personnel. Planners at various community levels represented roughly 16%, and others included agriculture, fishing, permitting, local government, environment, coastal resources, healthcare, and more. As part of the interviews, the SCIPP team provided a series of educational handouts focused on temperature, precipitation, and sea-level rise. Each handout is a two-sided publication that provides information about observed and projected changes for those three climate drivers.

Not surprisingly, the research has revealed that storm surge and hurricanes are the hazards with the biggest impact on the coast, while sea-level rise is an issue that stakeholders expect to become a bigger threat in the future. The engagement has also provided insight into the complex relationship between rainfall runoff and sea levels, as many stakeholders have indicated that heavy rainfall events do not drain well when sea levels are high or because of onshore winds. This finding reveals that even a slight rise in sea level could have serious impacts (such as reduced drainage rates), which could negatively impact coastal communities long before actual sea levels inundate the coast directly. Both documents are complete, and available for download from the SCIPP website http://www.southernclimate.org.
CIMMS Task III Project – Warn-on-Forecast and the Social Science Woven into Meteorology (SSWIM) Project

Eve Gruntfest (SSWIM at OU) and Stephanie Hoekstra (SSWIM at OU)

NOAA Technical Lead: David Stensrud (NSSL)

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

Funding Type: CIMMS Task III (NSSL)

Objectives
Assist weather tool developers in the future to disseminate weather information that will be the most useful to information users.

Accomplishments
SSWIM researchers conducted projects that worked with a variety of specific weather user groups to understand how they behaved during a sample of tornado warnings. Stephanie Hoekstra completed her Masters thesis titled How K-12 School District Officials Made Decisions During 2011 National Weather Service Tornado Warnings.

School district officials are responsible for the safety of large populations of students and staff. Yet, few have meteorological training to accurately interpret severe weather information to make the best decisions during tornado warnings, and little research has focused on further understanding the context in which these groups make weather sensitive decisions. Including the needs and perspectives of groups such as school district officials into weather product development is necessary in order to create the most valuable and useful products in the future. Eleven participants with various titles from six school districts in central and eastern U.S. were interviewed in the spring and summer of 2011. Semi-structured interviews were used to address four main questions: 1) What is the K-12 public school official’s timeline of decision making and action implementation before, during, and after tornado warnings? 2) What sources of weather information do key decision makers in K-12 public schools access and why? 3) What are the non-weather factors that influence how decisions are made? and 4) What types of weather information might improve operations for K-12 public schools, and how might longer lead times change the decision making process? Interviews were coded according to predetermined themes and analyzed.

Preparations for tornado warnings, such as conducting drills, educating the students, and crafting severe weather plans, occurred during the majority of the year when there was no severe weather. Additionally, much of the action taken, most notably communicating with staff, students, and parents, occurs throughout several phases beginning hours before the severe weather was approaching to when the tornado warning has passed. “Lead time” in the minds of these decision makers thus began several hours before the tornado warning was issued, emphasizing the need to step
away from the traditional mindset that a tornado warning lead time is only minutes before a tornado occurs. These decision makers used sources similar to what the general public is known to use, including NOAA websites, the television, and NOAA radios. Regardless of the severity of the weather, the majority of participants carried out their severe weather plans and sheltered students immediately after a tornado warning was issued for their district. Non-weather factors influenced how they perceived the warning and how students were brought into shelter, but they did not affect their decision of whether or not to shelter; taking shelter was an automatic response after a warning was issued. These participants prefer more spatial information with clear indication of whether or not the storm is likely to impact their district directly. Overall, participants found that extended tornado warning times would provide more time to go over plans and communicate with others, and recognized that this would require a modification of current warning plans and response. Several questioned whether a two-hour lead-time would still bring the same sense of urgency as current warnings. This study shows that new meteorological advancements should respond to the expressed needs of stakeholders.

A revised version of the thesis was co-authored with Amy Nichols and Eve Gruntfest and was submitted to the *International Journal of Mass Emergencies and Disasters* in July 2012; it is under review. Research is complete.

**Awards**

Stephanie Hoekstra received an award from the Department of Geography and Environmental Sustainability for Outstanding Publication of the Year in 2012.

Stephanie Hoekstra and her colleague Amy Nichols received the award of Outstanding Presentation during the American Meteorological Society Annual Meeting in New Orleans in January 2012.
Hypothesized timeline of school district officials’ response during tornado warnings and the weather information used.

Modeled hypothesis of the non-weather related factors influencing school district official decision-making and action implementation during tornado warnings.

Eve Gruntfest (SSWIM at OU), Amy Nichols (SSWIM at OU), Jennifer Spinney (SSWIM at OU)

NOAA Technical Leads: Kevin Kelleher (NSSL – The NWC’s Social Science Initiative); Penny Granville (NOAA/ESRL – What Makes Our Partners Tick?)

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

Funding Type: CIMMS Task III (NOAA/NSSL and ESRL)

Objectives
Understand the responses and decision-making processes of university officials during tornado warnings in the spring of 2011 and the possible impacts of changes to tornado warning lead-time on those processes.

Accomplishments
This study provided the university emergency management community perspective for those involved in the Hazardous Weather Testbed’s Experimental Warning Program Probabilistic Hazards Information project and NOAA’s Warn-on-Forecast project, and can assist in the development of future meteorological research on tornado warning and weather information products. Amy Nichols successfully defended and submitted her thesis entitled “How University Administrators Made Decisions During National Weather Service Tornado Warnings in the Spring of 2011” to the Graduate College at the University of Oklahoma earning her Master’s degree in Geography and Environmental Sustainability.

This research examined how public university officials made decisions during National Weather Service tornado warnings in the spring of 2011, how weather information and non-weather factors influenced decision making, and how new tornado warning practices may affect their decision making process. New tornado warning paradigms are under development by NOAA’s Hazardous Weather Testbed and Warn-on-Forecast groups that will increase tornado warning lead times.

Universities placed under tornado warnings were identified during the spring 2011 tornado season. Interviews with emergency managers and officials at five public universities were conducted to address four main research questions: 1) how and when do key decision makers use weather information in decision making about notifying the campus during tornado warnings? 2) how do non-weather related contexts affect the decisions made about emergency notification of the campus during tornado warnings? 3) what sources of information do key decision makers at universities access during
tornado warnings? and 4) what decision support tools would improve operations, with particular focus on changes in lead-time with probabilistic warning information?

This research found that NWS tornado warnings acted as a trigger to activate most emergency notification systems but multiple decisions and actions occur prior to the issuance of the tornado warning, including communication with other departments on campus, weather monitoring, and situational assessment. The main non-weather factors that influenced decision-making were the time of day or year and the location of people on campus. The most common and important sources of weather information used to make decisions were public or private radar sources and personal communication with weather information providers and local or neighboring emergency management.

Weather information preferences included increased spatial and timing specificity and the development of relationships with National Weather Service Weather Forecasting Offices. This research found that longer lead times with low probabilities would result in less decisive calls to action than shorter lead times with higher probabilities. This research also found that lead time for tornadoes may include the advanced notice provided by outlooks, forecasts, and watches provided by the National Weather Service from the perspective of university emergency managers.

Presentations of this research were given at the 2012 American Meteorological Society Annual Meeting in New Orleans, LA, the Warn-on-Forecast and High Impact Weather Workshop in Norman, OK, and the 2012 Association of American Geographers Annual Meeting in New York, NY. A revised version of the thesis was co-authored with Stephanie Hoekstra and Eve Grunfest – it was submitted to the International Journal of Mass Emergencies and Disasters in July 2012 and is under review. Research is complete.

**Awards**

Amy Nichols and her colleague Stephanie Hoekstra received the award of outstanding presentation during the American Meteorological Society Annual Conference in 2012.
General timeline for severe weather at universities from the university emergency management perspective.

Hypothesis model of non-weather factors influencing university official decision-making. Dotted line indicates that unanticipated factors do not always impact decision-making.
From Jennifer Spinney and Eve Gruntfest's NOAA CIMMS IHIS project – What Makes our Partners Tick Using Ethnography to Inform the NOAA Global Systems Division Integrated Hazards Information Service (IHIS).
Theme 5 – Doppler Weather Radar Research and Development

NSSL Project 1 – Advancements in Weather Radar

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

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

Funding Type: CIMMS Task II

1. WSR-88D Improvements

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

Accomplishments

a. Ground Clutter Mitigation

Sebastian Torres (CIMMS at NSSL), David Warde (CIMMS at NSSL)

A common dilemma in obtaining good-quality meteorological-variable estimates using Doppler weather radar is the application (or misapplication) of ground clutter filters (GCF) to mitigate contamination from ground returns. Typically, weather radars use static clutter maps (i.e., pre-identified clutter contaminated regions) to control the application of the GCF. Ideally, the GCF should only be applied if the ground clutter contamination obscures the weather estimate. However, the problem of applying the GCF becomes very complex considering the dynamic atmospheric effects on radar beam propagation. The goal of this project is to develop efficient techniques that provide both automated detection and application of ground clutter filtering. The Clutter Environment Analysis using Adaptive Processing (CLEAN-AP) filter is a spectral technique for automatic detection and mitigation of ground clutter contamination.

We had previously shown the clutter detection and mitigation performance of the CLEAN-AP filter using time-series data from the national network of weather surveillance radars (WSR-88D), the dual-polarized KOUN and OU Prime radars, and the NWRT PAR. In 2011, the NEXRAD Technical Advisory committee recommended the CLEAN-AP filter be transitioned into the WSR-88D system for further engineering evaluation and operational use. During FY12, we provided complete performance analysis of the CLEAN-AP filter comparing it alongside WSR-88D current ground clutter mitigation techniques. Additionally, we delivered the CLEAN-AP filter algorithmic description as part of the improved Staggered PRT algorithm to the ROC for inclusion
into the NEXRAD software update cycle. Compared to current technologies used for ground clutter suppression, the CLEAN-AP filter provides a real-time, integrated clutter mitigation solution with: (a) improved ground clutter suppression, (b) effective ground clutter detection, and (c) dynamic ground clutter suppression characteristics optimally matched to the existing atmospheric environment. All of this is achieved with modest computational complexity and increased quality of meteorological estimates.

Velocity bias (blue line) and standard deviation (green bars) performance comparisons of the CLEAN-AP filter compared to the current WSR-88D filter reveals that CLEAN-AP exceeds NEXRAD Technical Requirements performance criteria in severe ground clutter environments (60 dB clutter-to-signal ratio).
b. Range-and-Velocity Ambiguity Mitigation

Sebastian Torres (CIMMS at NSSL), David Warde (CIMMS at NSSL), Dusan Zrnić (NSSL)

In pulsed Doppler weather radars, the range and Doppler velocity ambiguity problems are coupled such that trying to alleviate one of them worsens the other. Special techniques are necessary to resolve both ambiguities to the levels required for the efficient observation of severe weather. Efforts in this area are expected to culminate in significantly improved WSR-88D data quality when implemented on the Radar Data Acquisition sub-system. The increased data quality will result in an improved ability for the WSR-88D to detect severe weather, flash floods, winter storms, and provide aviation forecasts. Over the last decade, two techniques have emerged as viable candidates to address the mitigation of range and velocity ambiguities in the WSR-88D thus reducing the amount of purple haze obscuration currently encountered during the observation of severe phenomena. These are: systematic phase coding (SZ-2) and staggered pulse repetition time (SPRT). The two techniques are complementary since they offer advantages at specific elevation angles; hence, they can be simultaneously incorporated into the same volume coverage pattern.

The first stage of upgrades is now complete and has been operational with great success for a number of years. The second stage of NEXRAD upgrades dealing with range and velocity ambiguities involves the operational implementation of SPRT. We developed a novel spectral processing SPRT algorithm that incorporates the mature CLEAN-AP filter, range-overlaid recovery, dual polarization and a generalized PRT ratio. During this year, we delivered the improved SPRT algorithmic description to the ROC for inclusion in the NEXRAD software update cycle. 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.

Novel spectral processing approach to range-and-velocity ambiguity mitigation allows the use of the CLEAN-AP filter to automatically detect and filter ground clutter using staggered PRT waveforms. Time-series data was collected with the ROC test bed radar in Norman, OK for SPRT processing in upper panels (left – unfiltered velocity, right – CLEAN-AP filtered velocity). Velocity image (bottom) from the operational radar (KTLX) indications both range and velocity ambiguities during the same period.
c. Coherency-Based Thresholding

Igor Ivić (CIMMS at NSSL), Sebastian Torres (CIMMS at NSSL), Dusan Zrnić (NSSL)

This project seeks to develop and demonstrate a method to mitigate the 3.5 dB loss in sensitivity per channel inherent to the simultaneous transmission and reception of H,V waves in the WSR-88D dual-polarized radar. Currently the WSR-88D network uses Signal-to-Noise Ratio (SNR) estimates for signal censoring. Thus, only data for which the corresponding SNR estimate is larger than the predetermined threshold are not censored and available to the users and automatic algorithms. The network upgrade to dual polarization resulted in a 3.5-dB SNR reduction because the transmitter output was split between the horizontal and vertical channels. As a result, radar sensitivity has been diminished.

To mitigate the effects of an SNR decrease, a Coherency Based Thresholding (CBT) technique has been accepted for implementation in the dual-polarized WSR-88D network. CBT improves radar data censoring by utilizing the weather signal coherency in sample-time and across channels, which has the potential to recover most of the lost signals. The technique was implemented in the operational WSR-88D software and is currently undergoing testing at the ROC. CIMMS has been supporting this effort by providing consultations to the ROC team conducting the testing. Also, test data cases have been processed offline by the CIMMS staff to validate outputs of the operational system. In addition, an addendum that integrates the CBT into the SZ-2 Algorithm Description has been delivered to the ROC. In the interest of further technique validation, research was conducted to compare CBT against two other techniques also aimed at enhancing radar coverage. These techniques utilize parts of the signal detection mechanisms built into the CBT. Results showed that CBT produces the highest rates of detection.

CBT’s ability to recover data lost is compared to two other techniques. These are the Cross Coherency Thresholding (CCT) and the Coherency Sum Thresholding (CST). Plots show comparisons of the detections rates among the three techniques and detections rates when the legacy SNR censoring is used. The plots show that CBT produces the best detection rates.
d. Noise-Power Estimation

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

This project seeks to develop and demonstrate a method to produce noise-power measurements at each antenna position in real time. Given sufficient accuracy of noise estimates, the application of the technique should produce improved radar products. During FY12, the algorithm was further improved in accuracy and efficiency. An additional step was included in the algorithm that detects and removes high gradient signals (e.g., point clutter). The efficiency was improved by changing the algorithm so it operates exclusively on estimated powers. Effects of the algorithm implementation on the radar products were presented at the International Symposium on Earth-Science Challenges (ISEC) in Norman, OK. It was demonstrated that the current noise calibration procedure on the WSR-88D network is plagued with problems. This especially reflects on the quality of dual-polarization variables because the differential-reflectivity and the correlation-coefficient estimates are sensitive to errors in noise floors. Implementation on real data shows visible improvement in the number of valid correlation coefficient and spectrum-width estimates. Assessment of biases in the differential-reflectivity estimates shows improvement when the radial-by-radial noise measurement is used compared to the legacy calibration noise. An additional benefit is the increased coverage in cases when the legacy calibration noise floor is overestimated. The algorithm was thoroughly validated to ensure that its description was correct and complete. This detailed description was delivered to the ROC for implementation on the WSR-88D network.

PPI of the correlation coefficient generated using legacy calibration noise (left), and the radial-by-radial noise measurement technique (right). Gain in the coverage is 20% and 4% in the number of valid estimates (scaled by the total number of detections) and is visible by visual comparison.
e. Range Oversampling Techniques

Sebastian Torres (CIMMS at NSSL), Chris Curtis (CIMMS at NSSL)

Obtaining radar data at rates faster than current radar systems can provide an important capability for the observation of fast-evolving aviation hazards, especially during landings and takeoff. The conventional trade-off when increasing data rates involves sacrificing either spatial coverage or data precision. However, with range oversampling it is possible to add a new dimension to this trade-off: signal processing. That is, with range oversampling it is possible to obtain low-variance data without sacrificing update time or spatial coverage. This is particularly important for the polarimetric variables, which are needed with higher precision than is possible using legacy, single-polarization dwell times.

During FY12, we continued our research on the practical effects of implementing range-oversampling techniques. This includes work on efficient adaptive pseudowhitenning (Curtis and Torres 2011), the effect of range oversampling on the range weighting function (Torres and Curtis 2012a), and the importance of accurately measuring the range correlation matrix (Torres and Curtis 2012b). All of these research areas are significant when looking at the real-time, operational use of range oversampling processing. We plan on applying this research to the processing on the NWRT and hope to extend that to the WSR-88D when these techniques are transferred in the future.
PPI displays of reflectivity (left panels) and Doppler velocity (right panels) fields from data collected with the NWRT on 2 April 2010 at ~10:54 UTC. The top and middle panels correspond to the original acquisition parameters (long dwells) with range oversampling processing and standard processing, respectively. The bottom panels correspond to the (simulated) modified acquisition parameters (short dwells) with range-oversampling processing. The top and middle panels are useful to qualitatively assess the performance of range oversampling compared to the standard processing. The smoother texture of reflectivity and Doppler velocity fields is an indication that the variance of estimates is smaller. Alternatively, comparing the middle and bottom panels illustrates the improvements realized after the scanning strategy was modified to account for the reduced variances from range oversampling. These images depict the benefit of using range-oversampling techniques to reduce update times.
f. Floating Radar Product Generation for Display in the AWIPS-2 Environment

Darrel Kingfield (CIMMS at NSSL)

The goal of this research is to migrate existing Radar Product Generator (RPG) software packages in NOAA’s Hazardous Weather Testbed (HWT) for display and playback into an AWIPS-2 real-time environment. With the Advanced Weather Interactive Processing System-2 (AWIPS-2) actively being deployed at NWS forecast offices across the nation, it became necessary to explore the interactions of the RPG software with the AWIPS-2 environment for internal algorithm development/exploitation. A flexible system for viewing/modifying RPG inputs was developed for the AWIPS-1 environment in the HWT but this transition allowed us to re-build a more optimal system for the playback of radar data.

A web-based, map-enabled page was added that allows the user to select up to 10 RPG sites for real-time processing. With AWIPS-2, the radar sites became location independent so users are free to select any grouping of sites without being constrained to a specific region. Since its development, this system serves as a backbone for radar processing within the Experimental Warning Program Spring Experiment, a display environment for developers at NSSL and at the ROC Applications Branch, and a general situational awareness tool for personnel and visitors to the HWT. Research and development is ongoing.

An Open Layers web interface allows a user inside the network to selection radars for playback (left). The resulting selections will be streamed into the AWIPS-2 display environment (right).
WSR-88D Improvements Publications

2. Dual-Polarization Research

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

Accomplishments

a. Validation of Polarimetric Rainfall Measurements Made by Operational WSR-88D Radars

Alexander Ryzhkov, Pengfei Zhang, John Krause, Hoyt Burcham, Dan Suppes (all CIMMS at NSSL)

The performance of the different polarimetric rainfall algorithms has been evaluated for 13 high-impact rainfall events observed by the KOUN WSR-88D radar in Oklahoma for the period from May 2010 till June 2011. The polarimetric algorithm based on the combined use of specific differential phase $K_{DP}$ and radar reflectivity $Z$ outperformed the $R(Z)$ relation for all examined events in terms of the bias and standard error.

Fractional RMS errors of the storm rain total radar estimate for 13 significant rain events observed by the KOUN WSR-88D radar in Oklahoma from May 2010 till June 2011. Thin and solid lines depict results for the conventional and best polarimetric algorithm ($R(Z,K_{DP})$) respectively.
b. Development of the New Polarimetric QPE Algorithm Based on Specific Attenuation

Alexander Ryzhkov (CIMMS at NSSL), Pengfei Zhang (CIMMS at NSSL)

A novel algorithm for rainfall estimation based on specific attenuation A has been developed and tested at S, C, and X bands. The R(A) relation is least sensitive to drop size distribution (DSD) variability compared to other existing algorithms and is immune to radar reflectivity biases caused by radar miscalibration, attenuation, partial beam blockage, and wet radome. Additionally, the fields of ran rate obtained from A have the same spatial resolution as the ones retrieved from Z. The method is especially beneficial for networking/compositing rainfall products obtained by different radars in the overlapping coverage areas. The impact of partial beam blockage can be eliminated without the knowledge of digital elevation maps. The R(A) algorithm was validated at S and X bands using rain gages and numerous polarimetric WSR-88D radars as well as X-band radar at the University of Bonn, Germany.

Maps of 6-hour rain total obtained from the KVNX WSR-88D radar on 20 May 2011 (08 – 14 UTC) using the R(Z) and R(A) algorithms. Gage accumulations are displayed in white squares. The R(A) algorithm completely eliminates the impact of partial beam blockage without using digital elevation information.
c. Improving Classification of Winter Precipitation Type by Combining Polarimetric Radar Data with Thermodynamic Output from Numerical Prediction Models

Terry Schuur, Alexander Ryzhkov, Heather Reeves, John Krause, Dan Suppes, Hoyt Burcham (all CIMMS at NSSL)

With the continued upgrade of the WSR-88D network throughout the 2011-2012 winter season, polarimetric observations of numerous transitional winter weather events were collected and archived for regions of the U.S. where polarimetric radar observations had previously not been made. These radar data, along with observations of surface precipitation type collected by the winter Severe Hazards Analysis and Verification Experiment (SHAVE) project, are now being used to develop, test, and validate the performance of a new surface-based winter precipitation type algorithm that is being developed for the WSR-88D network. Since most precipitation processes (such as melting and/or refreezing) important towards the determination of winter precipitation type often occur in a shallow layer < 1 km above the surface, they are not generally well sampled by the radar at ranges > 50 to 100 km. The new algorithm improves upon the capabilities of the existing algorithm by using thermodynamic information from the High-Resolution Rapid Refresh (HRRR) model to provide a “background” precipitation type that can then be modified, if necessary, by the polarimetric radar observations. Therefore, in addition to using radar data close to the radar to provide enhanced classification capabilities, the new technique also allows for the classification to be extended to more distant ranges where low-level radar data are not available.

Over the course of the 2011-2012 winter season, 1200 surface observations of precipitation type were collected by the Winter SHAVE project. Of those 1200 observations, 465 (38.8%) were found to have been collected within 100 km (the most distant range that we can likely expect the radar modification component of the algorithm to be effective) of 17 different polarimetric WSR-88D radars, thereby providing a broad, comprehensive data set encompassing 14 distinct events that is currently being used to test and validate the algorithm performance.
Final product from the new surface-based precipitation type classification algorithm for two transitional winter weather events: 1) Wichita, KS (KICT) WSR-88D at 210053 UTC on 7 February 2012, and 2) Grand Rapids, MI (KGRR) WSR-88D radar at 201024 UTC on 10 February 2012. Precipitation type categories are no echo (NE), ice crystals (CR), dry snow (DS), wet snow (WS), ice pellets (IP), freezing rain/ice pellets (FR/IP), freezing rain (FR), rain (RA), heavy rain (HR), and hail (HA). Location and precipitation type of the Winter SHAVE observations collected during each volume scan are indicated by the color-filled circles overlaid on each plot.

d. Validation of a New Winter Surface Hydrometeor Algorithm Using SHAVE and W-PING

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

To support the development of a winter surface hydrometeor classification algorithm that is part of the polarimetric upgrade to the NWS WSR-88D radars, a focused effort to actively collect winter surface precipitation type was initiated under the existing umbrella of the SHAVE and the Winter Precipitation Identification Near the Ground (W-PING). The effort started on 3 February 2012 and terminated at the end of the winter weather season. Operationally, SHAVE uses students to call the residents in designated areas experiencing winter weather to ask about the type of precipitation. In contrast, W-PING is a “passive” technique in the sense that it accepts voluntary reports, so that everybody can enter the information about current precipitation type into a specially designated weather page. A total of 1266 observations were collected via the two programs during the winter campaign. Considerable effort was spent into making the HCA algorithm viable in real-time setting thus allowing for express analysis of events. The “background” classifier, that is, the module of HCA that utilizes the HRRR model output, demonstrates good skills in discrimination between rain and snow precipitation.
The summary of classification results obtained via SHAVE and W-PING (top panel) and retrieved using the “background” classifier (bottom panel).

e. Investigation of Polarimetric Signatures in Winter Storms

Matthew Kumjian, Alexander Ryzhkov, Heather Reeves (all CIMMS at NSSL)

A unique, low-level signature in differential reflectivity ($Z_{DR}$) indicating the transition of freezing rain to ice pellets has been explored for a number of cases in Oklahoma observed with polarimetric radars operating at S and C bands. The results demonstrate the repeatability of the signature and offer some clues into a new microphysical process: the freezing of drizzle-sized droplets and subsequent rapid growth by vapor deposition into needle-like pristine ice crystals. A bulk microphysics model of crystal nucleation, depositional growth, and aggregation has been developed and applied to
the study of an enhancement of $Z_{DR}$ above the melting layer known from recent studies to precede an intensification of surface precipitation rates (rain or snow).

Display of quasi-vertical profiles of (a) $Z_H$, (b) $Z_{DR}$, (c) $K_{DP}$, and (d) $\rho_{hv}$, observed by the polarimetric WSR-88D KOUN on 27 January 2009 at three different times: 1939 UTC (solid black lines), 1955 UTC (solid gray lines), and 2010 UTC (dashed gray lines). The low-level refreezing signature is observed between about 300 – 600 m AGL as a decrease in $Z_H$, and relative maxima in $Z_{DR}$ and $K_{DP}$.

f. Hail Size Discrimination Using Polarimetric WSR-88D Radars

Alexander Ryzhkov, Matthew Kumjian, Scott Ganson, John Krause, Kiel Ortega (all CIMMS at NSSL)

The polarimetric model of melting hail was extended and modified by taking into account variability of hail density and vertical air velocity. The sensitivity of vertical profiles of radar polarimetric variables to the variety of microphysical factors was examined along with the issues of hail detection and determination of its size, polarimetric attenuation correction in melting hail, and polarimetric rainfall estimation in the presence of hail at different radar wavelengths. The radar algorithm for discriminating between hail of small (less than 2.5 cm), large (between 2.5 and 5 cm),
and giant (larger than 5 cm) size was developed and its validation started using SHAVE ground truth observations.

Example of preliminary validation work with the hail size discrimination algorithm, which has been incorporated into the existing hydrometeor classification algorithm. Color shading indicates the hydrometeor class (see legend at top of figure). Squares indicate SHAVE hail reports with hail size indicated by the number (in mm). Detection of “giant hail” occurs in the data just upstream of several giant hail surface reports.
g. Polarimetric Radar Analysis of Severe Convective Storms

Matthew Kumjian, Alexander Ryzhkov (both CIMMS at NSSL), David Bodine (ARRC at OU)

The feasibility of estimating tornado damage in near real time with polarimetric radar has been explored, and the results are documented in a journal article to be published soon. It was found that tornadoes receiving a larger EF rating had polarimetric debris signatures characterized by taller heights, larger volumes, larger 90th percentile values of reflectivity factor Z, and lower 10th percentile values of differential reflectivity $Z_{DR}$ and correlation coefficient $\rho_{hv}$. Analysis of drop size distributions (DSDs) within supercell hook echoes has revealed a dramatic increase in tropical-like DSDs (characterized by anomalously large concentrations of small drops) as the low-level mesocyclone undergoes its occlusion cycle. A theoretical model of $Z_{DR}$ columns has confirmed and quantified the observationally inferred link between updraft strength and $Z_{DR}$ column height in convective storms. Collaboration with the University of Alabama in Huntsville has confirmed the operational benefits of our previous research, namely the use of the $Z_{DR}$ arc signature to diagnose storm severity and tornadic potential and to perhaps improve warning lead times.

Stacked bar graphs of (left) tornado debris signature height, and (right) tornado debris signature volume for two sets of thresholds (top and bottom rows, respectively). The color of the bars represents tornado intensity ratings: EF-0 or 1 (light gray), EF-2 or 3 (dark gray), and EF-4 or 5 (black).
h. Investigating Microphysical Processes in Clouds and Precipitation with Explicit Modeling and Polarimetric Radar Data

Matthew Kumjian, Alexander Ryzhkov, Scott Ganson, Jelena Andric (all CIMMS at NSSL)

The impact of size sorting on the polarimetric radar variables has been investigated in the framework of an explicit bin model and compared to the results predicted by bulk microphysics parameterization schemes. Substantial errors in the simulated fields of the polarimetric variables (especially Z_{DR}) are found for simple bulk microphysics schemes. Polarimetric radar observations of coalescence have been analyzed and compared favorably to theoretical expectations. Freezing of raindrops in convective updrafts is explored, and found to be in good agreement with observed radar data. The impact of updraft strength on the depth and height of the freezing zone has been quantified. These models have been used to help quantify the expected values of backscatter differential phase in melting snow and hail, which compare favorably to radar observations at S, C, and X bands. A bulk model of snow processes (nucleation, deposition, and aggregation) has been developed to explain an observed signature in winter storms. A catalog of the polarimetric “fingerprints” of a number of microphysical processes has been developed.

Fields of (a) Z_H, (b) Z_{DR}, (c) \rho_{hv}, and (d) L_{DR} predicted from a one-dimensional explicit bin model of raindrop nucleation and freezing within convective updrafts. The three curves indicate three different updraft strengths. The arrows indicate the depth of the “freezing zone”. Heights are given in meters above the melting level (AML). From Kumjian et al. (2012).
i. Dual-Polarization QPE Evaluation

Kim Elmore (CIMMS at NSSL), Donald Burgess (CIMMS at NSSL)

The objective of this research is to evaluate the goodness of dual-pol QPE by comparison with rain gauges and compare QPE goodness to Legacy Precipitation Processing System (PPS) output. During 2012, the primary goal was to compare polarimetric radar quantitative precipitation estimation (DP QPE) to the prior legacy precipitation processing system (PPS) QPE algorithm. The question to be answered centered on whether the DP QPE algorithm was significantly (in a statistical sense) better than the PPS QPE algorithm. To that end, errors between storm total precipitation rain gauge amounts and DP and PPS QPE algorithm estimates are compared in both a bias sense as well as in a root-mean-square error (RMSE) sense.

In total, 4,133 radar-gauge (RG) pairs were extracted by ROC staff from the KOUN, KVNX, KICT, and KMHX radars (chosen because they are among the earliest to be upgraded and more data was available for comparison) over 16, 16, 11, and 10 cases, respectively. Due to spatial correlation between radar-gauge each pair could not be treated as an independent error source, but instead had to be grouped within events. While small, the number of cases is sufficient for an overall assessment of DP QPE compared to PPS QPE, though the data set is insufficient for a radar-by-radar assessment. To test for differences, a matched-pairs Monte Carlo form of Fisher’s Exact Permutation Test is implemented using 3000 permutations. Overall, the DP QPE displays significantly less bias (at the p = 0.05 threshold) and smaller RMSE than the PPS QPE. However, there is some range dependence that appears keyed to the range at which the lowest elevation scan intersects the freezing level. In particular, while DP QPE has a significantly smaller bias and lower RMSE than PPS QPE at ranges below the freezing level range, the improvement is even greater at ranges above the freezing level.

j. Improvement of Specific Differential Phase (K_{DP})

Kim Elmore (CIMMS at NSSL), John Krause (CIMMS at NSSL)

This research seeks to better understand the current K_{DP} measurements and devise methods to improve the calculation of K_{DP} and use of K_{DP} in the QPE Algorithm. K_{DP} (specific differential phase) is an important dual-polarization parameter for QPE, but is also known to exhibit noisy behavior and sampling artifacts. An initial effort to examine the nature of the problems and to investigate an initial approach to improvement has been completed. In all but exceptional cases, K_{DP} should be positive. However, initial assessment on a case from KOUN on 14 May 2003 shows that 40% of the K_{DP} values from KOUN at the 0.5° elevation scan were negative (see first figure below). A simple approach to “fixing” K_{DP} is shown in the second figure below, along with the original K_{DP}. Unfortunately, while this approach eliminates the spurious negative values, it induces some new, unacceptable problems. Most notable are an excessive number of small K_{DP} values added above 55—60 dBZ.
Because the complete nature of the problems affecting $K_{DP}$ is not fully understood, the affects of any particular approach are difficult to predict. This has the unfortunate consequence that methods must be implemented before their full affect can be ascertained. Approaches that are expected to hold promise include 1) limiting $K_{DP}$ computations to only those areas deemed free of partial beam filling artifacts, possibly determined by a total gradient vector of reflectivity, 2) using a more sophisticated method of computing the radial derivative of $\Phi_{DP}$ (the definition of $K_{DP}$) using robust regression techniques such as least median of squares or trimmed least squares, 3) robust regression techniques merged with a monotonic regression. Research and development are ongoing.

$K_{DP}$ plotted against reflectivity for all values of $K_{DP}$ associated with reflectivity greater than 30 dBZ. Values much larger than 5-10 deg km$^{-1}$ are likely to be erroneous as are negative values.
A simple approach to repairing $K_{DP}$ shown in black while original $K_{DP}$ is shown in green. Note that variance increases substantially for both the “fixed” and original $K_{DP}$ at 40 dBZ and that too many $K_{DP}$ values are added near zero for reflectivity values above 55—60 dBZ.

**k. Extending the Capabilities of the Polarimetric WSR-88D Radars**

Valery Melnikov (CIMMS at NSSL)

Various calibration issues of polarimetric WSR-88D radars have been explored. It was shown that the echoes from turbulent atmosphere could be used to check differential reflectivity calibration in the WSR-88Ds. It was also demonstrated that radar echoes from insects and birds should not be used for comparisons of radar calibration constants for the adjacent WSR-88D radars due to the effects of resonance scattering, which are very sensitive to small changes in the microwave frequency.

**Dual Polarization Publications**


Kaltenboeck, R., and A. Ryzhkov, 2012: Comparison of polarimetric signatures of hail at S and C bands for different hail sizes. *Atmospheric Research, Accepted.*


### 3. Phased Array Radar

#### Overall Objectives

Continue engineering research and development in collaboration with NSSL and various other agencies to determine the usefulness of the military phased array radar system for meteorological observations. Phased array radars have been used for many years in military applications for detection and tracking of aircraft and missiles. To determine the feasibility of using this radar for meteorological observations, it must be tuned. The NWRT phased array radar (PAR) testbed in Norman, Oklahoma, is the first of its kind to study meteorological applications of this technology. In addition, most phased array systems have only one polarization, so studies are being conducted to...
determine the feasibility of dual polarized phased array antenna systems along with the applications of using the radar for multi-purposes (i.e. aircraft tracking and wind profiling). Other areas of research and development include, improved algorithm development for fast scan radars, new display techniques, data analysis to study structure and dynamics of convective phenomena, new fast scanning techniques, and digital signal processing techniques.

Accomplishments

a. NWRT PAR Multi-Channel Receiver Experiments

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

The NWRT PAR provides a unique opportunity to study the effectiveness of sidelobe cancellation for mitigating ground clutter. The testbed is made up of a phased array antenna that has several receive-only auxiliary apertures that are separate from the main array and an eight-channel receiver for archiving multiple channels of time series data. This multi-channel receiver is a collaborative project between the ARRC and the NSSL. Sidelobe channels have previously been utilized on wind profiling radars to mitigate ground clutter, and some of the same techniques should also be applicable to weather surveillance radars. The sum and sidelobe channel data can be recorded and processed to explore different approaches for addressing ground clutter contamination. The goal of this project is to examine some of the existing algorithms employing sidelobe cancellers and apply these algorithms to collected time series data. This could lead to new ways to mitigate ground clutter on weather surveillance radars in the future.

During FY12, the theoretical aspects of using sidelobe cancellation to mitigate ground clutter on the NWRT phased array antenna were studied. This included measuring the positions of the array elements to produce accurate theoretical antenna patterns for the sum and sidelobe canceller channels. Many algorithms were examined and applied to weather/clutter simulations to look at the performance of spatial filtering. This research was shared at two conferences, and coauthoring work was done for a recently published journal paper (Yeary et al. 2012).
Modified antenna pattern using the quadratically-constrained LCMP (Linear Constrained Minimal Power) algorithm for a simple point source simulation.

b. National Weather Radar Testbed Phased Array Radar Software Upgrades

Sebastian Torres (CIMMS at NSSL), Richard Adams (CIMMS at NSSL), Chris Curtis (CIMMS at NSSL), Eddie Forren (CIMMS at NSSL), Igor Ivić (CIMMS at NSSL), David Priegnitz (CIMMS at NSSL), John Thompson (CIMMS at NSSL), David Warde (CIMMS at NSSL), Michael Jain (NSSL)

This work seeks to use the NWRT PAR to demonstrate the potential of PAR technology to simultaneously perform aircraft tracking and weather surveillance as multi-function phased-array radar (MPAR) while highlighting many of its unique advantages for weather observations. During FY12, work continued to improve the quality of meteorological data produced by the NWRT PAR, to demonstrate adaptive scanning capabilities for weather observations, and to demonstrate dynamic scheduling of multi-function scanning strategies. Major accomplishments are reported next.

Adaptive Pedestal Control Algorithm. In the fall of 2011, we added a weather-feature tracking/pedestal control algorithm. The purpose of the algorithm is to track a user-defined “weather feature” and automatically adjust the pedestal position to keep the feature in the field of view. The operator uses the Radar Control Interface (RCI) to identify the weather feature and define the field of view. The algorithm is based on the
reflectivity field at the lowest elevation cut. An improved version, utilizing reflectivity at all elevation cuts was implemented in the spring of 2012. The algorithm and some early results were presented at the 23rd AMS IIPS Conference in New Orleans in January.

Example of the RCI reflectivity display for a tornadic supercell that was successfully tracked for over 2 hours. The images correspond to 4 times in this period. Preliminary tornado tracks (thick white lines) are shown (courtesy of the National Weather Service Norman Forecast Office).

**Surveillance Scan Capabilities.** To improve scan times, a surveillance scan was implemented using only a small number of pulses in areas that are determined to not currently have significant weather. The surveillance scan will then determine when significant weather is detected so that the full dwell time will be collected. The fewer pulses of the surveillance scan degrade the ability to mitigate ground clutter and estimate the noise power. To alleviate this problem, a history is now kept of the most recent ground-clutter power and noise power determined with full dwell times at each beam position. These values are then used in the surveillance scan for determining whether there is potentially significant weather in the radar beam. This improves the ability to detect early initiation of weather in a surveillance scan.
Adaptive Scan Control Infrastructure. Discussions and refinement of scan-control concepts occurred during the year. It was established that treating weather features and scanning tasks independently within the design is necessary for fully optimizing scan time and quality. Scanning subtasks with overlapping sequences that are not necessarily controlled by the scheduler may be needed for fully optimizing scans. It is also simpler for algorithms if the system is able to deal with higher level abstractions like features, scan resolution, scan sequence, and scan control instead of lower level abstractions like scan stimulus. However, a system that allows both high level and low level specification of adaptive scans would provide simplicity for high level clients and nearly complete control for lower level clients.

Real-Time Controller Improvements. Work continued to address the current limitations of the NWRT PAR Real Time Controller (RTC) to dynamically change purse repetition times (PRT). The theory that the digital receiver setup was not happening on time during PRT switching was confirmed. With data collection not starting until 10 km, the software has 58 microseconds to set up the receiver when a transmit occurs. It was confirmed that the original implementation is taking more than 58 microseconds some of the time and this was the cause of failures during PRT switching. Improvements to the system were implemented to reduce the receiver set up time and a 3-hour PRT switching data collection was successful. During this process, reasonable familiarity with the transmit and system timing functions in the software was attained.

Distributed Computing Infrastructure Improvements. Support for binary scientific data embedded within and XML data stream was implemented late this year for the purposes of feeding data to AWIPS. Feedback from Raytheon revealed the need to support conversion from XML with binary data to text based XML expected by most XML parsing software and the base-64 encoding scheme needed for this is partially implemented at this point. Test PAR XML archive II data was sent to Raytheon contractors for testing and ingest into AWIPS. This work will allow forecasters to use the AWIPS system that they are familiar with without running data through and ORPG and an evolving data stream that allows new information to easily be added and passed to AWIPS has been established to allow new features in the future. The XML infrastructure built for this has the potential to be leveraged to establish a linked PAR products database that easily evolves over time, can be generically transported to offline scientific environments, and provides scientists with the ability to access all of the information used to produce any given meteorological product as opposed to some subset of that information that is included in current archiving schemes. This may turn out to be critical for an adaptive scanning system because so much of the data is dependent upon information that is determined dynamically.

Testing. Testing is an important factor in our research-to-operations success, and thus continued during this past year. After research ideas are accepted and designed for integration into the system, developers begin coding that design. Separate implementations are built into a development system that is tested as it evolves. Once the developers are satisfied that they have accomplished the design, an integrated build
is created and loaded onto our test system. An independent approach to system testing is then used to ensure that all possible flaws are identified and corrected. Once the team is satisfied that the system is robust and meets the design objectives, it is moved into operations.

c. Radar Data Management

Dan Suppes (CIMMS at NSSL)

Data management continues to be the focal point for the archiving and distribution of radar data for RRDD. During FY12, over 8.1 Terabytes of KOUN, KCRI, NWRT PAR, OUPrime, and mobile radar data were archived. CIMMS was active in coordinating with IT staff for the maintenance and development of the RAID systems. We also maintained a web-based catalog of radar data for distribution. This catalog is available on the Internet to the general public. Several scripts were developed and maintained to facilitate data sorting and retrieval. Some of these scripts were used to help customers with special requirements. Data sets were re-run through algorithms to produce specific products for scientific research. Another duty was to pull data from NCDC and provide it for the rainfall validation project. Part of our requirements is to provide raw data for the lab scientists to use in their research. We also provided data for several students working on graduate and postgraduate studies at OU and NSSL. Data was provided to several outside customers, including the ROC and Lincoln Laboratories. Total data distributed was approximately 5 Terabytes.

Phased Array Radar Publications

4. Weather Radar Applications Research and Development

Accomplishments

a. Rotation Tracks: An Automated Method for Depicting Mesocyclone Paths and Intensities

Valliappa Lakshmanan (CIMMS at NSSL), Travis Smith (CIMMS at NSSL), Madison Miller (OU School of Meteorology)

We developed an automated method for depicting mesocyclone paths and intensities. The location and intensity of mesocyclone circulations can be tracked in real-time by accumulating, over time, areas of high azimuthal shear computed from Doppler velocity observations at low (0-3 km AGL) and mid-levels (3-6 km AGL). Azimuthal shear is
computed in a noise-tolerant manner by fitting the Doppler velocity observations in the neighborhood of a pulse volume to a plane and finding the slope of that plane. Rotation tracks created in this manner are contaminated by non-meteorological signatures – these are caused by poor velocity dealiasing, ground clutter, radar test patterns and spurious shear values.

In order to improve the quality of these fields for real-time use and for an accumulated multi-year climatology, new dealiasing strategies, data thresholds, and Multiple Hypothesis Tracking (MHT) techniques were implemented. These techniques remove nearly all non-meteorological contaminants and successfully isolate the rotation tracks. The resulting rotation tracks are closely associated with mesocyclone paths and intensities. Storm survey information was then used to compare the rotation tracks to observed tornado damage.

Rotation tracks products before and after quality control was implemented for four outbreak cases: 27 April 2011 before (a) and after (b), 16 April 2011 before (c) and after (d), 2 March 2012 before (e) and after (f), and 24 May 2011 before (g) and after (h).
b. Precipitation Nowcasting

Valliappa Lakshmanan (CIMMS at NSSL), J.J. Gourley (NSSL), Yang Hong (OU Civil and Environmental Engineering)

In collaboration with researchers from UC Irvine and the Civil and Environmental Engineering Department at OU, we introduced a pixel-based algorithm for Short-term Quantitative Precipitation Forecasting (SQPF) using radar-based rainfall data. The proposed algorithm called Pixel-Based Nowcasting (PBN) tracks severe storms with a hierarchical mesh-tracking algorithm to capture storm advection in space and time at high resolution from radar imagers. The extracted advection field was then extended to nowcast the rainfall field in the next three hours based on a pixel-based Lagrangian dynamic model. The proposed algorithm was compared with two other nowcasting algorithms (WCN: Watershed-Clustering Nowcasting and PER: PERsistency) for ten thunderstorm events over the conterminous United States. Object-based verification metric and traditional statistics have been used to evaluate the performance of the proposed algorithm. It is shown that the proposed algorithm is superior over comparison algorithms and is effective in tracking and predicting severe storm events for the next few hours.

(a) Event 1 on 8 May 2009 10:00 UTC observation, 1 Q2 1 [km]. (b, c) PBN +30 [min] prediction and 5 and 20 [mm/hr] thresholds. (d, e) WCN +30 [min] prediction with 5 and 20 [mm/hr] thresholds (Rainfall Unit = mm/hr).
c. Hail Climatology

John Cintineo (OU School of Meteorology), Travis Smith (CIMMS at NSSL), Valliappa Lakshmanan (CIMMS at NSSL), Kiel Ortega (CIMMS at NSSL), Harold Brooks (NSSL)

CIMMS student John Cintineo developed a hail climatology over the CONUS and compared the results with a reports-based climatology. Past hail climatology has typically relied on NOAA’s NCDC Storm Data, which has numerous reporting biases and non-meteorological artifacts. This research seeks to quantify the spatial and temporal characteristics of CONUS hail fall, derived from multi-radar multi-sensor (MRMS) algorithms for several years during the NEXRAD era, leveraging the Multi-Year Reanalysis Of Remotely Sensed Storms (MYRORSS) dataset at NSSL. The primary MRMS product used in this study is the maximum expected size of hail (MESH). The preliminary climatology includes 42 months of quality-controlled and re-processed MESH grids, which spans the warm seasons for 4 years (2007-2010), covering 98% of all Storm Data hail reports during that time. The dataset has 0.01° latitude x 0.01° longitude x 31 vertical levels spatial resolution, and 5-minute temporal resolution. Radar-based and reports-based methods of hail climatology are compared. MRMS MESH demonstrates superior coverage and resolution over Storm Data hail reports, and is largely unbiased. The results reveal a broad maximum of annual hail fall in the Great Plains and a diminished secondary maximum in the southeast U.S. Potential explanations for the differences in the two methods of hail climatology are also discussed.

Annual hail days from year, estimated from radar data from 2007-2010.
d. Range-Correction of Azimuthal Shear

Jennifer Newman (OU School of Meteorology), Valliappa Lakshmanan (CIMMS at NSSL), Pamela Heinselman (NSSL), Michael Richman (OU School of Meteorology), Travis Smith (CIMMS at NSSL)

Graduate student Jennifer Newman developed a range correction for LLSD shear so as to better enable tornado detection from Doppler velocity data. We examine linear regression and artificial neural networks as range correction models and find that both methods produce good fits for simulated shear data. We find that range correction increases tornadic shear values by nearly an order of magnitude, facilitating differentiation between tornadic and nontornadic scans in the tornadic events.

![Shear Values Graph](image)

0.5 degree shear values for a cyclic supercell from the 10 February 2009 Oklahoma Case. a) shows original uncorrected shear, b) shows original and corrected shear produced by the linear regression, and c) shows original and corrected shear produced by the ANN. Circles show actual times and maximum shear values for radar scans. Black lines denote approximate tornado times with tornado intensities as indicated.

e. Tuning AutoNowCaster

Valliappa Lakshmanan (CIMMS at NSSL)

AutoNowCaster (ANC) is an automated system that nowcasts thunderstorms, including thunderstorm initiation. However, its parameters have to be tuned to regional environments, a process that is time-consuming, labor-intensive and quite subjective. When the National Weather Service decided to explore using ANC in forecast operations, a faster, less labor-intensive and objective mechanism to tune the parameters for all the forecast offices was sought. CIMMS, working in conjunction with staff at the NWS Meteorological Development Laboratory, developed a genetic algorithm approach to tuning ANC. The process consisted of choosing data sets,
employing an objective forecast verification technique and devising a fitness function. ANC was modified to create nowcasts offline using weights iteratively generated by the genetic algorithm. The weights were generated by probabilistically combining weights with good fitness, leading to better and better weights as the tuning process proceeded.

The nowcasts created by ANC using the automatically determined weights were compared with the nowcasts created by ANC using weights that were the result of manual tuning. It was shown that nowcasts created using the automatically tuned weights are as skilled as the ones created through manual tuning. In addition, automated tuning can be done in a fraction of the time that it takes experts to analyze the data and tune the weights.

The top row shows (a) Radar observation on 14 May 2010 at 17:15 UTC. The domain is centered on the Dallas-Fort Worth WSR-88D (KFWS) and (b) the radar observation an hour later. The bottom row shows (c) 60-minute initiation nowcast at 17:15 UTC by manually tuned ANC (d) 60-minute initiation nowcast at 17:15 UTC by auto-tuned ANC.

f. Incorporating Dual-Pol Algorithms and Processing into WDSS-II

Jeff Brogden, John Krause, Valliappa Lakshmanan, Carrie Langston, Kevin Manross (all CIMMS at NSSL)

CIMMS scientists and programmers implemented the operational dual-pol preprocessing, hydrometeor classification and precipitation estimation algorithms into
WDSS-II. This work will enable future improvements to these dual-pol algorithms and the use of the output of these algorithms to improve existing WDSS-II algorithms.

g. Developing a Virtual Globe Display of Weather Information

Robert Toomey (CIMMS at NSSL)

Work continues on the development of a virtual globe display of weather information. Data such as polar data, and data mapped to the earth’s surface can be displayed in conjunction with other georeferenced data in a Java display that is meant to replace the existing display program. The new program is being built using the NASA WorldWind infrastructure.

![Different views of a radar data volume scan.](image)

h. Development and Application of a Satellite-Based Convective Cloud Object Tracking Methodology

Valliappa Lakshmanan (CIMMS at NSSL)

In collaboration with scientists at the University of Wisconsin Space Science and Engineering Center, we built upon the WDSS-II object tracking capabilities. The system uses an IR-window based field as input to WDSS-II for cloud-object identification and tracking and a UW-CIMSS developed post-processing algorithm to combine WDSS-II cloud-object output. The final output of the system is used to fuse multiple
meteorological datasets into a single cloud-object framework. The object tracking system performance is quantitatively measured for 34 convectively active periods over the central and eastern United States during 2008 and 2009. The analysis shows improved object-tracking performance with both increased temporal resolution of the geostationary data and increased cloud-object size. The system output is demonstrated as an effective means for fusing a variety of meteorological data including: raw satellite observations, satellite algorithm output, radar observations and derived output, numerical weather prediction model output, and lightning detection data for studying the growth of deep convective clouds.

11-µm top of troposphere cloud emissivity (a), final merged cloud-objects and IDs from the UW-CIMSS post-processing system without mature object extension option (b), merged mature cloud-objects (c), and final merged cloud-objects and IDs from UW-CIMSS post-processing system with mature object extension applied (d) valid at 2032 UTC 15 May 2009.

i. Multi-Function Phased Array Radar Display and Playback in AWIPS-2

Darrel Kingfield (CIMMS at NSSL), Eddie Forren (CIMMS at NSSL)

The aim of this work is to develop a system to ingest PAR data for playback and display in the AWIPS-2 environment. The 2012 Phased Array Radar (PAR) Innovative Sensing Experiment (PARISE2012) involved visiting NWS forecasters evaluating PAR data and
making simulated warning decisions. NWS Forecast Offices use parts of the AWIPS for storm interrogation/issuing warnings and the second generation of this software (AWIPS-2) is currently being deployed nationally. In order to provide an optimal environment for forecaster evaluation, it was essential that PAR data be ingested into the AWIPS-2 environment.

Leveraging the Common Operations and Development Environment (CODE) Radar Product Generator (RPG) software platform, an RPG was built that could handle the 238m-product resolution generated by the PAR. The PAR files were converted into Message-31 format files and played through the RPG into the AWIPS-2 environment. The AWIPS-2 ingest and display environment was extended to handle the non-standard PAR elevation angles up to 56°. Each PAR data case was stored as its own raw data archive and was re-ingested into the AWIPS-2 environment in displaced real-time during PARISE2012.

Lessons learned from this development process are not only aiding in the development of an AWIPS-2 plugin that will be able to ingest PAR data in real-time, but also in other radar initiatives such as testing the Supplemental Intra-Volume Low-Level Scan (SAILS) schemes. Research and development is ongoing.

An AWIPS-2 display of the lowest four PAR elevations in displaced real-time during the PARISE 2012 experiment.
Weather Radar Applications Publications
Lakshmanan, V., J. Crockett, K. Sperrow, M. Ba, and L. Xin, 2012: Tuning the auto-nowcaster automatically. *Weather and Forecasting*, Accepted.

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

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

Funding Type: CIMMS Task II

1. *ROC Applications Branch*

NOAA Technical Leads: Richard Vogt, Bob Lee, Richard Murnan, and Dave Zittel (all ROC Applications Branch)

Objectives
Our CIMMS student employees (Steve Castleberry, Lindsey Richardson, and Jason Godwin) provided important contributions to the validation and verification of new Dual-Polarization technology. The Applications Branch has the responsibility to collect and analyze radar data that will lead to improvements in the QPE algorithm. To do this, we needed a tool that could take raw data as input and quickly generate various statistics and graphics.

Accomplishments
Steve Castleberry developed a software module called “gauge-radar” that will run in an existing software program. This project involved troubleshooting code, implementing a method to smooth out calculations, editing Linux commands and provided an instruction manual and a checklist users can use when playing back data through the software.

Steve’s Capstone project (Spring 2012 semester) was to build upon Dr. Boon Leng Cheong’s (ARRC/OU ECE) research to use base radar moments, statistical calculations from them, and then use a software tool to detect and subjectively identify clutter from wind farms (Wind Turbine Clutter – WTC) on radar imagery. This study is important
because if radar imagery is contaminated from wind turbines, precipitation accumulation and other radar-based algorithms can be negatively impacted. This study used data from a WSR-88D where wind turbine clutter was present. To analyze the data he developed a generic MATLAB tool that ingests Level II radar data, allows a user to set plotting parameters and boundaries, and finally plots one or more statistical histograms of user-selected radar moments/variables. Steve integrated this new tool into the previously mentioned MATLAB I&A GUI program for ease of use. Steve also developed two VBA (Visual Basic for Applications) Macro programs to automate data file formatting and image importing / animating in MS Excel and PowerPoint. The program for Excel takes downloaded .csv VCP data files from the ASP View website and then automatically transfers and formats them. The program for PowerPoint finds image files in specified folders and imports them, resizes the images, then applies animation formatting to the image groups to create a time series of data / histogram images. These can then be visually analyzed for statistical trends and anomalies.

Lindsey Richardson made python scripts for ZDR that can perform bulk scattergram and histogram statistics over several linear buffers of radar data. This program has become a method the branch uses to estimate ZDR bias. The branch chief also used the program to compare ZDR to QPE and Gauge data on an hourly basis for certain events. Automating this process saved weeks of manually trying to do bulk statistics in Excel. It used to take eight hours to do statistics for 25 volume scans. With this program, it now only takes around 20 minutes to do the statistics and create the needed plots and relevant text info.

Lindsey collected and analyzed 2D Velocity Dealiasing data for several tropical storms and hurricanes, which was of great assistance to Applications Branch (Dave Zittel) work. This work eventually led to a presentation made at the hurricane conference this past summer showing the many improvements of 2D Velocity Dealiasing.

During the summer, Lindsey added new MATLAB tools to assist with future QPE work. Data from the NSSL NMQ site can now successfully be imported into MATLAB. This scatterplot data then gets used in statistical calculations. It can perform Gauge vs. DP vs. PPS scattergrams and other statistics relative to each data set and with consideration for the melting layer.

Lindsey and Steve worked together to clean up some of the older code and create a users manual for the MATLAB graphical user interface. They cleaned up extraneous programs, merged some together, and reduced the overall number of files. Updates to the manual include updating the Clickable Table of Contents and placing How-To-Use instructions and pictures for all of the new features. This manual gets distributed to places like the Hotline when we send out the graphical user interface package.

Jason Godwin (Fall 2011 and Spring 2012) added a new MATLAB tool to measure the behavior of Differential Reflectivity (ZDR) under varying filters such as signal-to-noise thresholds, selectable ranges of Reflectivity (Z), and selectable ranges of Correlation Coefficient (CC) in order to see the resulting ZDR histograms for each range of Z
selected. Statistics such as moving averages, averages across the range of Z, standard deviations, etc. were visually displayed upon the ZDR histograms. Trend data for past volume scans as well as running averages of multiple volume scans were also displayed. Taking these MATLAB images and introducing animation provided insight into how ZDR changes with time. This application was also introduced into the I&A GUI tool. As Jason completed his undergraduate degree in the spring 2012, the ROC’s work experience with MATLAB was a contributing factor to Jason’s acceptance to Miami University’s Meteorology graduate program to study his long-time interest in hurricane research.

2. ROC Engineering Branch

**NOAA Technical Leads:** Richard Vogt, Rex Reed, Russ Cook, and Bill Urell (all ROC Engineering Branch)

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

**Accomplishments**
Ms. Braxton collected and compiled information on the security posture of the WSR-88D network to ensure all systems providing data are secure. Mr. Bonsu and Mr. Hong Sick Wong developed and populated databases on the communications links that transmit radar data to central repositories. These data enabled the ROC to work with communications vendors to correct problems with unreliable links that deprived us of critical operational and research data. Mr. Milligans updated and perfected simulators that are used to simulate a normal radar environment in order for researchers to be able to play back radar data. Source scientists use the resultant secure data and playback capabilities to optimize QPE algorithms in order to improve the timeliness and accuracy of future operational forecasts.

Robert Palmer1 (primary), Wascar Bocangel1,3, Bill Chappell5, Boon Leng Cheong1,3, Phillip Chilson1, Jerry Crain1, Richard Doviak4, Caleb Fulton1,3, J.J. Gourley4, Matthew Harger5, Yang Hong7, Eric Jacobsen1,2, Shaya Karimkashi1, James Kurdzo1,2, Redmond Kelley1, Lei Lei1,3, Yinguang Li1,3, Baokun Liu1,3, Isaac Meier1, John Meier1, Valery Melnikov4, Yu Pan1,3, Sudantha Perera1,3, Damon Schmidt6, Hernan Suarez1,3, Dan Thompson1,3, Sebastian Torres1,4, Y. “Berry” Wen1,3, Mark Yeary1, Tian-You Yu1, Qing Zhao1, Allen Zahrai4, Guifu Zhang1, Yan (Rockee) Zhang1, Dusan Zrnic4

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

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

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

Accomplishments

1. An Optimized Pulse Compression Waveform for High-Sensitivity Weather Radar Observations

Faculty: Robert Palmer, Boon Leng Cheong, Guifu Zhang and John Meier; Student: James Kurdzo

The eventual goal for phased array antennas in the weather radar field includes the use of active arrays, meaning each element would be its own transmit/receive module. This advancement would lead to significant advantages, however such a design must be capable of utilizing low-powered, solid-state transmitters at each element in order to keep costs down. In order to provide acceptable sensitivity, as well as the range resolution needed for weather observations, pulse compression has been shown as a viable technique for implementation. Pulse compression has been used for decades in
military applications, but is yet to be applied on a broad scale to weather radar, due in part to concerns regarding sensitivity loss.

A broad, detailed optimization technique for pulse compression waveforms with minimalistic windowing using a genetic algorithm is being developed. The optimization framework allows for customization based on user needs and actual system performance, and allows for significant flexibility. A series of continuous nonlinear frequency modulated waveforms, which take into account transmitter distortion and system nonlinearities, have been developed. Primary testing in practical use scenarios has been carried out using the ARRC’s dual-polarized PX-1000 mobile radar, which utilizes dual 100-Watt solid-state transmitters. Point targets, as well as both stratiform and convective scenarios, have been documented. Additionally, dual-polarization observations have been made with optimized waveforms with overall success. Significant improvements in sensitivity over previous pulse compression methods have been demonstrated, while maintaining range sidelobes of approximately -60 dB and range resolution of 120 meters, despite a pulse length of 67 microseconds. With power efficiencies greater than 95%, the waveforms that are being developed have the potential to achieve desired specifications for weather observations with very low power transmitters.

![Observed sidelobes from an optimized wavefrom after going through the PX-1000 transmitter. With 2.2 MHz of bandwidth, a 67 microsecond pulse, and 95% power efficiency, peak sidelobes of nearly -60 dB are achieved, with 3 dB range resolution of 120 meters.](image)

**2. Performance Requirements for a Future MPAR System**

**Faculty:** Guifu Zhang, Richard Doviak; **Student:** Yinguang Li

This line for MPAR research started with jointly utilizing the NWRT/PAR sum and difference signals for crossbeam wind measurement and inhomogeneity detection using Spaced Antenna Interferometry (SAI) (Zhang and Doviak 2007&2008). In the past year,
our focus was mainly on ground clutter detection. Three algorithms have been proposed: the SCI (Spectrum Clutter Identification) algorithm (Li et al. 2012), the scan-to-scan correlation technique (Li et al. 2012), which is an extension of the multi-pattern technique tested on the NWRT PAR (Zhang et al. 2011), and the PCI (Polarimetric Clutter Identification) algorithm.

The SCI algorithm examines both the power and phase in the spectral domain and uses a simple Bayesian classifier (SBC) to combine four discriminants: spectral power distribution (SPD), spectral phase fluctuations (SPF), spatial texture of echo power (PT), and spatial texture of spectrum width (SWT). These discriminants are combined to make decisions as to the presence of clutter that can corrupt meteorological measurements.

The polarimetric clutter identification (PCI) algorithm combines four discriminants: a polarimetric test statistic obtained from the generalized likelihood ratio test (GLRT) and three other measurements obtained from the covariance matrix of the received complex vector, consisting of vertical and horizontal components. A simple Bayesian classifier (SBC) is used to combine all four discriminants and make decisions as to the presence of ground clutter. This work is focused on detecting ground clutter without the use of spatial textures and reducing the false alarms caused by narrow-band, zero-velocity weather signals. In the following figure the clutter maps obtained from the PCI algorithm and ground truth are shown for a controlled dataset.

The scan-to-scan correlation takes advantage of the nature of correlated ground clutter echoes. The scan-to-scan correlation technique examines both the magnitude and phase fluctuations of the cross-correlation coefficient between adjacent scans. This work is focused on detecting ground clutter without using spatial textures, which is challenging with the existence of narrow-band zero-velocity weather signals. A subjective comparison with the CMD algorithm (see figure below) shows the scan-to-scan correlation method performs equally well in discriminating ground clutter from weather signals, but presents clutter locations with higher spatial resolution and thus less false detections. This discrimination is especially useful if the clutter is from fixed scatterers being scanned by the weather radar's beam. Furthermore, the scan-to-scan correlation method might be applied to WSR-88Ds because all WSR-88Ds use Volume Coverage Patterns (VCPs) that contain two 360° azimuthal scans, each with different PRTs at the two lowest elevation angles (0.5 and 1.5°) where clutter matters the most. Although the scan-to-scan method was tested with KOUN data, it is applicable to any phased array radar. The scan-to-scan data experiments have been planed and conducted with the NWRT in collaboration with NSSL engineers.
Detection of clutter mixed with weather using (a) the scan-to-scan correlation method and (b) the CMD method.


Faculty: Tian-You Yu, Sebastian Torres; Student: Baokun Liu

Typical polarimetric measurements include differential reflectivity, co-polar correlation coefficient, differential phase, and linear depolarization ratio, all of which contain information integrated over the radar resolution volume. However, the size of the radar resolution volume can be too large. Spectral polarimetry seeks to combine Doppler and polarimetric measurements so that the distribution of polarimetric variables as a function of radial velocity within the radar resolution volume can be obtained. Specifically, spectral polarimetry for weather radar capitalizes on both Doppler and polarimetric measurements to reveal polarimetric variables as a function of radial velocity through spectral analysis. For example, spectral differential reflectivity represents the differential reflectivity from all the scatterers that have the same radial velocity of interest within the radar resolution volume. Here, spectral polarimetry has been applied to suppress both ground and biological clutter, retrieve individual drop size distributions from a mixture of different types of hydrometeors, and estimate turbulence intensity. Although spectral polarimetry has gained increasing attention, statistical quality of the estimation of spectral polarimetric variables has not been investigated.

During this project period, the relationship between the commonly used polarimetric variables and the spectral polarimetric variables was established. Both the differential reflectivity and co-polar correlation coefficient can be represented as the weighted sum of their spectral components. Furthermore, the estimators for spectral differential reflectivity and spectral cross-correlation coefficient were defined based on averaged auto and cross spectra. The bias and SD of the two spectral polarimetric variables were derived using the perturbation method. These statistical errors have similar forms to those from polarimetric variables and decrease as the spectral SNR increases.
Moreover, the spectral co-polar correlation coefficient and the number of spectrum averages play a significant role in these errors. These derived statistics can also be used to determine the minimum number of spectrum averages needed to meet statistical error requirements. Consequently, a threshold on spectral signal-to-noise ratio can be determined for a given number of spectrum averages to obtain the region where spectral polarimetric estimates have achieved the expected quality. One of the limiting factors for the application of spectral polarimetry to operational observations could be the requirement of a relatively long time sequence to achieve reasonable frequency resolution and statistical quality. In this work, we assumed that the number of spectrum points is sufficiently large so spectrum estimators are unbiased. To effectively increase the number of spectrum averages, a combination of time and range averaging could be used. Another possibility is to apply overlapped data windows so that the frequency resolution is maintained, while the data quality is compromised.

These derived statistical errors were further verified using simulations, where the time series signals for both H and V channels were generated based on modeled spectral polarimetric variables and regular SNR. Three cases with different values of spectral co-polar correlation coefficient and three variations of spectral differential reflectivities were simulated. The results demonstrate that not only the model spectral differential reflectivity and spectral co-polar correlation coefficient can be reconstructed, but also that the bias and SD obtained from simulations are consistent with the theoretical derivations.

Examples of spectral polarimetric variables are shown for the three cases from left to right columns, respectively. The average spectra from H and V channels are denoted by solid and dashed lines, respectively, on the top row. The horizontal dotted lines depicted the spectral SNR threshold needed to meet required accuracy and precision. The estimated and modeled spectral differential reflectivity and spectral correlation coefficient are shown in the middle and bottom panels, respectively. The modeled values are denoted by solid line, while the estimates are depicted using dashed lines. The darker dashed lines denote the region of estimates that meet the requirement.

Faculty: Phillip Chilson, Valery Melnikov; Student: Eric Jacobsen

Previous research has demonstrated the viability of detecting weak echoes (specifically Bragg scatter) with S-band radar, and explained the usefulness of the refractive index parameter $C_n^2$ in identifying convective motions in clear air (Melnikov et al. 2011). Our principle aim in the past several months has been to develop a robust, careful process of deriving $C_n^2$ values from S-band radar and wind profiler measurements, for purposes of direct comparison. Once developed, the performance of this process will dictate how confidently we can move forward with studies of the hydrometer-free convective boundary layer using S-band radars as a measurement tool. Data for this study has been collected from KOUN (a polarimetric WSR-88D), from the Purcell NOAA UHF wind profiler in Oklahoma, and from the Oklahoma Mesonet.

In seeking to make direct comparison of $C_n^2$ values, considerable effort has first gone into making sure these comparisons are as accurate as possible. A method of determining meteorological signal power needed to be determined for the wind profiler data. Both intrinsic noise level and the low-level attenuation imposed by the STC filter were corrected for using data from receive-only modes of the profiler, which occur routinely during search-and-rescue satellite overflights. Values of radar reflectivity factor $Z$ calculated from this data were also calibrated, using the Marshall Palmer relationship and co-located Mesonet rain gauge measurements during stratiform rain events. Though KOUN is already well calibrated, the RHI data we obtained from it also required some attention, particularly given the extremely weak signal and consequent need for highly effective noise removal. A program was developed to automatically determine noise levels in both channels, and also to apply a speckle filter for further reduction of randomly distributed, anomalous points of low SNR return. With near completion of these signal-processing tools, we have begun to see promising similarity between the two instruments’ vertical profiles of $C_n^2$, in terms of both vertical distribution of peaks and also, to a degree, magnitude (see figure below).

Early results have confirmed for multiple datasets that KOUN is able to detect structures in the atmosphere with high $C_n^2$ to a good degree of similarity with the wind profilers. With proof of concept, a new instrument for studying Bragg scatter is potentially being unveiled. The broad spatial extent of S-band radar data (especially compared with the traditional overhead measurements of wind profilers) means a greatly expanded domain for studying the occurrence of Bragg scatter and, by extension, the convective boundary layer. In the upcoming stages of the study, we hope to better relate environmental conditions to the occurrence of this type of echo, and to document the best methods of detection through observation of a range of datasets. With this information, it may be possible to recommend an MPAR scanning strategy suited to high-resolution parameterization of the boundary layer, particularly prior to convective initiation.
An RHI of KOUN data from 3/11/2008, depicting an elevated peak of reflectivity at ~4km (note: axes not marked with distance) in a clear sky. The RHI reflects data after noise correction and speckle filtering.

Overlapped vertical profiles of $C_n^2$ from KOUN and the Purcell wind profiler, depicting reasonably similar peaks and magnitudes, particularly at 4km where the occurrence of Bragg scatter is expected.
5. Spaceborne QPE (TRMM/GPM) and Implications for MPAR Resource Allocation: Create Synergy between Ground- and Space-Based Weather Radar Precipitation Measurements

Faculty: Yang Hong, Guifu Zhang, J.J. Gourley; Student: Y. “Berry” Wen

Our ultimate goal is to incorporate TRMM/PR observations into the NMQ/Q2 system for the enhancement of QPE products. TRMM/PR has high-quality observations of vertical profiles of precipitation and is immune to mountain blockage and degradation of vertical resolution that usually deteriorate precipitation measurements from ground-based radars. Based on these benefits, we plan to take full advantage of TRMM/PR and improve the ground-based radar QPE through the use of vertical information of precipitation. Given this motivation, as of end of the fiscal year, we have completed the following major research topics:

- Conduct event-based cross validation of NASA space-borne radar TRMM and ground-based polarimetric radar (KOUN).
- Propose physics-based VPR conversion and investigate the reflectivity conversion from Ku-band to S-band.
- Investigate the approach of incorporating TRMM/PR products into NMQ/Q2 products to fill the gap of NMQ radar coverage.
- Develop the VPR Identification and Verification (VPR-IE) method to improve the QPE from NMQ/Q2 system in mountainous regions where beam blockage is a serious problem.

The rest of this section shows some illustrative examples of our major achievements in two projects.

a. Cross Validation of TRMM/PR and KOUN

TRMM/PR suffers from relatively high uncertainty and attenuation with correction. Ground weather radar with polarimetric capability can significantly improve QPE by identifying rain echoes from different hydrometeor types and, therefore, provides physical insight into the development and interpretation of TRMM/PR algorithms and observations. We have compared and resolved discrepancies in hydrometeor retrievals and reflectivity observations between TRMM/PR and KOUN polarimetric weather radar (see first figure below) (Wen et al. 2011). By comparing reflectivity with respect to different hydrometeor types, the bias is found from echoes that are classified as rain-hail mixture, wet snow, graupel and heavy rain (see second figure below). The discrepancy is mainly caused by the difference of frequency of KOUN (S-band) and TRMM/PR (Ku-band).

b. TRMM-Based VPR Identification and Enhancement (VPR-IE)

Based on space-borne radar measurements, we have successfully identified and corrected for ground radar VPR and filled the gap where ground radar suffers from beam blockage (Wen et al. 2012). The third figure below summarizes the VPR-IE
method. We first identify the vertical distribution of hydrometeors and PSD from the PR measurements and fit the Ku-band VPR with a physics based model (figure part a). Due to the difference in frequency, S-band and Ku-band radars have different radar echoes for hydrometeors, especially for particles in melting phase. A conversion from Ku-band to S-band is required to make the VPR be equivalent (figure part b). Finally, this simulated VPR is convolved with ground radar sampling properties to compute apparent GR VPRs used for surface QPE computation (figure part c). The fourth figure below presents an example of VPR-IE method. In this example, the radar gaps of observation have been filled. In addition, QPE on the surface has been improved based on the VPR correction. The height of melting layer is low for this winter event. The NMQ/Q2 rain is overestimated, likely due to the contamination of bright band (BB) at middle distance (50-80 km), and underestimated, likely due to the overshooting of radar beam at far distance (e.g., >80 km). With VPR correction, the surface rain estimation is improved (over/underestimation reduced).

*Left: Scatterplot with colored data density of KOUN and TRMM 2A23 melting layer heights for every pixel in 19 events. The correlation coefficient, bias ratio, MAE, RMSE, and sample size are shown in the embedded text. Right: Scatterplots with colored data density and histograms of KOUN and TRMM PR reflectivity. Non-meteorological echoes based on KOUN's hydrometeor classification algorithm (HCA) have been removed and a minimum 18 dBZ threshold has been applied.*

*Bias (%) of TRMM PR reflectivity observations relative to KOUN for different hydrometeor types as discriminated by the dual-polarization HCA.*
Steps for incorporating TRMM-PR measurements into NMQ-QPE (VPR-IE method).

The representative example of the VPR on December 8, 2009 is shown: (a) fit a physically based VPR model (5 parameters) on the Ku-band TRMM-PR reflectivity profiles; (b) convert the Ku-band VPR (dotted grey line) into S-band VPR (solid black line); (c) convolve the S-band VPR with the sampling properties of WSR-88D ground radars. On panel (c), apparent VPRs are simulated from the S-band VPR from (b) at various distances (from 20 to 240 km with an interval of 20 km) using the beam characteristics of WSR-88D radars.

QPE example of VPR correction based on TRMM PR observations: (up-left) one hour rainfall from NMQ/Q2 radar only; (up-right) corrected one hour rainfall with combination of NMQ/Q2 and TRMM products; (low-center) QPE error in terms of radar distance (black line: Q2 radar only; red line: corrected Q2; observations of surface rain gauge are assumed to be the truth).
6. A Test of Cylindrical Polarimetric Array Configuration Using the Digital Array Radar

Faculty: Guifu Zhang, Caleb Fulton, Robert Palmer and John Meier; Students: Wascar Bocangel; Collaborators: Matthew Harger, Bill Chappell

The DAR Project has two concentrations. The first is the in-house production of a polarimetric, cylindrical, phased-array system using the DAR (digital array radar) as its backend. The second is to propose and test a procedure for aligning and calibrating a cylindrical phased array, thus permitting an objective comparison between the cylindrical and planar approaches to phased array implementation.

In order to build a flexible platform which will permit a valid characterization of a faceted cylindrical array, a design of a 180° system has been done. The system consists of 18 columns, each being a linear array of 10x1 elements. A sample column has been built and tested for performance assessment and comparison with simulated results. In addition, a two-stage switching network has been designed and implemented. This is so we can receive on all columns of the cylindrical array with the limited number of channels available from the DAR (16). Finally, simulations have been made to determine the optimum arrangement of the elements along the faces of the array (element separation) as well as the location of the feeding probes on the elements to reduce mutual coupling and increase cross-polarization isolation. The design portion is now at the stage of replicating the single column 18 times and start mounting the system for data acquisition. A method for alignment has been agreed upon and a method for calibration based on switching projections will be tested.

7. Calibration for Polarimetric Phased Array Radar

**Faculty:** Guifu Zhang, Richard Doviak; **Student:** Lei Lei

The antenna elements designed for Polarimetric Phased Array Radar (PPAR) such as dipole, slot, patch, slot-dipole, and patch-dipole have been studied. The slot and patch antenna elements have a complementary projection matrix, just as dipole antennas (Lei et al. 2012a). An ideal slot-dipole antenna element consists of a horizontally polarized slot and a vertically polarized dipole; an ideal patch-dipole antenna element consists of a horizontally polarized patch combined with a vertically polarized dipole. It was found that the off-diagonal terms of the projection matrix for the ideal slot-dipole or patch-dipole are zero. In other words, by using slot-dipole or patch-dipole antenna elements, H and V polarizations are always perpendicular to each other in all scan angles for the planar array structure. The radiation patterns of these five ideal antenna elements have been theoretically derived; the radiation patterns including feed lines and finite size ground planes were obtained using HFSS (High Frequency Structure Simulator).

To make unbiased polarimetric measurements, radar systems need to be calibrated for each beam steering direction. We investigated two possible calibration procedures: a) projection/correction matrix method (see figure below) and b) polarimetric variable calibration method. The correction matrix method adjusts amplitude and phase of each element for the H and V polarizations (Lei et al. 2012b), whereas the polarimetric variable calibration corrects the polarimetric estimates such as $Z_{DR}$ and $\rho_{hv}$.

![Projection/correction matrix method, Left: Before calibration Right: After calibration.](image)

8. Innovative Beam-Steering Reflectarray Antennas

**Faculty:** Yan (Rockee) Zhang; **Students:** Yu Pan, Sudantha (David) Perera, Qing Zhao

Our sub-topic is focused on further enhancement of advanced polarimetric array testbeds with two innovations. First is to merge the ESA scanning together with existing
reflector antenna (called reflectarray). This approach achieves the electronic scanning capability while retaining the low-cost and high efficiency of reflector antennae. The second innovation is a fully reconfigurable polarimetric array testbed based on OU’s own S-band TR module technology.

In FY12, the team has successfully built and tested two systems. One is a 16-element, dual-polarized subarray operating at receiving mode. Dual-polarized radiation patterns were measured and shown to match the full-wave simulations. The other system is a Ku band reflectarray to demonstrate the broadside pattern performance of a planar reflectarray and study the beam-blockage effect of feedhorns. A new method that achieves a compromise between accuracy and computational load, called Obstacle-Located Blockage (OLB), was developed and validated for beam-blockage analysis.

Left: Comparison of measured and predicted polarimetric array radiation patterns of the Conformal Phased Array Demonstrator (CPAD), Right: The first Ku band experimental to study the beam blockage effect and mitigations.

9. Polarimetric Phased Array Weather Radar

Faculty: Guifu Zhang; Post Doc: Shaya Karimkashi

PAR technology, recently introduced to the weather community, is able to make reliable weather measurements. Compared to conventional reflector antennas with mechanically steered beams, the PAR takes advantage of its electronic beam steering capability, resulting in shorter surveillance times and faster data updates. While PAR is starting to receive attention in the weather community, radar polarimetry has already matured to the stage that WSR-88D radars are being upgraded with dual-polarization capability. Therefore, it is desirable to combine electronic beam steering and polarimetry capabilities. However, a planar polarimetric phased array radar (PPPAR) has some deficiencies when the beam is scanned off-broadside. The PPPAR, with multiple faces to scan the whole azimuth space, suffers from the disadvantages of increase in beamwidth, loss in sensitivity, and bias in polarization qualities when the beam points away from the broadside angle.
The Cylindrical Polarimetric Phased Array Radar (CPPAR) has been recently proposed as a candidate for weather measurement and multi-missions (Zhang et al. 2011, Karimkashi and Zhang 2012). Compared with the planar array radar, the CPPAR has many advantages, such as scan-invariant beam characteristics and polarization orthogonality, which are crucial for accurate weather measurements. In order to demonstrate the concept, a dual-polarization frequency scanning array design is considered to scan the beam while avoiding the use of phase shifters. The frequency scanning antenna has been designed and tested. Initial simulated and measured results for an antenna column show that a very low cross-polar pattern can be achieved (Karimkashi et al. 2012b). It is also shown that by changing the frequency, the beam can be scanned to almost 25 degrees off-broadside. Mounting 48 antenna columns on a cylinder will constitute a cylindrical array which can be used to demonstrate this concept.

![Graphical representation of measured and simulated co- and cross-polarization pattern of the antenna array with V-pol. excitation at frequency of 3GHz.]

**10. Development of a Demonstrator CPPAR**

**Technical Leads**: Redmond Kelley, John Meier, Shaya Karimkashi; **Team**: Jerry Crain, Richard Doviak, Shaya Karimkashi, Redmond Kelley, Isaac Meier, John Meier, Bob Palmer, Damon Schmidt, Hernan Suarez, Dan Thompson, Mark Yeary, Allen Zahrai, Guifu Zhang, Yan (Rockee) Zhang, Qing Zhao, Dusan Zrnic

**Overall CPPAR Project Objectives**

This project is aimed at the development of a medium-scale CPPAR demonstrator capable of making high-quality polarimetric weather measurements. Although the primary objective of the project is to demonstrate and explore the polarimetric capabilities of a CPPAR system, an ancillary benefit of the project is the development of a more general multi-channel S-band backend suitable for use in a broad range of phased-array applications. All of the development work associated with this project
began in December 2011. The project can be broken down into the following sub-projects:

a. CPPAR Mechanical Sub-System Objectives

The mechanical sub-system for CPPAR is aimed at providing a trailer-mounted integration platform for all of the other electrical sub-systems. A high-precision cylindrical frame to serve as the mounting structure for the antenna sub-system was required. The cylindrical frame had to achieve a nominal diameter of 2m +/- 1mm and must hold its precision after being subjected to the vibration associated with a mobile system. An electronics/system enclosure was also required which would provide the amount of 19” rack-space needed by the other sub-systems. The electronics enclosure also needed to provide adequate access to system assets while also allowing for a high degree of flexibility/adaptability for future phased-array applications.

b. CPPAR Antenna Sub-System Objectives

The CPPAR antenna sub-system was envisioned as the primary enabler for a system with a large enough scale for weather measurements. The enabling factor is the ability to change the elevation angle of the system by changing the operating frequency of the radar. This eliminates the need for element-level T-R modules and results in massive simplification of the overall system with very little degradation in the capabilities of the system. The proposed antenna solution was a modular, dual-pol, frequency-steered vertical column antenna with microstrip patches as radiators. This challenging design would need to provide enough bandwidth to achieve the intended elevation scan range while also maintaining superior electromagnetic and polarimetric properties over all elevation angles. The physical size objectives are also challenging with a roughly 2.5”x60” form factor required to achieve the desired beamwidth and grating lobe performance.

c. CPPAR RF Transceiver Sub-System Objectives

The CPPAR RF transceiver sub-system was intended to provide all of the electronics necessary to interface the IF transceiver sub-system to the antenna sub-system. This includes providing synchronous up-down converter channels with enough bandwidth to cover the elevation scan range, high-power transmitters with enough power to provide adequate system sensitivity, and all of the necessary power/control circuits/sub-assemblies required to achieve the desired level of integration and modularity. Due to the scale of the system, health-monitoring functions are also required with the ability to autonomously power-down individual components when failures occur. This is critical since the system may be deployed at a remote site.

d. CPPAR IF Transceiver Sub-System Objectives

The CPPAR IF transceiver sub-system is to be the synchronous “brains” of the system. The proposed system would provide the ability to synchronously generate the transmit
chirp waveforms and sample the receive signals for all radar channels. Precise phase and amplitude offsets are applied here to accomplish the calibration and azimuth beamforming functions of the system. Synchronous T-R trigger generation and asynchronous system communications are also accomplished in this sub-system. High data rate I/Q streams are saved to disk for all radar channels resulting in very large amounts of overall data. A limited real-time would also be provided.

Overall CPPAR Project Accomplishments
Much progress has been made in the individual sub-systems, but none of the system-level objectives can be met until the sub-systems are completed. Work is being currently undertaken to come up with a calibration strategy for the system based on a combination of mutual coupling measurements and far-field pattern measurements.

a. CPPAR Mechanical Sub-System Progress

Base trailer modifications have been carried out including extension, reinforcement, and new paint. The precision cylindrical frame is almost complete with the diameter precision exceeding expectations. The expected precision is now +/- 0.01". Machined antenna brackets are being created to mount the column antennas to the frame and form a piecewise continuous ground plane. The development of the electronics enclosure is also going well. The antenna support structure houses the centralized system-level power/controls and provides a stable base for the cylindrical antenna. There are also two identical tri-rack enclosures that mate with the central enclosure. These house the majority of the radar electronics. These are being fabricated first so that they can be pre-loaded with equipment prior to system integration. The solidworks design is almost complete and drawings are being sent to the machine shops.

b. CPPAR Antenna Sub-System Progress

An initial design was undertaken based on a single-layer PCB due to the attractive cost and relative simplicity. The results were satisfactory, but it was decided that a multilayer PCB design would provide enough of an improvement in cross-pol, bandwidth and scanning range to warrant its higher cost. After many design iterations and an exhaustive search for a supplier capable of fabricating such a large multilayer design, a PO is finally in place for 8 prototype units. We expect to receive the prototypes by mid-November. Once they have been tested, we will make any necessary design changes and order 48 production units. This will allow us to populate ½ of the array. The final version is expected to have excellent performance; 20dB sidelobes (very difficult for this type of antenna), 30-40dB cross-pol, high efficiency, etc.

c. CPPAR RF Transceiver Sub-System Progress

The approach taken on the RF transceiver sub-system was to design around logical modular sub-assemblies. Not only does this result in lower risk, it also allows the system to be reconfigured based on the interconnections between sub-assemblies and/or changing out individual sub-assemblies. The critical chain of an individual RF
transceiver channel consists of three microwave sub-assemblies. The three sub-assemblies are the up-downconverter, radar front-end, and dual-transmitter. All three are based on multilayer PCB designs within milled aluminum RF gasket enclosures. There are also 4 other unique sub-assemblies aimed at performing the various power/control function of the RF transceiver. They also drastically simplify the potentially arduous integration process. All sub-assemblies have been prototyped, tested and are currently awaiting the final production run. A complex inventory management system has been implemented to handle the order generation and component tracking process since thousands of components are involved. Once all components are received, enough sub-assemblies will be built to populate 96 RF transceiver channels (half) of the system. At this stage, a full channel has been assembled and tested, but further testing will be needed once the system is scaled up. The 8-channel RF transceiver modular sub-assembly should be completed by mid-October.

d. CPPAR IF Transceiver Sub-System Progress

The IF transceiver sub-system is based on modular 2-channel IF transceiver cards. Each card contains 2 transmit channels based on DDS’s and 2 receive channels based high-speed ADC’s. The cards also handle the synchronous controls and communications for each dual-pol RF column. The cards use a Spartan-6 FPGA and are integrated into a modular 4-card (8-channel) sub-assembly where they are plugged into a backplane. The backplane distributes power and synchronization signals and aggregate the high-speed data interfaces into a single FPGA datalink board. The datalink board establishes a PCIe link with a control computer. Each control computer is responsible for 4 datalink connections resulting in a 32-channel radar signal processing capacity. Currently a first version of the 2-channel card has been thoroughly tested and a revision is currently being undertaken. This final version should be ready for fab by late September. The backplane is also being redesigned based on the changes to the card. Lastly, a housing for the 8-channel IF transceiver sub-assembly will need to be designed. There is also still a lot of software development that needs to be done.
2-Channel IF Transceiver Card

Project Publications


Additional Publications


**CIMMS Task III Project – Wind Turbine Radar Clutter Modeling and Adaptive Mitigation Incorporating Laboratory Measurements**

Yan Zhang, Robert Palmer, Fanxing Kong, Ying Bai (all ARRC at OU)

**NOAA Technical Lead:** Richard Vogt (ROC)

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

**Funding Type:** CIMMS Task III (ROC)

**Objectives**
Establish statistical relationship between controlled laboratory emulation and actual field measurements of wind turbine clutter (WTC); demonstrate that lab emulation is a key basis for the time-series signature mitigation and prediction for operational weather radars; and develop and demonstrate intelligent wind turbine clutter estimation and mitigation processing and statistical performance.

**Accomplishments**
One of the achievements during this period was the development of the Adaptive Spectrum Processing (ASP) algorithm for WTC mitigation. ASP exploits statistics of weather moment estimates and adaptively forms bandpass filters over the wind farm area. Implementation of the algorithm can significantly reduce the bias of moment estimates due to the presence of wind turbines, thus improving radar data quality in and around wind farm areas.

In addition, some interesting radar signatures of wind turbine have been discovered in the laboratory measurements. Examples include the average RCS variation, dual-pol signatures, and the frequency variation. A comparison between X-band (10.5 GHz) and Ka-band (40 GHz) step-frequency measurements indicates that radar frequency change may completely alter wind turbine radar signatures. Therefore, higher frequency laboratory measurements are desired to approximate the radar signature of actual wind turbines at NEXRAD frequency. To overcome this frequency mismatch encountered in laboratory studies, two field measurements were launched. The mobile radar RaXPoI was deployed in both measurements, one at Minco wind farm, the other at Lawton wind
farm. RaXPoI has very fast Pulse Repetition Frequency (PRF), and dual-pol capability. The dual-pol non-aliasing wind turbine radar data was acquired for the first time as is shown in the figure below. The data reveal detailed Doppler features that have never been observed before, and are still being studied.

**Awards**
The oral presentation “Development of Simple Radar Signature Models of Wind Turbine for Knowledge-Aided Wind Turbine Radar Interference Analysis” by Ying Bai, Fanxing Kong, Yan Zhang, and Robert Palmer was given the Award of Commendable Oral Presentation at the Student Competition of the American Meteorological Society’s 92nd Annual Meeting in New Orleans, Louisiana, January 2012.

The oral presentation “Wind Turbine Clutter Mitigation for Weather Radar by Adaptive Processing” by Fanxing Kong, Robert Palmer, Yan Zhang, and Ying Bai was awarded second place in engineering category at the Student Research Performance Day, University of Oklahoma, March 2012.

![Time-evolving Doppler spectrum observed by RaXPoI at the Minco, Oklahoma, wind farm.](image-url)
CIMMS Task III Project – Advanced Detection and Mitigation of Wind Turbine Clutter for the Multi-Mission Phased Array Radar (MPAR) Program

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

NOAA Technical Lead: Kevin Kelleher (NSSL)

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

Funding Type: CIMMS Task III (NSSL)

Objectives
Develop a robust algorithm for the mitigation of wind turbine interference on weather radar

Accomplishments
In the previous year of the project, the Range-Doppler Regression (RDR) algorithm was developed as a potential signal processing solution to the WTC problem. The RDR algorithm exploits the spatial continuity of weather signals in the range domain to mitigate WTC contamination while retaining as much weather signal as possible. Furthermore, the RDR algorithm is suited for real-time implementation on typical operational weather radars because it only uses time-series from one radial, and it can estimate the range-Doppler spectrum (RDS) with the required precision using samples collected within typical dwell times of a WSR-88D. The figure below shows an example application of the RDR algorithm: the left panel shows the RDS of a simulated convective-precipitation case; the middle panel shows the same weather signal contaminated by WTC; and the right panel shows the spectral coefficients that were determined to be mostly likely related to the weather signal by the RDR algorithm. The black asterisks indicate the mean Doppler velocity estimates. By using only the remaining spectral coefficients to estimate the spectral moments, the biases caused by WTC contamination is reduced, as illustrated by the improved agreements of the mean Doppler velocity estimates between the left and right panels.

Simulations were performed to evaluate the RDR algorithm’s performance for stratiform and convective precipitation. In the simulation, the mean Doppler velocity, spectrum width, and signal-to-noise ratio (SNR) for the weather signals were varied to test the RDR algorithm’s ability to handle different types of weather. Similarly, the clutter-to-signal ratio (CSR) for the WTC signal was varied to evaluate the RDR algorithm under different degree of contamination. The RDR algorithm has shown the capability to reduce the biases caused by WTC in the three spectral moment estimates to acceptable levels for the majority of the simulated cases.
The weather (left), contaminated (middle), and mitigated range-Doppler spectra (right) for a convective-precipitation case. Mean Doppler velocity estimates are indicated by the black asterisks. Visual inspection shows that the biases in the spectral-moment estimates are reduced by applying the RDR algorithm.
Theme 6 – Climate Change Monitoring and Detection

CIMMS Task III Project – Program Support for the Assimilation, Analysis and Dissemination of Pacific Rain Gauge Data: PACRAIN

Mark Morrissey (OU School of Meteorology), Susan Postawko (OU School of Meteorology), Scott Greene (OU Department of Geography and Environmental Sustainability)

NOAA Technical Lead: Mike Johnson (NOAA Climate Program Office)

NOAA Strategic Goal 1 – Climate Adaptation and Mitigation: An Informed Society Anticipating and Responding to Climate and its Impacts

Funding Type: CIMMS Task III (NOAA Climate Program Office)

Objectives
Tropical rainfall data taken over both land and ocean is particularly important to the understanding of our climate system. Not only is it a tracer of latent heat, it is vital to the understanding of ocean properties as well, such as latent and sensible heat flux, salinity changes and attendant local ocean circulation changes. In addition, rain gauge observations from low-lying atolls are required to conduct verification exercises of nearby buoy-mounted rain gauges, most of which are funded by NOAA’s Climate Observations and Monitoring Program (COM) Program.

This project supports the effort to “build and sustain the global climate observing system that is needed to satisfy the long-term observational requirements of the operational forecast centers, international research programs, and major scientific assessments”. Our current and future efforts include expanding our mission to collect, analyze, verify and disseminate global rainfall data sets and products deemed useful for Operational Forecast Centers, International Research Programs and individual researchers in their scientific endeavors. Housed in the Environmental Verification and Analysis Center (EVAC) at OU, the Comprehensive Pacific rainfall Database and the Schools of the Pacific Rainfall Climate Experiment (SPaRCE) have built upon work from past NOAA-supported projects to become a unique location for scientists to obtain scarce rain gauge data and to conduct research into verification activities. These data are continually analyzed to produce error-assessed rainfall products and are easily assessable via our web page (http://pacrain.evac.ou.edu/). We’re also actively involved in research of the tropical rainfall process using data obtained from this project.

Scientists need only to access the PACRAIN website (http://pacrain.evac.ou.edu/) to obtain the most comprehensive Pacific rainfall data set anywhere in the world. Also available are validation data for various regions. Many of these regional data sets are impossible or impractical to obtain elsewhere. The EVAC serves the research community by actively working with individual countries in environmentally important locations to help provide them with infrastructure, education and other short and long-
term support. One example is our collaboration with the International Precipitation Working Group in conducting satellite rainfall algorithm verification studies. The return on this investment by NOAA has been significant in terms of enabling EVAC to provide the scientific community with critical, one-of-a-kind rain gauge data sets and to have established ongoing mutually beneficial relationships that should lead to future collaborations. Past successes with this strategy have proven very worthwhile on a cost-benefit basis.

Our Pacific educational program, SPaRCE (http://sparce.evac.ou.edu/) contributes in a direct way to the PACRAIN database through the contribution of Pacific schools taking manual read daily rain gauge measurements while learning about the importance of weather and climate. Underlying these projects is the long-term effort to help build the capacity of the all the Pacific Nations Meteorological Services (PNMS) to better serve their constituents. This will ultimately result in the PNMS being able to self-sustain their data networks. We continue to contribute to this effort by providing what we can in terms of needed supplies, education and communication infrastructure (e.g. involvement in the Radio/Internet (RANET) project) until the PNMS become completely self-sustainable.

**Accomplishments**

1. **Data Collection Archiving and Web Access Development**

Due to the importance of tropical Pacific rainfall data to climate research and operational and climate forecasting we work collaboratively with the Pacific Island Global Climate Observing System (PI-GCOS) program to effectively and efficiently match the areas of commonality among both COM’s and PI-GCOS’s objectives. One of these common areas is the strengthening of the existing Pacific observation climate network for both atmosphere and ocean.

Specifically, we collect all available rain gauge data 1) in environmentally critical locations (e.g. tropical Pacific), 2) where dense rain gauge networks exist and 3) where agreements can be made to help construct rain gauge networks in these critical locations. These data are assimilated, homogenized, and error-checked and then made available to the general research community. To create the most comprehensive Pacific rain gauge database possible it is necessary to continue to work closely with the Pacific meteorological services to help them sustain high their quality gauge networks. One of our most successful efforts during the last few years is the implementation of a large network of new manual-read rain gauges and automatic data-logger equipped tipping bucket rain gauges located on various atolls and islands managed by the local Pacific meteorological services. A total of approximately 60 automatic, high quality tipping bucket gauges are being operated by various Pacific Island meteorological services. We currently are collecting the data in tip format and converting it to 1-minute resolution. One of new efforts this year has been to conduct research using the tipping bucket data. The PACRAIN data set has been used by many researchers for a variety of purposes (e.g. Delcroix et. al, 1996, Xie et al., 2007). The uses include incorporation into climate
models, climate studies, and the verification of satellite rainfall algorithms. The data set is also referenced by many programs (e.g., the International Precipitation Working Group, (IPWG), the Global Energy and Water Cycle Experiment (GEWEX), etc.) and is included in NASA’s Global Change Master Directory.

It is our belief that by working directly with local Pacific island meteorological services, we bring tangible benefits to the global climate research community through data base development and enhancement. In turn, the local meteorological services also benefit directly through enhanced forecast products developed by the scientific community using these critical data sets.

2. Pacific Rainfall Climate Network Development and Delivering vital Rainfall Data to the Research Community Through On-line Access of the PACRAIN Database

Rain rate measurements over open ocean regions are very important in the assessment of satellite rain algorithms and climate change and modeling of physical processes. Until recently, no Pacific island rainfall measurements have been available at resolutions less than one hour. Our new MetONE rain gauges tipping bucket gauges are equipped with data loggers and have been donated by OU for this project. In turn, they have been given to the PI-GCOS Coordinator, headquartered at SPREP, for distribution to the various PNMS. We have deployed over 50 of these gauges throughout the Pacific region since 2008. We are currently receiving rainfall tip data back from many PNMS and these data are inserted into the PACRAIN database. These data are particularly important in the understanding of basic tropical rain systems and consequently, more accurate global climate models. These data are all included in the PACRAIN database.

The achievement of this objective could not be accomplished without the close collaboration of the PI-GCOS Steering Group and the current PI-GCOS Coordinator. Other important collaborative groups are the Global Ocean Observing System (GOOS), the New Zealand Meteorological Service, and the New Zealand Institute for Research in Water and Atmosphere, the Australian Bureau of Meteorology, Meteo-France and the U.S. NWS.

Last year 60 new rain gauges were delivered to the Vanuatu Meteorological Service to enhance that rainfall climate observation network. This collaboration will greatly enhance the spatial density of rainfall observation in the western Pacific.

3. Provide High Spatial Density World Regional Rain Gauge Datasets for Use in Satellite Rainfall Algorithm Verification

EVAC maintains a database of selected high-density rain gauge network data for use in satellite rainfall algorithm assessment. Parts of our responsibilities include provide surface validation rainfall data to researchers associated with the Global Precipitation Climatology Project (GPCP) and the IPWG. Our tasks in this capacity include identifying and collecting these data sets and making them available to researchers for
this purpose. We also conduct studies on the errors involved when comparing satellite and rain gauge data. During 2008 we began research on the rain rate characteristics of tropical rainfall by developing a tropical point process model. The fit of the model at various temporal scales was tested using the data from the tipping bucket gauges.

The results of our research, one of the first on stochastic modeling of tropical rainfall, (e.g., Morrissey, 2009) indicate that the model is able to reproduce the rain rate statistics computed from Tongan METOne gauges quite well. This study would not have been possible without the tipping bucket data. The model now can be further tested at other sites that will allow the assessment the statistical characteristics unique to tropical rainfall.

4. Assess the Consistency of the TAO/TRITON Buoy Capacitance Rain Gauges through a Comparison with PACRAIN Island Tipping Bucket Gauges

Collaboration with oceanographers is one of our top priorities. The common use of remotely located, buoy-mounted capacitance rain gauges in the tropical oceans for satellite rainfall verification studies provides motivation for an in-situ gauge bias assessment. A comparison of the biases in rainfall catchment between Pacific island tipping bucket rain gauges and capacitance rain gauges mounted on TAO/TRITON moored buoys in the tropical Pacific was conducted using the relationship between the fractional-time-in-rain and monthly rainfall initially investigated by Morrissey et al. (1994). This study utilized the widespread spatial homogeneity of this relationship in the tropics to assess the rain catchment of both types of gauges at given values for the fraction-time-in-rain. The results indicate that the capacitance gauges are not statistically significantly biased relative to the island-based tipping bucket gauges. In addition, given the relatively small error bounds about the bias estimates any real bias differences among all the tested gauges are likely to be quite small compared to monthly rainfall totals. The paper has been accepted by the Journal of Atmospheric and Oceanic Technology (Morrissey et al. 2012).

Capacitance rain gauge mounted on TAO/TRITON moored buoys in the Tropical Pacific (left) and Pacific Island tipping bucket rain gauge (right).
5. Ongoing Research into Trends and Patterns in Pacific Rainfall Using the PACRAIN Dataset and Other Available Sources

For this effort, we continue to expand our research into variability and trends in pacific rainfall (e.g., see Greene, et al., 2009; Klatt, et al., 2012, 2011; Morrissey, 2009, etc.) Our most recent efforts involve the investigation of the historical (1942-2010) and future (2000-2100) rainfall and El Nino Southern Oscillation (ENSO) trends of selected sites from PACRAIN. The sites selected were chosen for the length of continuous historical data as well as their spatial locations across the Pacific Ocean. Future data is sourced from three different climate models: GFDL, MRI, and CSIRO. Both rainfall and surface pressure trends of the climate models are analyzed for indication of an ENSO phase signature, the main driver for rainfall trends in the South Pacific.

6. Outreach and Education Through the SPaRCE Program

Progress related to the SPaRCE Program included:

- 21 schools actively participating: 9 new schools have yet to send in data, 7 have sent in data past 12 months, and 3 have not sent in data within past 12 months
- SPaRCE data are available via a dedicated online interface at (http://sparce.evac.ou.edu/)
- Participants can enter data online at the SPaRCE website
- A quarterly SPaRCE newsletter is published and distributed to participants and others
- Ten new or reinstated sites in past 12 months
- Updated application and supporting documents
- Mailed out recruitment packets to over 200 schools
- Sent letters to dormant schools
- Contacted each Pacific meteorological service to get more schools
- Created SPaRCE calendar for participants
- Created a new electronic mailing list for newsletter and information distribution
- Created a SPaRCE Facebook group to encourage participant networking

Publications
Public Affairs and Outreach

NOAA Weather Partners – Public Outreach

Daphne Thompson (CIMMS at NSSL)

NOAA Technical Lead: Keli Pirtle (NOAA Public Affairs)

NOAA Enterprise Objective: An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions

Funding Type: CIMMS Task II

Objectives
Provide outreach to the public on the activities of the NOAA Weather Partners in Norman.

Accomplishments
NOAA’s Weather Partners offer scheduled tours of the NWC building throughout the work week for groups interested in learning more about the five NOAA organizations in Norman. These tours are offered to anyone from 3rd grade and up. Between 1 July 2011 and 30 June 2012 Ms. Thompson gave tours to more than 2,270 people who visited the building during 112 scheduled tours. These included public school groups, homeschoolers, private schools, church groups, engineering groups, senior citizen groups, and many others.

A tour of the NWC includes a presentation about the NSSL, along with a weather safety lesson, and these are followed by another presentation on the Science on a Sphere. Visitors then see the 7th floor observatory where the NSSL and ROC radars located in north Norman are pointed out. The training done by the WDTB also is discussed. On the second floor, the SPC and Norman NWS Forecast Office are shown so that visitors can see forecasters at work and learn about the watch/warning process.

Besides the scheduled tours, another important event where we are able to show the public the various science and forecasting done by the NOAA Weather Partners is the National Weather Festival. In 2011 it was held on 29 October 29 and was attended by about 3,000 people.

Additional highlights include:

- Participation with Susan Cobb (CIMMS at NSSL) in the AMS WeatherFest at the AMS Annual Meeting in New Orleans and giving a presentation on outreach at the NWC
- Assisting with the Women in Science Conference
- Assisting with the National Tornado Summit Meeting
• Speaking through Skype to the Masters of Disaster teacher workshops at the University of Georgia
• Assisting with the Oklahoma Mesonet Summer Camp

Ms. Thompson serves on the NOAA Weather Partners Communication Team, participates as a co-chair for the Norman Chamber of Commerce Weather Committee, and is a board member of the National Weather Museum and Science Center.

“Science on a Sphere” inside the NWC Atrium, a favorite tour stop.

**NOAA Weather Partners – Communications Outreach**

Susan Cobb (CIMMS at NSSL)

**NOAA Technical Lead:** Keli Pirtle (NOAA Public Affairs)

**NOAA Engagement Enterprise – An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions**

**Funding Type:** CIMMS Task II

**Objectives**
Engage all audiences in NSSL severe weather science through a variety of communication tools.
Accomplishments

1. Social Media

Susan Cobb (CIMMS at NSSL)

Managed our social media accounts:

- Facebook “Likes”
  - NSSL – 16,002 (+5321 from 2011)
  - VORTEX2 – 14,662 (+786 from 2011)
  - CI-FLOW – 267 (+116 from 2011)
  - CIMMS (new in 2012) – 88

- Twitter “Followers”
  - NSSL – 6189 (+3937 from 2011)
  - VORTEX2 – 6807 (+1951 from 2011)
  - CI-FLOW – 25
  - CIMMS – 43

- Flickr
  - 497 photos
  - 2326 views

- Pinterest
  - New in 2012

2. NSSL Website

Susan Cobb (CIMMS at NSSL), Vicki Farmer (INDUS)

Updated all content for NSSL website (last update – 2005), including research, outreach, history and education pages. This site is nearly updated.

3. OAR Hot Items

Susan Cobb (CIMMS at NSSL)

Authored 30 OAR Hot Item articles highlighting new NSSL research.

4. OAR Spotlight and News Articles

Susan Cobb (CIMMS at NSSL)

Authored three articles for NOAA Research News/Spotlight pages.
5. **NOAA Articles**

Susan Cobb (CIMMS at NSSL)

Authored one article for the main NOAA Web page.

6. **Press Releases**

Susan Cobb (CIMMS at NSSL)

Authored and assisted with two NOAA press releases. This also involved working through clearance at NOAA headquarters, and collaboration with NCAR and ESRL.

7. **NSSL Briefings Online**

Susan Cobb (CIMMS at NSSL)

Posted 34 stories on NSSL Briefings Online, NSSL’s news blog.

8. **NSSL Fact Sheets**

Susan Cobb (CIMMS at NSSL)

Revised the CI-FLOW, MPAR, and Warn on Forecast fact sheets in 2011-2012. Also managed the revision of the NSSL Fact Sheet 2012 used by Congressional Affairs.

9. **San Francisco Exploratorium**

Susan Cobb (CIMMS at NSSL), Sean Waugh (OU School of Meteorology)

Spent one week in Fall 2011 and two weeks in Spring 2012 working with San Francisco Exploratorium science museum staff and guests highlighting NSSL research and severe weather.

10. **Scientific Paper Reporting**

Susan Cobb (CIMMS at NSSL)

Summarized and reported 26 published papers determined to be “significant” to OAR leadership.

11. **American Meteorological Society WeatherFest**

Susan Cobb and Daphne Thompson (CIMMS at NSSL)
Set up and hosted a booth representing NSSL and engaging visitors in severe weather science through activities and handouts.

12. Outreach Email Answers

Susan Cobb (CIMMS at NSSL)

Answered 58 email inquiries to NSSL by email, phone or USPS.

13. NSSL News Flash

Susan Cobb (CIMMS at NSSL)

Wrote 48 emails informing NSSL staff of research activities.

WDTB Outreach Activities of CIMMS Staff

Les Lemon, Andy Wood, Clark Payne, Veronica Holtz, Mark Sessing, Dale Morris, Steven Martinaitis, Chris Spannagle, Aaron Anderson, Darrel Kingfield, Daphne LaDue (all CIMMS at WDTB)

NOAA Technical Lead: Ed Mahoney (WDTB)

NOAA Enterprise Objective: An Engaged and Educated Public with an Improved Capacity to Make Scientifically Informed Environmental Decisions

Objectives

Inform college students, emergency personnel, and the general public about warning-related research and training.

Accomplishments

CIMMS personnel have participated in various outreach activities within and outside the NWC. Activities within the NWC included:

- Facilitation of training for ten visiting Korean meteorologists in a partnership with OU instructors,
- Co-organization of the Severe Weather Preparedness and Planning for Public Assembly Venues and Events workshop,
- Participation in career fairs for OU School of Meteorology students,
- Participation in media-requested interviews,
- Participation in the annual National Weather Center Weather Festival in November, and
- Active involvement in the National Employees Association (NEA) and Central Oklahoma Chapter of the American Meteorological Society (COCAMS).
Activities outside the NWC included:

- Visiting elementary and junior high schools to talk about weather and meteorology careers,
- Participating in the United Way Day of Caring,
- Providing a public safety presentation to local cub scouts and participating in community meetings throughout Norman,
- Working a booth during American Meteorological Society 92\textsuperscript{nd} Annual Meeting.
Appendix A

CIMMS AWARDS AND HONORS

Adam Clark (CIMMS at NSSL) received an Editor’s Award for the American Meteorological Society journal *Weather and Forecasting*

Stephanie Hoekstra (SSWIM at OU) received the Department of Geography and Environmental Sustainability award for Outstanding Publication of the Year, 2012

Stephanie Hoekstra and Amy Nichols (both SSWIM at OU) received the award of Outstanding Presentation at the Student Competition of the 92nd American Meteorological Society Annual Meeting in New Orleans, Louisiana, January 2012

Xuguang Wang (OU School of Meteorology) received the 2012 College of Atmospheric & Geographic Sciences Dean’s Award for Excellence in Research and Scholarship

The oral presentation “Development of Simple Radar Signature Models of Wind Turbine for Knowledge-Aided Wind Turbine Radar Interference Analysis” by Ying Bai, Fanxing Kong, Yan Zhang, and Robert Palmer (all ARRC at OU) was given the Award of Commendable Oral Presentation at the Student Competition of the American Meteorological Society's 92nd Annual Meeting in New Orleans, Louisiana, January 2012

The oral presentation “Wind Turbine Clutter Mitigation for Weather Radar by Adaptive Processing” by Fanxing Kong, Robert Palmer, Yan Zhang, and Ying Bai (all ARRC at OU) was awarded Second Place in the Engineering category at the Student Research Performance Day, University of Oklahoma, March 2012

CIMMS Scientists at NSSL Valliappa Lakshmanan (Leader), Jeffrey Brogden, Kimberly Elmore, Charles Kerr, Travis Smith, Lulin Song, Gregory Stumpf, Robert Toomey, and Thomas Vaughan, along with NSSL Scientists Kurt Hondl, Robert Rabin, and Jian Zhang, received the 2012 Innovator Award from the OU Office of Technology Development. The citation includes the following statement: *This groundbreaking (WDSS-II) software is used worldwide to help predict weather phenomena including hail, precipitation, mesocyclones, and tornadoes. Used by private companies, research labs, National and International governments across the globe, this technology provides users across the world with the information needed to make property and life-saving decisions in the event of hazardous weather.*

CIMMS Scientists at NSSL Carrie Langston, Ami Arthur, Brian Kaney, Heather Moser, and Youcun Ci, along with NSSL Scientists Kenneth Howard, Jian Zhang, J.J. Gourley, and Steven Vasiloff, were awarded the 2011 U.S. Department of Commerce Bronze Medal for the design and implementation of a seamless gridded system for multi-sensor-derived precipitation estimation over the continental U.S.
### Appendix B

**PUBLICATION SUMMARY***

<table>
<thead>
<tr>
<th>Peer Reviewed</th>
<th>CIMMS Lead Author</th>
<th>NOAA Lead Author</th>
<th>Other Lead Author</th>
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*Publication numbers are approximate.

**This listing is partial because publications for CIMMS projects conducted during the fiscal year under the new Cooperative Agreement will be tallied and listed in the report for it and as such are not included here.*
### NOAA-Funded Research

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<th>Ph.D.</th>
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<td>Research Scientist</td>
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<td>Visiting Scientist</td>
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<tr>
<td><strong>Total (&gt; 50% NOAA support)</strong></td>
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<td>Graduate Students</td>
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<td>Located at a NOAA unit</td>
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<td>ROC-7</td>
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<td>Obtained NOAA employment within the past year</td>
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Appendix D

COMPILATION OF CIMMS-RELATED PUBLICATION 2011-12

Publications compiled here were funded under the Extension Agreement (NA08OAR4320904).

Peer-Reviewed Journal Articles, Books, and Book Chapters Published, In Press, or Accepted


Ge, G., J. Gao, M. Xue, and K.K. Droegemeier, 2012: Diagnostic pressure equation as a weak constraint in a storm-scale three dimensional variational radar data assimilation system. Journal of Atmospheric and Oceanic Technology, Accepted.


Kaltenboeck, R., and A. Ryzhkov, 2012: Comparison of polarimetric signatures of hail at S and C bands for different hail sizes. Atmospheric Research, Accepted.


Wang, S., M. Xue, and J. Min, 2012: A four-dimensional asynchronous ensemble square-root filter (4DEnSRF) and tests with simulated radar data. Quarterly Journal of the Royal Meteorological Society, Accepted.

Wang, X., 2011: Application of the WRF hybrid ETKF-3DVAR data assimilation system for hurricane track forecasts. Weather and Forecasting, 26, 868-884.


