Observations of Supercell Structures in Hurricane Irene

Senior Capstone 2011-2012

Jason Godwin, Brian Squitieri, and Bryan Trachier
Project Mentor: Dr. Michael Biggerstaff, University of Oklahoma
Project Summary

In August of 2011, Hurricane Irene impacted much of the East Coast of the United States. Mobile radars from the University of Oklahoma (OU) School of Meteorology (SoM) were deployed in an attempt to obtain high-resolution, rapid scan radar data. The radars used in this project included the Rapid Scan X-Band Polarimetric Radar (RaXPol) and SMART-R 2 (SR2) which were deployed near Beaufort, North Carolina. Data from the National Weather Service Morehead City’s WSR-88D will also be used. As Irene was striking coastal North Carolina, several supercell structures were observed by radar very near the RaXPol radar site. Doppler and dual-polarimetric radar data from RaXPol was obtained at a very high temporal and spatial resolution.

In this project, we will examine some of the radar observations of these supercell structures with the use of dual-polarimetric Doppler radar data. Some of the products we will use include reflectivity, differential reflectivity (ZDR), velocity, and spectrum width. One initial observation that has been made is that “rings” of large ZDR values were found very near the circulations. One hypothesis is that this is the result of enhanced droplet growth by coalescence due to relatively large vertical velocities in the vicinity of these circulations. We feel that this observation is significant because Irene is one of the first hurricanes to be thoroughly observed with dual-polarimetric radar at these high temporal and spatial resolutions, and that this “signature” could be crucial for detecting potentially tornadic circulations embedded within hurricanes.

First, we will assess the meteorological environment in and around Hurricane Irene using data from the Morehead City upper-air soundings to diagnose wind shear and convective instability, as well as some of the synoptic-scale features that may have contributed to the large number of supercell structures observed. The SoloII software will be used to edit and evaluate the radar data. Another program will be used to run a dual-Doppler analysis (using data from SR2 and the Morehead City 88D), allowing us to estimate the vertical velocities associated with these circulations. Once all the necessary data is received and edited, we will evaluate the observed properties on the structure and motion of these embedded supercells.
We are hoping to discover consistent trends in ZDR and velocity fields associated with these embedded circulations within Hurricane Irene that may have never been observed before. A thorough examination of these trends could lead to the improvement of tornado detection within hurricanes where detection is normally difficult. This research comes at a time where the National Weather Service is upgrading its radar network to dual-polarimetric capabilities, giving forecasters a suite of new radar products. By using dual-polarimetric data in our research, we can determine what forecasters should be looking for in tropical cyclone landfall situations where embedded tornadoes pose a serious threat to life and property.

**Project Narrative**

*Introduction/Background*

Tropical cyclone supercells and their associated tornado activity have been studied in depth using radar technology since the 1980s. While doing a research case study on the Hurricane Danny induced supercell/tornado outbreak, McCaul (1987) noted that the weaker reflectivity values of the supercells in conjunction with light rain falling within rainbands made supercell observations very difficult. The Huntsville National Weather Service Forecast Office had to switch their current radar unit to a logarithmic mode to detect the hook echoes associated with the supercells. As it turned out, the hook echo and inflow notch combined with the cells did not exceed 5 km in diameter.

McCaul later conducted detailed analysis of the supercells through the use of WSR-88D Doppler radar technology. In one research project, McCaul (2004) had investigated the three longest lived supercells identified in radar reflectivity imagery from Tropical Storm Beryl making landfall on August 16-17th, 1994 in South Carolina. Like many of the classic tornadic supercells within the Great Plains, the three supercells observed by McCaul all had prevalent mesocyclones. The main difference though, was the size of the mesocyclones (with a radial velocity of only 2 km as opposed to the Great Plains storms which are greater in size and even smaller from the Hurricane Danny mesocyclones. In addition, the studies of these cells showed that measured values of angular momentum, rotational velocity and shear were weaker than typical supercells out in the Great Plains. Lastly, McCaul (2004) had discovered that within these
three supercells, the echo-cloud top height and the vertically integrated liquid (VIL) values were also smaller in reference to the Great Plains supercells.

Although tropical cyclone induced supercells may be smaller in size in comparison to their Great Plains counterparts, the environment that promotes the development of these storms is rather complex in nature. An important section of this project is to research the environmental characteristics of the atmospheric environment associated with Hurricane Irene. McCaul (1996) found that environments with high amounts of moisture but relatively small CAPE, veered hodographs and maximum buoyancy at the 700 mb were the favorable parameters associated with major supercell/tornado events. The largest vertical shear and helicity values were also found in the right front quadrant of the tropical cyclone as well.

As mentioned by McCaul and Weisman (1996), “The structure and dynamics of the tornadic storms may differ between mid-latitude events and tropical cyclone events, but this is hard to confirm. To our knowledge, no multiple Doppler analysis or other complete four-dimensional observations of the circulations of hurricane-spawned tornadic storms have ever been obtained.” The purpose of our project is to conduct a multiple Doppler analysis for tropical cyclone induced circulations so that a three dimensional perspective of these circulations could be evaluated in great detail. More importantly, the radar data collected is in dual-polarimetric form from two mobile radar units (SMART R-2 and RaXPol radars). This means that detailed volumetric features of tropical cyclone convective circulations can be evaluated from Hurricane Irene in ways that have never been done before. With the recent upgrade in WSR-88D Doppler radars being upgraded to dual-polarimetric technology, the results found in this project could prove to be useful to operational meteorologists in providing timely warnings that could lead to saving many lives.

**Objectives**

The main objective in this project will be to develop a catalog of radar signatures and identify trends in dual-polarimetric radar fields.

![Figure 1: "ZDR Ring" (Biggerstaff, 2011)](image)
for supercell-like structures in Hurricane Irene as well as hypothesize reasons for these trends. One of the most interesting trends discovered in the differential reflectivity (ZDR) field is that rings of elevated ZDR values (known as “ZDR rings”) were found near the rotating structures. An example of a ZDR ring associated with a rotating structure can be seen in Figure 1. Our hypothesis for why there may be enhanced ZDR values is that enhanced vertical velocities in the vicinity of these structures may have led to the generation of larger droplet sizes through collision and coalescence growth.

Description of the Project

The first step of the project will be to edit the radar data using the SoloII software. This software allows for noise and clutter to be removed from each radar scan. The software can be accessed on the School of Meteorology (SoM) computer network via SSH. The second step will be to use a dual-Doppler analysis using the northern lobe seen in Figure 2. These dual-Doppler lobes will use data from the Shared Mobile Atmospheric Research and Teaching Radar (SR-2) and the Morehead City, North Carolina WSR-88D radar. A dual-Doppler analysis will allow us to estimate vertical velocities by using mass conservation equations. The northern lobe is preferred because (a) the majority of the rotating structures occurred in this lobe, and (b) there was more interference (i.e. trees and buildings) in the southern lobe. The third step of the project will be subjectively look at radar volume scans in which rotating structures move through the dual-Doppler lobes and near the radar site. We will document trends in the reflectivity, velocity, and differential reflectivity fields associated with these rotating structures. To go along with our radar studies, we will do a brief overview of the storm environment using surface and upper-air maps as well as radiosonde data from soundings on the North Carolina Coast to compare the storm environment of Hurricane Irene to high plains tornado outbreaks and to Eugene McCaul’s findings in his 1991 paper entitled Buoyancy and Shear Characteristics of Hurricane-Tornado Environments. The primary
focus of our study is on radar characteristics, but as background, we will need to examine the environment in which the rotating structures formed.

Broader Impact

Tropical cyclones (TCs) typically spawn multiple tornadoes as they make landfall. Some TCs, such as Hurricane Danny (1985) and Hurricane Ivan (2004), produce large numbers of tornadoes as they made landfall. Ivan produced 119 tornadoes over a three-day period after making landfall (Kovach, et. al., 2010). Although most TC tornadoes are short-lived and weak in comparison to tornadoes spawned by supercell thunderstorms observed in the Great Plains of the United States, tornadoes spawned in TCs nonetheless can be strong, and cause loss of life and property as extensive as Great Plains tornadoes. As an example of the danger posed by TC-spawned tornadoes, one of the rainbands of Hurricane Andrew spawned an F3 tornado that struck Laplace, Louisiana on 26 August 1992. The tornado tracked a total distance of nine miles, killed two people, injured 32 others, and left 60 families homeless. In 2011, Hurricane Irene spawned tornadoes in the Mid-Atlantic after making landfall, causing significant damage as well as killing and injuring several people.

Many TC tornadoes currently go undetected on conventional Doppler radar because the circulations are too small to be detected and they lack the classic signatures typically seen from Great Plains supercell tornadoes. The result is inadequate warning lead-times for the public to take appropriate safety measures in the event that a tornado develops within a TC rainband. Hurricane-spawned tornadoes account for 10% of all tropical cyclone fatalities (Kovach, et. al., 2010). Furthermore, fatalities often occur when tornadoes spawned by TCs strike densely populated areas with little to no warning. For this reason, analyzing radar data collected from mobile dual-polarization, X-band, and Doppler radars from Hurricane Irene may help usher in a new era of improved tornado detection during TCs, leading to better and more advanced tornado warnings during TC events, which may ultimately reduce the death toll associated with TC tornadoes.

Statement of Work
All three members of the group will be working together on editing the radar data in January and February, then working on the data analysis in March and into April. The results of the study will be put together as a paper, poster, and presentation in late April.

1. Editing radar data (January and February): The first step in our research process will be to edit the radar data from SR-2 and RaXPol in order to remove clutter and noise, allowing us to get radar data that predominantly shows precipitation elements. The radar data will be edited using the SoloII software in the School of Meteorology computer laboratory.

2. Data analysis (March and early April): The second step of our research process will be to analyze the radar data. We will be using reflectivity, velocity, and differential reflectivity fields in order to catalog and observe trends in these radar fields near circulations embedded within Hurricane Irene. Of particular interest are the differential reflectivity rings that were observed near the circulations (see the project objectives section above). Another main interest is to perform vertical wind velocity retrieval as this will aid in determining the cause of the larger drop sizes near the circulations.

3. Presentation/Paper (late April and early May): The final step of this research will be to prepare a poster and presentation summarizing our research findings as well as writing a paper to go along with it.

Jason Godwin will undertake much of the radar data editing as well as examine the differential reflectivity fields. Brian Squitieri will be working with the vertical velocity retrievals. Bryan Trachier will be computing statistics in order to come up with quantitative information for our findings. All three of us will work together on writing the final paper, creating and giving the presentation, and presenting the poster at the capstone poster session.
Curriculum Vitae for Participating Members

Jason Godwin

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Personal Statement
Atmospheric sciences have been a lifelong interest of mine, and my ultimate goal is to use my knowledge in this field to help the general public through the improvement of forecasting tools. My main research interest lies in the understanding of tropical cyclone intensity changes and hurricane dynamics. During the past several years, track forecasts for tropical cyclones have dramatically improved, but there has been little progress made into intensity forecasting. While I wish to eventually work in operational meteorology, my goal for graduate school is to enhance my understanding of atmospheric processes and to specialize in the study of tropical cyclones.

Education
(In progress) B.S. in Meteorology with Minor in Mathematics, University of Oklahoma, 2012.

- Expected graduation date: May 2012

Research
In the summer of 2011, I worked as a NOAA Hollings Scholar intern at the National Weather Service Weather Forecast Office in Charleston, South Carolina. My research project, entitled Multi-Dimensional Radar Analysis of Summertime Pulse Thunderstorms involved developing baselines for determining severe hail probabilities in summer pulse thunderstorms over southeastern South Carolina and coastal Georgia. This project involved examining the storm-top divergence using base velocity data, and the reflectivity at the -20C isothermal level. The research was presented in the forecast office as well as the NOAA Headquarters in Silver Spring, Maryland in August of 2011.

During my time at the NOAA Radar Operations Center in Norman, Oklahoma, I worked extensively with MATLAB to examine trends and problems with differential reflectivity for dual-polarimetric radar. One of my main focuses involved testing the quantitative precipitation estimation (QPE) algorithms used with dual-polarimetric radars. One case study I worked on involved data from the Morehead City, North Carolina radar collected during Hurricane Irene.

For my senior capstone project, I will be examining tornadic circulations within Hurricane Irene using data obtained by the University of Oklahoma’s Rapid X-Band Polarimetric Doppler Radar
(RaXPol). My mentor for this project is School of Meteorology professor Dr. Michael Biggerstaff.

**Work Experience**

- **June 2010 – Present**: Student Intern at the NOAA Radar Operations Center in Norman, Oklahoma. My main duties involved writing scripts in MATLAB (as well as a few in Python) to troubleshoot issues with differential reflectivity data from the dual-polarimetric radar beta tests, most notably the Norman, Moorehead City, Wichita, and Vance Air Force Base radars. Much of my work involved examining the output from dual-polarimetric QPE algorithms.
- **May 2011 – August 2011**: NOAA Hollings Scholar Intern at the National Weather Service Weather Forecast Office in Charleston, South Carolina. In addition to working on a research project (discussed above), I also took on some operational duties that involved collecting observational data (land and marine), creating daily climate summaries, and preparing, launching, and monitoring the evening radiosonde launch. During severe weather events, I primarily made and received phone calls concerning severe weather damage reports and issued local storm reports.

**Technical Skills**

I have worked some with C, Java, JavaScript, and Python programming languages. I have worked a lot with MATLAB scripting while at the Radar Operations Center. I have mastered basics of HTML and know some about advanced HTML topics.

**Teaching**

During my time at the University of Oklahoma, I have been an active member of a student forecasting organization called Oklahoma Weather Lab (OWL). For my junior and senior years, I have been a forecasting shift leader which heavily involved teaching new members forecasting skills. Some of these skills include looking at surface and upper-air charts, satellite data, and model forecasts.
Brian Squitieri

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Education:
University of Oklahoma, Norman, OK, 2008-Present
   B.S. in Meteorology, 2008-Present, Minors in Mathematics and Hydrology
   Overall GPA: 3.66
Raritan Valley Community College, North Branch, NJ, 2006-2008
   AA in Liberal Arts, 2006-2008 with Magna Cum Laude
   Overall GPA: 3.87

Research Experience:
Research Intern: Storm Prediction Center, Norman, OK, August, 2011-Present (Mentors: Dr. James Correa, Jonathan Garner)
*Performed analysis on mesoscale processes via hand analysis
*Used GEMPAK system software and Excel to compare data observations with model projections
*Evaluate radar data to determine the scope and areal extent of severe weather events
*All Research is based upon a case study for the Warm Sector Analysis and forecasting dilemmas for the April 27th, 2011 Tornado Outbreak.

Student Employee: Severe Hazards Analysis and Verification Experiment (Cooperative Institute for Mesoscale Meteorological Studies/National Severe Storms Laboratory), Norman, OK, May-August, 2010 (Supervisors: Kiel Ortega, Travis Smith)
*Make phone call to citizens to acquire information on severe weather that occurred at their location. (11,356 total phone calls made)
*Classify severe weather events and diagnose storm mode, intensity and tracks
Volunteer: National Severe Storms Laboratory, Norman, OK, May-June 2011 (Supervisors: David Rust, Don MacGorman)

* Assisted in launching balloon’s into thunderstorm updrafts
* Provided photography and videography as requested

Research Interests:

* Tornadogenesis in classic supercell activity
* Tropical cyclone induced tornado activity within imbedded cells in the outer rain-bands
* Deep convective initiation in environments aided by weak boundaries and little to no dynamic forcing
* Mesoscale features which enhance the severity of convective events
* Analysis of observational trends vs. model outputs involving severe convective events

University Activities/Services:

Outreach Specialist: National Weather Center, University of Oklahoma, 2008-Present (Supervisor: Dr. Kevin Kloesel)

* Give in depth tours of the National Weather Center (100 tours, 1,715 visitors)
* Provide knowledge of atmospheric processes and severe weather safety to all visitors
* Participate or Coordinate outreach events upon request

President (2010-2011), Active Member (2008-2010): University of Oklahoma Student Chapter of the American Meteorological Society, University of Oklahoma

* Coordinated monthly meetings and acquired guest speakers
* Conducted educational field trips, outreach activities
* Established internships with meteorological firms and governmental establishments for active members

Shift Leader (2009-Present), Committee of Adverse Weather Deputy Director (2010-2011), Outreach Chair (2011-Present): Oklahoma Weather Lab, University of Oklahoma

*(Shift Leader): Teach students how to forecast via evaluating observations, conducting hand-analysis, and using model data as a supplement, issue Podcasts, bulletins and forecast narratives.
References

Biggerstaff, M.I., 2011: RaXpol Deployment Summary


