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FACTORS THAT CONTRIBUTED TO THE HURRICANE GASTON FLOODING EVENT IN RICHMOND, VIRGINIA

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1. INTRODUCTION

Hurricane Gaston made landfall in South Carolina on 29 August, 2004, as a minimal Category 1 hurricane. On 30 August, over 12 inches of rain fell in the Richmond, Virginia, metro area causing extensive flooding, eight deaths, and nearly $20 million in damage. The event was largely unforecast as the Hydrometeorological Prediction Center (HPC) and the NCEP North American Mesoscale model (NAM) both called for an inch or less of precipitation. The goal of this study is to identify the factors that combined to produce the heavy precipitation and explore ways modelers and forecasters can improve precipitation prediction methods for future events involving decaying tropical cyclones (TCs).

2. BACKGROUND AND METHODOLOGY

As wind speed in a TC decreases, so does the public's perceived risk. This view, however, ignores what had become the leading cause of death in tropical cyclones for the final 30 years of the twentieth century: inland freshwater flooding (Rappaport 2000). While TC intensity should be considered when forecasting inland precipitation, it is only one of many factors. Previous research has found that interactions with jet streaks (Attalah and Bosart 2003, Sinclair 1993), fronts (Bosart and Dean 1991, Harr and Elsberry 2000), and orography (Sinclair 1993, Lin et al. 2001) control the location, duration, and intensity of precipitation more than TC intensity and structure. Many of these interactions occur during the transformation of a warm core tropical cyclone to a cold core extratropical cyclone in a process known as extratropical transition (ET). A conceptual model of ET developed by Klein et al. (2000) can describe the behavior of most transitioning cyclones.

While recent studies have improved our understanding of the ET process, storms that do not follow the Klein model still present a difficult challenge to forecasters. Hurricane Gaston, a weak hurricane at landfall, remained warm core for more than 24 hours over land, during which it produced record-breaking rainfall in southeast Virginia. Synoptic analysis of the region reveals no substantial jets and no preexisting low-level baroclinicity (not shown), and the topography of the region is not significant enough to provide strong lifting. Therefore, the previously listed physical processes are not likely to have played an important role in this precipitation event.

To understand this flash-flooding event, we will apply an ingredients based methodology developed by Doswell et al. (1996). While the ingredients-based method was developed for mid-latitude precipitation systems, the goal was to provide a heavy precipitation framework not limited by geography that could be applicable anywhere.

The concept behind the ingredients method is simply that the heaviest precipitation occurs where rainfall rate is highest for the longest time, or

$$P = RD$$

where P is the total precipitation produced, R is the average rainfall rate, and D is the precipitation duration. While simple, it provides a focus to our research. We will examine the two necessary ingredients, R and D, and the underlying causes of each.

3. OBSERVATIONS

WSR-88D radar imagery is used extensively to investigate both the rainfall rate and duration. The highest rainfall rate (indicated by the highest base reflectivity) occurred in a rain band that developed just south of Richmond around 1600 UTC and continued through 2000 UTC on 30 August. During this period, the Storm Prediction Center (SPC) listed 20 reports of damage by tornadoes associated with this line of convection (Figure 1). Further analysis of the radar imagery revealed numerous individual short-lived shallow supercells propagating across the Richmond area (Figure 2). The environment in southeast Virginia had vigorous wind shear in the lowest 3 km and CAPE values of just over 1900 J/kg in both the RUC analysis and the Morehead City 1200 UTC sounding. This is

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consistent with the favorable environments for TC supercell development found by McCaul (1991).

Two important ingredients for deep buoyant convection are a conditionally unstable environmental lapse rate and sufficient low-level moisture (Doswell et al. 1996). A tongue of high θ_e air extends off the Atlantic into southeast Virginia and provided the low-level moisture necessary for the explosive convective development (not shown). Daytime surface heating, limited elsewhere by cloud cover and rain, enhanced the CAPE in this region (Figure 3). Convection develops between 1100 and 1200 local time as solar heating approaches its maximum. Vertical temperature profiles near the circulation are nearly moist adiabatic and saturated throughout the column, except in the area devoid of clouds. Here, solar heating had created a superadiabatic near surface layer, destabilizing the lower atmosphere.

Rainfall duration is fundamental to the flooding in Gaston as Doppler radar shows base reflectivities of at least 35 dBZ over Richmond for six consecutive hours. Storm movement appears to almost pivot over Richmond as cells develop upstream and continually track across the area. Advection off the Atlantic provided a nearly tropical source of rich θ_e air for these cells (not shown). Deconstructing the precipitation maintenance dynamics will be the focus of the second part of this research.

4. MODELING

A modeling component to this study will investigate the representation of each of these ingredients in the Mesoscale Atmospheric Simulation System (MASS) model. Adjustments can then be made to improve model performance in relation to these ingredients and ultimately provide a more accurate simulation.

Preliminary results show a high sensitivity to initial conditions. Using relatively coarse initialization, such as the NCAR/NCEP Reanalysis dataset, fails to capture the intensity of the low-level circulation due to Gaston's compact nature. Different initialization times provide substantially different solutions after only 24 h of runtime, indicating that there is much room for improvement. Simulations are currently being performed with higher resolution datasets and a method of bogussing moisture fields from satellite data is under development. Our hypothesis is that these improvements to the initial fields will yield a more accurate representation of the heavy rainfall by the model.

5. CONCLUSIONS

The flooding associated with Hurricane Gaston in southeast Virginia was due to a combination of tropical and continental convective dynamics. Supercells that formed benefited from high θ_e ocean air in an atmosphere destabilized by solar heating. Future work will attempt to determine why this was the only area devoid of clouds on the morning of 30 August 2004.

Also difficult to explain is the duration of the rainfall. Our hypothesis is that a deformation zone formed along the axis of heavy convection. Base velocity imagery from the WSR-88D shows convergence along the axis of the rain-band that persists long after the convective supercells transform into stratiform precipitation. Manual surface analysis is being performed to investigate this hypothesis.

6. ACKNOWLEDGEMENTS

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Figure 1: Tornado reports on 30 August 2004, from the Storm Prediction Center.

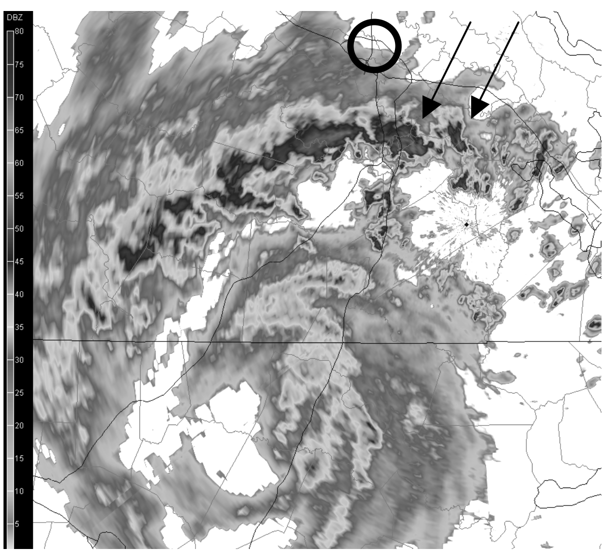

Figure 2: Base reflectivity image from radar site AKQ on 30 August 2004, at 1722 UTC. Arrows point to identified supercells. Cell on left produced a confirmed tornado in the city of Hopewell, VA. Richmond, VA circled.

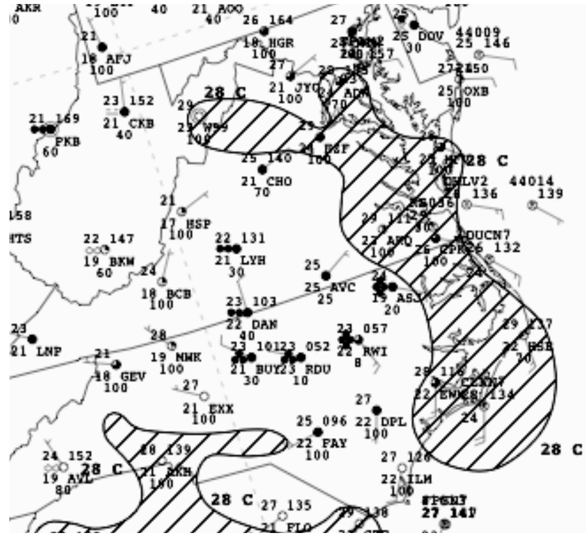

Figure 3: Station plot for 1500 UTC 30 August 2004. Hatched area indicates surface temperature of 28 degrees Celsius and above.