P2.24 COMPARISON OF THE INTENSITY EVOLUTION DURING TROPICAL STORMS GABRIELLE (2001) AND EDOUARD (2002) USING THE METHOD OF POINT-DOWNSCALING IN A HIGH RESOLUTION MODEL

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1. Introduction

A newly developed technique to simulate tropical disturbances known as point-downscaling (Nolan 2011) is employed to compare intensification (or lack thereof) in Tropical Storms Gabrielle (2001) and Edouard (2002). Point-downscaling uses modifications to the equations of motion such that high resolution models can maintain relatively constant vertical profiles of temperature, humidity, or wind across a large domain. This allows for a tropical cyclone in the model to be embedded in a homogenous environment making evolutionary analysis simpler. Simulations of Gabrielle and Edouard are performed using the Weather Research and Forecast (WRF) model in which mean vertical profiles from each storm are interchanged using point-downscaling. This allows for insights into why Gabrielle intensified and Edouard did not, though the storms were in similar environments (both storm environments were characterized by shear of 10-13 ms^{-1} and had SSTs above 29°C). We attempt to identify whether intensity differences are due to environmental factors such as adjacent dry air (for example) or if they are due to subtle differences in directional shear.

2. The Point-Downscaling Method

Nolan (2011) takes an alternative approach of resolving the convective scale and approximating the large scale environment using the method of point-downscaling (PDS). Homogenous tropical environments with vertical profiles of temperature, humidity, and wind are held nearly constant across a large domain with periodic boundary conditions. These profiles may be derived from average conditions over a large domain or may come from one specific location. To maintain these nearly constant profiles throughout the simulations, small changes to the equations of motion in the WRF model are introduced. The main issue involves the necessity of wind shear without a compatible temperature gradient in a doubly periodic domain. For this reason an extra forcing term is added to the momentum equation to balance the pressure force that would be required if the temperature gradient were allowed to exist. This technique can be thought of as the Coriolis force acting only on the perturbation winds and has been used in the modeling of mid-latitude convection (e.g., Skamarock et al. 1994 ; Davis and Weisman 1994 ; Weisman and Trapp 2003).

The key advantage to using the PDS method in this study is that it allows for the isolation of environment variables around TCs when doing

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evolutionary analysis. For example, one can use PDS to insert the vertical profile of winds from the environment of one storm into a different storm and then see how the second storm evolves. In this study we vary both thermodynamic variables and kinematic variables. In the case of thermodynamics, variables such as temperature, pressure, specific humidity, and height are predominantly dependent upon each other and must be kept together when exchanging storm environments (with the exception of specific humidity, which can be exchanged in the manner described below). That is to say one cannot simply insert the vertical profile of temperature from one storm into another storm without also exchanging the pressure and specific humidity. To allow exchanges of moisture in these simulations, relative humidity was calculated from the vertical sounding from the environments of both storms. This relative humidity was then applied to the temperature and pressure profiles from the other storm to calculate the appropriate specific humidity. In this way the second storm could be simulated with a moisture profile that resembles the first storm while the environment remains in thermodynamic balance. For the case of exchanging the *u* and *v* components of wind, no intermediate steps are necessary and wind from the environment one storm can be directly applied to the other storm. Thermodynamic variables included temperature, specific humidity, pressure, and height which were computed as average values from ECMWF reanalyses averaged over a 200 km to 800 km annulus centered on the storm. Kinematic environmental variables were the *u* and *v* wind components (averaged from ECMWF reanalysis data within 500 km of the storm center). Sea-surface temperature was another environmental variable and it was set to match observations for each storm (30.0°C for Gabrielle and 29.25°C for Edouard). SST was held constant both spatially (identical everywhere in the domain) and temporally throughout the simulations performed in this study. The final environmental variable considered was relative humidity. This relative humidity was used to calculate the specific humidity profile that was in balance with pressure and temperature as described above. The naming convention (referred to in figure 1) for these simulations simply uses the first letter of the storm in a Thermo-Winds-SST-RH ordering sense (i.e. The EGEG simulation contains SST and the thermodynamic profiles from the environment of Edouard and wind and relative humidity profiles from the environment of Gabrielle). This allowed us to create a complete set of "hybrid" storms derived from the environmental conditions of each storm. These environments were then used in WRF simulations out to 48 h. These simulations of Edouard and Gabrielle provided a continuum of development scenarios from which conclusions about the relative importance of environmental factors could be assessed.

3. Storm synoptic background

Tropical Storm (later Hurricane) Gabrielle developed in the southeastern Gulf of Mexico during the afternoon of 11 September, 2001. After making a small counter-clockwise loop it turned northeastward, crossed the Florida peninsula, and proceeded northeastward to the north Atlantic. The period of simulation for Gabrielle was 0600 UTC 13 September to 0600 UTC 15 September. Gabrielle did cross the Florida peninsula during this time period but no land was included in our idealized simulations. Gabrielle was upgraded from a Tropical Depression to a Tropical Storm by the National Hurricane Center (NHC) at 1200 UTC September 13 (Lawrence and Blake, 2001). Using Best track data, during the period of simulation, the minimum central pressure of Gabrielle decreased from 1005 hPa at 0600 UTC 13 September to 983 hPa at 1200 UTC 14

September before increasing to 995 hPa during its passage over Florida. Its maximum wind speed increased from 30 kt at 0600 UTC 13 September to 60 kt at 1200 UTC 14 September before falling to 40 kt during its passage over Florida.

Tropical Storm Edouard was classified as a tropical depression at 1800 UTC 1 September, 2002. Edouard achieved tropical storm status at 0600 UTC 2 September. The environment of Edouard was consistently characterized by significant 850 hPa to 200 hPa wind shear of 10 – 12 ms^{-1} and this caused its deep convection to remain primarily northeast of the low-level center. The mid-level air surrounding Edouard was also drier than that surrounding Gabrielle. After making a clockwise loop Edouard drifted westward, crossing the Florida peninsula before dissipating over the eastern Gulf of Mexico shortly after 1200 UTC 6 September (Pasch, 2003). The period of simulation for Edouard was 0600 UTC 3 September to 0600 UTC 5 September. As was the case for Gabrielle, land effects were not included in our idealized simulations. Edouard achieved a peak intensity of 55 kt with a central minimum pressure of 1004 hPa at 1200 UTC 3 September before decreasing to an intensity of 25 kt with a central pressure of 1011 hPa at 0600 UTC 5 September.

When comparing Gabrielle and Edouard, some key similarities and differences are noteworthy. Both storms developed in regions with mean SSTs above 29°C (30.0°C for Gabrielle and 29.25°C for Edouard). Both storms developed at similar latitudes and at similar times of the year. Both storms developed with initial pressures around 1005 hPa and were characterized by winds in the 30 – 60 kt range during the period of simulation. Each storm was influenced by shear in the 10 – 13 ms^{-1} range. One of the primary differences was that the middle to upper-level environment of Edouard was drier than that of Gabrielle with relative humidities 20% drier in the 400 – 500 hPa layer. The PDS method allows us to determine the relative importance of these differences with regards to the evolution of the storms.

4. Model

The Weather Research and Forecast Model (WRF) version 3.3.1 was used for the simulations performed in this study. Doubly periodic boundary conditions were used for the outer grid with resolution of 18 km. Two vortex-following nested domains with resolutions of 6 and 2 km were centered on the storms in the simulations. Microphysical processes are simulated with the WRF 6 class microphysics scheme, which includes graupel (WSM6, Hong and Lim 2006). Surface fluxes, friction, and vertical mixing in the planetary boundary layer (PBL) are parameterized using the Yonsei University PBL scheme (YSU, Noh et al. 2003; Hong et al. 2006). The parameterizations for surface fluxes of heat, moisture and momentum for fluxes at high wind speeds follow Dudhia et al. (2008). For the present simulations longwave and shortwave radiation are not active. The simulations depict TC development from a pre-existing, low-level vortex with peak tangential winds speed of 18 (Edouard) or 21 (Gabrielle) ms^{-1} at a radius of maximum winds of 90 km. The simulations used a modified Rankine vortex with decay parameter a = 0.4, which is more realistic for the development stage (Mallen et al. 2005). The Coriolis parameter is set to 6.5×10^{-5} s^{-1} across the domain.

5. Results

Figure 1 shows the minimum central pressure for all 16 simulations performed in this study. The figure shows the “continuum” of development scenarios that arises by systematically varying the environments of the two storms. Because the two storms were initialized with equal initial pressures, the authors can analyze the

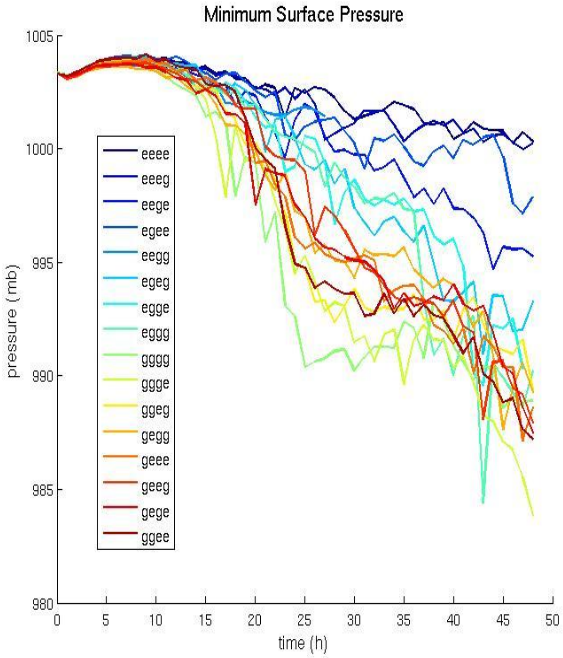

Figure 1. Minimum central pressure for each of the 16 simulations for forecast hours 0 to 48. Naming conventions are defined in Section 2.

various hybrid storms and assign relative importance of environmental factors. Qualitative analysis of the 16 scenarios suggests that the thermodynamics and SSTs played the greatest role in determining how rapidly the storms deepened, with wind profiles playing the second greatest role. Figure 2 shows hodographs for the simulated environment of Gabrielle (top) versus the simulated environment of Edouard (bottom). While the two hodographs in Fig. 2 are similar in shape, the hodograph from Gabrielle shows stronger clockwise curvature in the low levels. Though the effects of exchanging the wind profiles in the simulations are smaller in terms of falling central pressure (when compared to the effects of switching thermodynamic variables), the clockwise curvature observed in the Gabrielle hodograph does appear to be more favorable. When Edouard is simulated with the environmental winds of Gabrielle, it deepens by approximately 2 hPa more than the Edouard control run at 24 h. This 2 hPa drop in pressure is smaller when compared to the 4 hPa drop in the simulation with winds and relative humidity from Edouard and SST and thermodynamic variables from Gabrielle. In a similar manner, the deepening of Gabrielle is slowed the most by inserting the thermodynamic sounding of Edouard (GGGG vs. EGGG). The GGGG simulation deepens by approximately 12 hPa during the first 24 h of the run while the EGGG simulation deepens by just 4 hPa.

Along with comparisons of the changes in minimum central pressure one can also examine differences in storm structure that arise from altering environmental conditions. Figure 3 shows simulated satellite imagery of Gabrielle with 4 different sets of environmental conditions. Interestingly, the simulation of Gabrielle appears to be more symmetric about its center when simulated with environmental relative humidity or SST from Eduard than in the control run. However, when environmental winds from Edouard are used Gabrielle exhibits an appearance similar to observed images of Edouard (Fig 4).

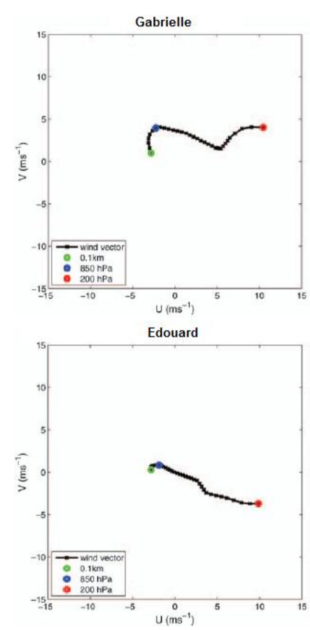

Figure 2. Environmental hodographs for Gabrielle (2001) and Edouard (2002) which are held relatively constant throughout the simulations.

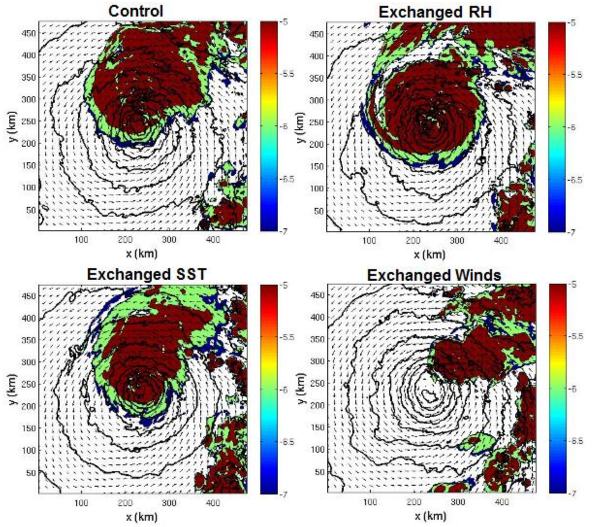

Figure 3. Simulated satellite imagery as depicted in terms of shaded contour plot of the base 10 logarithm of the concentration of ice condensate on vertical model level 34, with 10 m wind vectors and surface pressure for Tropical Storm Gabrielle at forecast hour 36. The upper left panel in the Control run, the upper right panel is Gabrielle simulated with environmental relative humidity from Edouard. The lower left panel is Gabrielle with SST from Edouard, and the lower right panel is Gabrielle with environmental winds from Edouard.

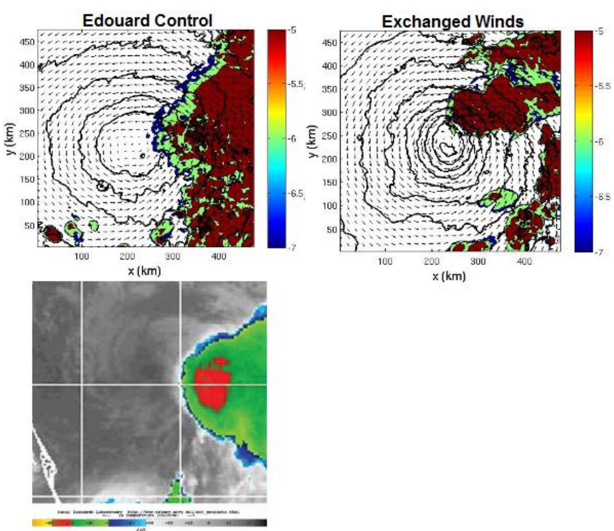

Figure 4. Simulated (upper) and Observed (lower) satellite imagery for Edouard (left) compared to simulated results from Gabrielle (right) with environmental winds from Edouard. The upper panel is valid at forecast hour 36 while the lower image is valid at 0715 UTC September 3, 2002.

6. Conclusions and Future Work

The 16 simulations of Gabrielle and Edouard give the authors some insight into the developmental mechanisms of each storm. It appears that the thermodynamics (temperature, pressure, and specific humidity) played the strongest role in determining the rate of deepening of the storm. However, environmental winds do play a role in the strengthening (or weakening) of the two storms and play an important role in the distribution of deep convection as seen in simulated satellite imagery. These simulations illustrate the utility of the point-downscaling method and how it can be applied to the analysis of tropical cyclones. We plan to apply this technique in future simulations in which variable profiles of environmental winds are applied to observed tropical cyclones. Further study will examine the role of clockwise versus counter-clockwise curvature in environmental hodographs. The effects of hodograph shape will be considered with regards to the traditional methods which consider 850 – 200 hPa vector shear (i.e., two hodographs with equal values of shear may have significantly different shape). These are the types of simulations that can be performed using the point-downscaling method.

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