13D.4 A NUMERICAL STUDY OF THE TOPOGRAPHIC EFFECTS ON STRUCTURE AND RAINFALL IN HURRICANE GEORGES (1998)

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1. INTRODUCTION

The interaction of a landfalling tropical cyclone (TC) with mesoscale topographic features is not well understood. Significant variations in wind, pressure, and precipitation distribution in TC's have been observed over mountainous regions. The impact of the Caribbean islands on passing TC's is one of the difficult problems in hurricane prediction in the western Atlantic. Hurricane Georges (1998) made direct landfalls on the mountainous islands of Puerto Rico and Hispaniola as a strong category 2 on the Saffir-Simpson intensity scale. Georges produced copious rain (up to 800 mm), deadly flash floods, and mud slides over the two islands, with over 400 fatalities in Hispaniola alone. Operational forecast models did not accurately predict Hurricane Georges' track at the landfalls. In this study, we use a high-resolution mesoscale model to investigate the physical processes associated with a powerful hurricane's landfalls on the topographic Caribbean islands.

2. MODEL AND DATA

The model used in this study is the high-resolution, non-hydrostatic, 5th generation Pennsylvania State University-NCAR Mesoscale Model (MM5). We used four nested domains with 45, 15, 5, and 1.67 km grid resolutions, respectively. The outer domain size is 120 x 150 grid points, the second and the third domains size are 121 x 121 grid points and the fourth domain is 151 x 151 grid points. The second, third, and fourth domains are following the vortex (Tenerelli and Chen, 2001). All the domains have 28 sigma levels with 9 sigma levels within the planetary boundary layer (PBL). The model initial and lateral boundary conditions are the 0.75 x 0.75 degree Navy Operational Global Atmospheric Prediction System (NOGAPS) global analysis fields including sea surface temperature (SST). The model is initialized at 0000 UTC 21 September 1998 and integrated for 96 hours. One of the problems using global analysis fields to initialize a high-resolution model is that the initial vortex is usually much weaker than the observations. We use a procedure similar to the one described in Liu et. al (1997), relocating a vortex spun up in MM5 to the best track location at the initial time.

For comparisons we analyzed radar reflectivity and wind speed fields using two center crosses a few hours prior to Puerto Rico landfall from the NOAA WP-3D aircraft tail Doppler radar. The data was in a 80 x 80 x 11 km domain, with a grid resolution of 1.5 x 1.5 x 1 km. In addition, comparisons are also made with the WSR-88D ground radar from San Juan, Puerto Rico. The WSR-88D radar provides 1-h mean rain estimates (R) over a domain extending to a 230 km range from the radar with a 4 x 4 km resolution (Digital Precipitation Array). The WSR-88D uses two different Z-R relations: (i) the default relation ($Z=300R^{1.4}$); (ii) a tropical relation ($Z=200R^{1.2}$); the latter is used here.

3. RESULTS

The simulated storm displays a good agreement with the observed storm in terms of track and intensity. As shown in Fig. 1, the MM5 track is slightly south at Puerto Rico landfall and slightly north at Hispaniola landfall. However the entire track corresponds very well with the best track. Fig. 1 also shows that the simulated and observed storms are at equal intensity, near 970 hPa, at Puerto Rico landfall. The modeled storm strengthens slightly when in the vicinity of Puerto Rico while the observed storm displays near steady intensity or slight weakening. This discrepancy could be due to the more southerly landfall on the island in the MM5, while the observed storm tracked over the center of the island where the highest terrain is located. After crossing Puerto Rico the intensity trends appear similar through Dominican Republic landfall. Hurricane Georges weakened significantly with the sea level pressure filling from 964 to 996 hPa during a 24 hour period when interacting with the high terrain of Hispaniola. The model simulated storm also weakens but less than what was observed. After departing Hispaniola the observed storm moved into the Windward Passage and made landfall on the northern coast of eastern Cuba and skimmed the coast throughout its west/northwest propagation.

The main features of the observed storm are well reproduced by the model. Similar rainfall and wind speed structures are observed before Puerto Rico landfall by comparing radar composites of the 2 km reflectivity and horizontal wind speed from the NOAA WP-3D aircraft tail Doppler radar. Both show a very strong asymmetry with dominance of heavy rainfall and strong winds in the east and northeast quadrant of the storm with significantly less rain and lower wind speeds in the front quadrants of the hurricane.

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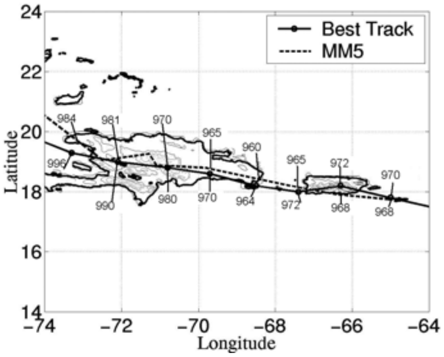

Fig. 1: Observed and simulated tracks of Hurricane Georges with sea level pressure (hPa) indicated every six hours from 1800 UTC 21 to 1200 UTC 23 September and model terrain contours every 200m.

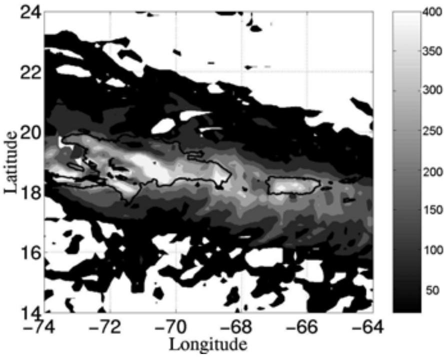

Fig. 2: Accumulated rainfall (mm) from the MM5 simulation.

Comparisons with the WSR-88D radar from San Juan, Puerto Rico shows that the model is displaying a similar rainfall structure while interacting with the landmass and topography of Puerto Rico with the heaviest rainfall rates occurring in the SE quadrant, the predominate quadrant with the onshore and upslope flows . The comparisons with the USGS rain gauges in Puerto Rico show that the model is displaying similar regions of accumulated rainfall maximums near the Cordillera Central, the mountain chain over the central part of the island. The model also correctly detected a local rainfall maximum south of San Juan, in the Sierra di Luquillo, where the elevation is near 900 m.

Fig. 2 shows that the majority of the heavy rainfall is produced from the orographic enhancements of the islands' topography. Rainfall totals around 500 mm are indicated in the MM5 near the highest terrain in Puerto Rico and near 800 mm in Hispaniola with pronounced rain shadows on the lee sides of the mountains.

Fig. 3a shows the orographic enhanced rainfall as Georges tracks over the high terrain of Puerto Rico. Rainfall rates near 75 mm/hr are indicated in the MM5 on the upslope side of the mountains with little, or no rain, on the downsloping sides. As the airflow impinges on the high terrain of Puerto Rico and Hispaniola, the nearly saturated layer from the surface to 500 hPa is lifted above the mountains. It then descends to the lee side of the mountains, generating subsident warming and drying in the lower troposphere as shown in Fig. 3b The entire troposphere has an relative humidity (RH) close to 100% except for the localized drying due to subsidence in the upper troposphere above the mountain and the lee of the mountains (minimum RH of 57% in Puerto Rico and a minimum of 46 % in Hispaniola). This result is consistent with the observed foehn phenomenon.

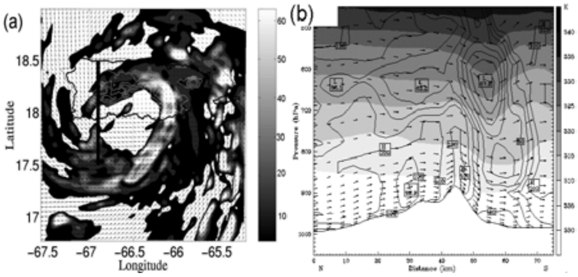

Fig. 3: (a) MM5 simulated instantaneous rainfall rate at 0000 UTC 22 September (two hours after Puerto Rico landfall). The black vertical line displays the location of the vertical cross section shown in b. (b) North-south vertical cross section along 66.9 W of potential temperature (K) (color contours) and relative humidity (%) (contours) through the Cordillera Central of Puerto Rico.

4. CONCLUSIONS

The model has adequately captured the main characteristics of Hurricane Georges prior to and during the landfalls of Puerto Rico and Hispaniola. As Hurricane Georges interacted with Puerto Rico only minor intensity changes occurred; however the onshore and upslope flows over the Cordillera Central greatly enhanced the rainfall and altered the structure of the storm. Over Hispaniola, significant rainfall rates and intense updrafts occurred on the windward sides of the mountains and mountain tops, with an acceleration in wind speed, and adiabatic warming and drying on the leeward side of the mountains which weakened the modeled storm 23 hPa in 24 hours. Future simulations, in which the island terrain will be altered, and more detailed observational comparisons with help to quantify the significance of the storm-mountain interaction.

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5. REFERENCES

References are available from the author upon request.