8A.7 ASYMMETRIC STRUCTURE OF A LANDFALLING HURRICANE

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1. INTRODUCTION

It has been known that asymmetries in hurricanes can affect their intensity (e.g., Montgomery and Kallenbach 1997; Möller and Montgomery 2000; Wang 2002). During hurricane landfall, the land-sea contrast may cause highly asymmetric structures to affect also the distribution of precipitation, wind guests, and even tornadoes at preferred locations relative to the storm center. Therefore, understanding the dynamics of asymmetries is important not only to intensity change but also to the quantitative forecast of precipitation. In this study, we examine the development of asymmetric structures in an explicitly simulated hurricane during landfall using potential vorticity (PV) dynamics. Previous studies (Chen and Yau 2001, and references therein) have demonstrated a good correlation between PV bands and inner spiral rainbands.

2. MODEL AND SIMULATIONS

The simulations are performed using an improved version of the nonhydrostatic Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model Version 5 (MM5) with 6-km resolution and 232×169 grid points. In the control simulation, the surface is assumed all water. In the landfall run, one third of the grid mesh to the west of the domain is assumed to be over flat land with marsh or wet land characteristics. The remaining two third is assumed over ocean with a constant sea surface temperature (SST) of 28°C. The land surface temperature, initially the same as the SST, is allowed to evolve with time. Other initial and boundary conditions are given by the control experiment of Chen and Yau (2001). The hurricane generally moves from east to west and makes landfall at 19 h of the 24-h simulation.

3. RESULTS

Interaction of the hurricane vortex with boundary layer friction affects the intensity of the storm. Figure 1 depicts a comparison of the minimum sea level pressure for control and the landfall runs. The hurricane deepens rapidly until 15 h, when the vortex center is 120 km from shore. PV and radar reflectivity maps from the landfall experiment show a quasi-stationary outer spiral rainband inland near the shoreline around 12 h. The band is initiated by friction induced convergent winds in the boundary layer and is characterized by a positive PV anomaly associated with shallow convective clouds extending to a height of 3 km. At 15 h, this PV band merges with the PV ring of the eyewall. The event results in a temporary weakening of the vortex but is followed quickly by a 2-h reintensification of the storm. This phenomenon resembles the eyewall replacement process just before landfall discussed by Willoughby (1990) and Wang (2002).

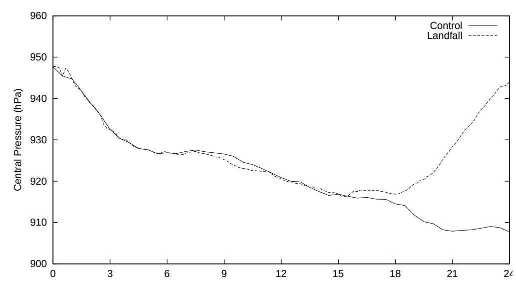

Figure 1: Comparison of the time series of the minimum central sea level pressure (hPa) between the Control (solid) and landfall (dashed) simulations.

Interaction with the underlying surface also alters the structure of the hurricane, particularly in terms of PV. Fig. 2a depicts results from PV budget calculations which show that boundary layer friction and the associated convection produce positive PV ahead and negative PV behind the hurricane when it makes landfall. The positive PV generation tends to enhance convection and the associated diabatic heating in the low levels to further amplify the low-level PV in the front quadrants. This asymmetric configuration breaks the low-level PV ring. As a result, air parcels with low equivalent potential temperature enter the eye to stabilize the stratification in the core (Fig. 2b). Consequently, PV increases significantly in the core within

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and just above the boundary layer where weak stratification was present when the hurricane was offshore.

The PV structure above the boundary layer also changes after landfall. As convective heating and PV generation reduces due to the loss of oceanic heat source, the eyewall PV ring in the middle and upper levels evolve into a monopolar structure by the non-linear PV mixing process (Schubert et al. 1999).

The changes in the mean PV structure affect the mean PV gradient in the radial direction. This in turn changes the PV anomalies and the tangential wind through wave-mean flow interactions. Fig. 3 depicts the mean tangential wind tendency due to eddy momentum advection after landfall. The vortex Rossby waves redistribute the angular momentum in the middle and upper troposphere to decelerate (accelerate) the tangential wind at (inside) the radius of maximum wind. On the other hand, asymmetries in the low levels accelerate the tangential wind and offset the momentum loss due to the interaction of the mean circulation and surface friction.

4. CONCLUSIONS

The landfall of an idealized mature hurricane over a flat surface with wet land characteristics is simulated using MM5. It was found that asymmetric structures in the hurricane arising from boundary layer processes can change the mean circulation significantly. When a low-level PV band formed onshore ahead of the vortex merged with the PV ring of the eyewall, a temporary weakening/reintensifying cycle is observed. It implies that a landfalling hurricane may change its intensity under the influence of PV anomalies ahead of the vortex. Interactions between the vortex and the PV anomalies may lead to eyewall replacement and deflection of the track of the storm.

After the hurricane makes landfall, the initial eyewall PV ring evolves into a monopolar structure. The low-level monopole forms from the stabilization of the low-level atmosphere in the core. The upper monopole results from non-linear PV mixing processes. The redistribution of the horizontal momentum by wave-mean flow interaction effects a change in the tangential wind.

5. REFERENCES

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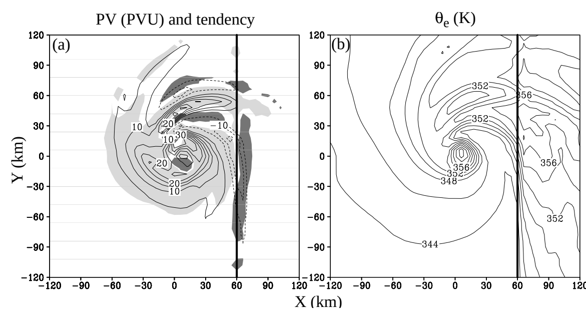

Figure 2: Horizontal distribution of the (a) PV (in contours with intervals of 5 PVU, zero contour is supressed) superposed with the PV-generation rate (values less than -18 PVU h^{-1} are in dark shading, greater than 18 PVU h^{-1} are in light shading), (b) equivalent potential temperature with intervals of 2 K, at the lowest model level valid at 20 h 50 min. Thick solid line denotes the shore.

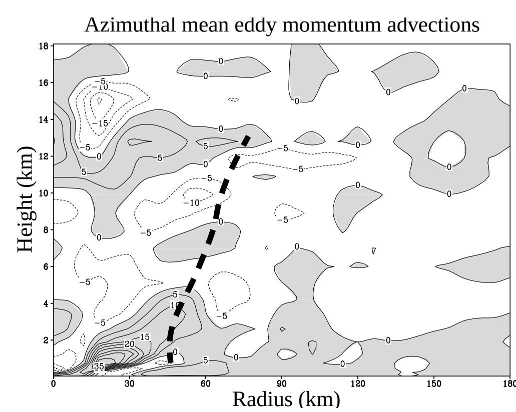

Figure 3: Radius-height plot of the mean tangential wind tendency due to eddy advection terms, valid at 20 h 50 min. The contour intervals are 5 m s^{-1}h^{-1}. Positive values are shaded. Thick dashed line denotes the radius of the maximum mean tangential wind.