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A NUMERICAL STUDY OF THE EVOLUTION OF HURRICANE BONNIE (1998)

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1. INTRODUCTION

It is well known that predicting tropical cyclone intensity is much more difficult than the track forecast. The tropical cyclone intensity depends on many factors, such as SST, environmental flow (or vertical shear), model physics, air-sea and air-land interaction. Numerical models are a powerful tool to study the impact of each factor on storm intensity change.

Hurricane Bonnie (1998) is an interesting case for this kind of study. Bonnie had two distinct characters compared to other tropical storms. First, Bonnie deepened rapidly (at a rate of 0.8 hPa/h) in the first two days after reaching hurricane Category 1 at 0000 UTC 22 August 1998. During the next three days (i.e., 24-27 August), its intensity remained nearly unchanged over the open ocean. It weakened as it was close to landfall. Second, Bonnie had strong asymmetric structures, with a partial eyewall observed during August 22-25.

2. MODEL DESIGN

In this study, the evolution of Hurricane Bonnie (1998) is explicitly simulated using the latest version of the Penn State-NCAR nonhydrostatic, two-way interactive, movable, triply nested grid mesoscale model (MM5V3.4) with the finest grid length of 4 km. The model physics package used includes the Goddard Tao-Simpson (1993) explicit cloud microphysics scheme, the Blackadar PBL scheme and a radiation scheme that are similar to those given in Liu et al. (1997). The initial mass, moisture and wind fields of the hurricane vortex are incorporated into the model initial conditions (i.e., at 0000 UTC 22 August 1998) using the AMSU satellite sounding data. The daily SST changes are used to simulate the oceanic feedback under high wind conditions. A 5-day simulation is performed, which covers the initial rapid deepening, steady variation and landfalling stages of the storm.

3. VARIFICATION

As verified against various observations and the best analysis, the 5-day control simulation captures reasonably well the evolution and basic structures of the storm. The simulated track is within 2 degree lat/lon of the best analysis during the 5-days integration, with the landfalling point close to the observed (see Fig.1). However, the simulated storm moves faster the observed, so the landfalling time is about 15 hours earlier than the observed. This is mainly because the model does not capture the slow moving stage between 24 to 48 h during which period the simulated track is too far to the west of the observed. Thus, the simulated storm may have a mean anticyclonic steering flow that is different from that in nature.

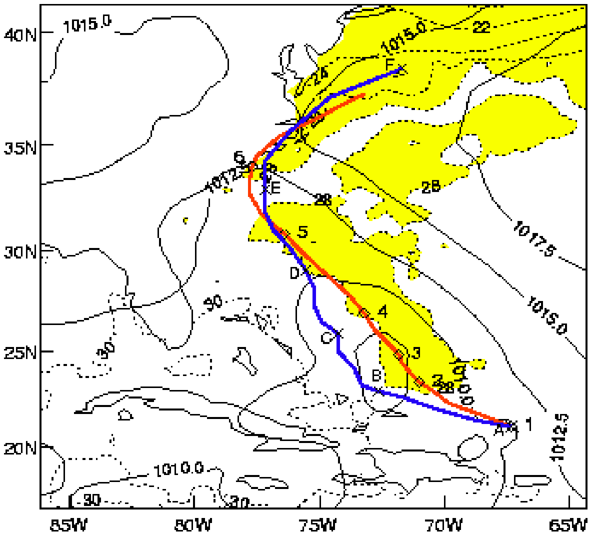

Fig. 1. Tracks of Bonnie from the 6-h best analysis (light thick line), and the model simulation (heavy thick line), together with the 5-day (22-27 August) averaged sea-level pressure (solid) and SST (dotted, <28^0C shaded).

The model also reproduces the hurricane intensity changes during the 5-day period (see Fig. 2). The first 48 h was the hurricane's deepening stage, so its maximum wind increased rapidly. The next three day was the maintaining stage. From Fig. 1, one can see that the hurricane induced SST cooling is concentrated to the right of Bonnie's track. The oceanic cooling feedback appears to be one of the reasons why Bonnie could maintain its intensity over the open ocean for the three days. During the period from 24 to 72 h, the simulated storm goes over the area where SST is about 1-2K warmer than that of observed. So the storm gets more latent and sensible heat from the ocean, this can lead to the predicted central pressure deeper than the observed. The simulated radar reflectivity shows pronounced asymmetries in the eyewall and rainbands (Fig. 3a) at 48 h, in agreement with the observed. The axis-symmetric pattern (Fig. 3b) and double eyewall pattern (not shown) are found during the last 2 days, similar to the observed.

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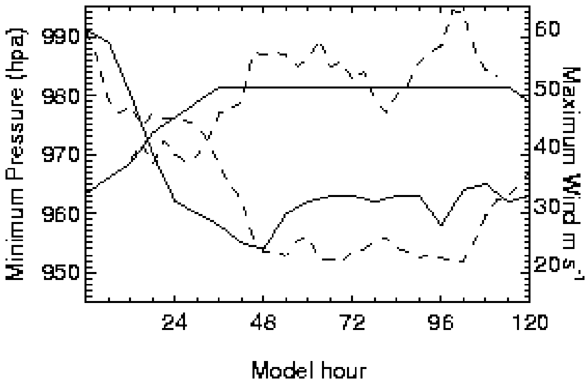

Fig. 2. Time series of the minimum central pressures and the maximum winds from the best analysis (solid lines) and model simulation (dashed lines).

4. STROM STRUCTURES

Since the simulation results captured the basic characters of the evolution of Hurricane Bonnie, we can use the model output to conduct diagnostic analyses. Upper level winds and PV (not shown) indicate that there was a jet, associated with a trough, interacted with the hurricane. As the upper level jet and the storm approached each other, the westerly winds at altitudes of 10-12 km increased to its peek at 48 h over the hurricane center. This environmental shear led to the distribution of strong convective in northeast side of the storm (see Fig. 3a). This down shear left pattern is consistent with the observation and also found in the idealized initial environment modeling study by Frank and Ritchie (1999). However, the upper level jet caused convergence and descending flow in the periphery of the storm outflow, thereby suppressing the updraft development on the west portion of the eyewall. Thus, the cyclonic flow in the eyewall was forced downward in the region. Because of this strong descending motion, the warm core shifted to the west. The hurricane circulation center and the local minimum pressure center were about the same. At this time the hurricane center tilted to the east with height.

At 97 h (Fig. 3b), Bonnie was near the east coast of North Carolina, and its structure was much more axis-symmetric. The warm core appeared at the center. During this weakening period, the radius of eyewall (or RMW) increased from 50 km at 48 h to about 100 km at 97 h, in agreement with the observed. The RMW was a little irregular because of the weakly organized tangential winds as compared to those at 48 h. The size of the hurricane eye was very large, and the ascending motion in the eyewall also weakened. During the first 4.5 days when the storm was still in the open ocean, the total angular momentum of the system increased with time (not shown).

5. CONCLUDING REMARKS

A 5-day simulation of Hurricane Bonnie (1998) is performed with the initial hurricane vortex retrieved from AMSU satellite sounding data. The model can simulate the asymmetric structures of the storm at 48 h. The deepening and maintaining stages of Bonnie are also reproduced. The diagnostic analyses are conducted to study the hurricane's partial eyewall features and the processes that influence the hurricane intensity change. The environmental vertical shear appears to play an important role in the formation of the hurricane asymmetric structures. The SST cooling feedback is one of the important factors for the storm to remain its intensity for a long period of time over the ocean. More results will be presented during the conference.

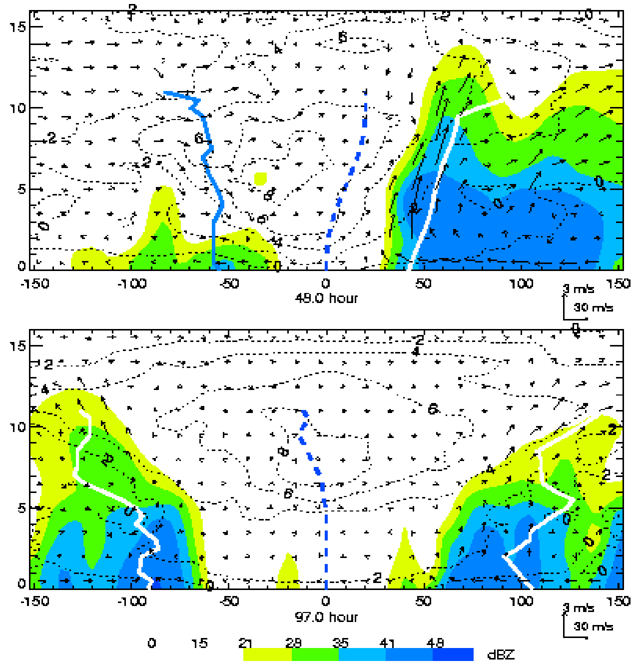

Fig. 3. West-East vertical cross section of the simulated radar reflectivity (shaded), the temperature deviation (dashed), the radial and vertical winds (vector). The thick dashed lines indicate the local minimum pressure center at each height. The thick solid lines denote the RMW.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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