The Role of Horizontal Eddy Momentum Fluxes on Hurricane Core Structures

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1. Introduction

Numerical and observational studies have shown that hurricane core structure changes with time and is closely related to changes in the intensity of hurricanes. Schubert et al (1999) showed that a ring of potential vorticity (PV) similar to that an eyewall can be mixed into the eye of a hurricane by vortex Rossby waves generated from the barotropic instability. Kossin and Eastin (2001) showed that there are differences in the kinetic and the thermodynamic structures of hurricane cores during the intensification and the weakening periods through aircraft data analysis. Their results support the existence of the barotropic instability in the hurricane core.

Previous studies, however, do not fully explain the hurricane eye oscillations observed by Lewis and Hawkins (1982) and Muramatsu (1986). Observations reveal periodic breaking of the eyewall, the formation of a polygonal eye, and rebuilding of the maximum PV along the eyewall, the return to the circular eye shape. In this study, high-resolution numerical simulation is used to investigate the complete oscillation of the core structure of the Hurricane Floyd(1999).

1. Methodology

The non-hydrostatic Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model Version 5 (PSU/NCAR MM5) is used in this research. The horizontal model domain is 1800km at each side with 6km grid spacing. The model top is 30hPa with 30 half-sigma levels vertically. NOGAPS analysis data at 2° resolution are used for the initial and the lateral boundary conditions. A 48 hour forecast is made beginning at 1200UTC 11, Sept 1999. Model outputs are written at 10 minute interval to examine the high temporal frequency of the hurricane core oscillation. While several processes interact to determine the strength of the inner core winds, we will focus on the role of the horizontal eddy momentum fluxes and their relationship to possible eyewall instabilities.

3. Results

The time series of the simulated minimum sea level pressure (SLP) and azimuthal mean maximum tangential wind speed (TW) are shown in Fig. 1. SLP (TW) shows decreasing (increasing) trend with time on the whole, though they have temporal fluctuations. These fluctuations are related to (PV) oscillations, which PV is mixed into the hurricane eye, and followed by rebuilding of the PV maximum band along the inner edge of the hurricane eyewall. Fig. 2 shows the composite of the radial PV profile during the minimum and the maximum TW periods, respectively. The PV maximum is located in the center of the hurricane during the minimum TW periods while the PV rebuilds in the hurricane eyewall during the maximum TW periods. The structure of the potential temperature field (not shown) also shows similar to that of PV field, as in the Kossin and Eastin's study.

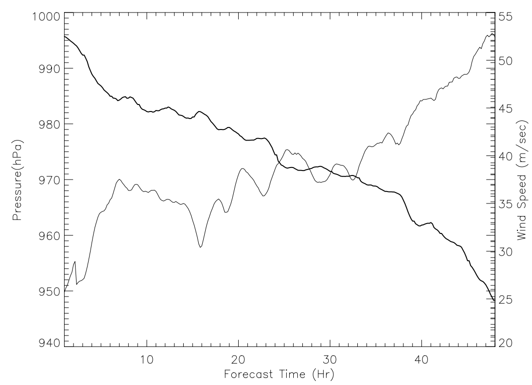

Fig. 1 The simulated maximum tangential wind speed(TW) and minimum sea level Pressure(SLP). The thick line represents SLP and thin line for TW, respectively.

The processes of rebuilding PV in the eyewall are not well understood, but the processes of PV mixing into the eye are understood to result from barotropic instability. The analysis result in this study shows that the radial profile of the horizontal eddy momentum flux convergence makes a significant contribution to the strengthening phase of the tangential wind oscillation. This suggests the possible existence of baroclinic instability in the hurricane core, which would tend to produces up-gradient momentum flux.

Fig. 3 is the time series of the eddy momentum flux convergence and the radial equivalent potential temperature gradient at the radius of maximum winds (RMW). Eddy momentum divergences at the RMW are dominant as expected, while eddy momentum convergence, up-gradient momentum fluxes, occurs intermittently for short time periods. It is also shown in Fig. 3 that eddy momentum convergence occurs when temperature gradients become strong, and followed by a weakening of the radial temperature gradient. These results suggest the baroclinic instability plays a role in rebuilding of the PV maximum in the eyewall.

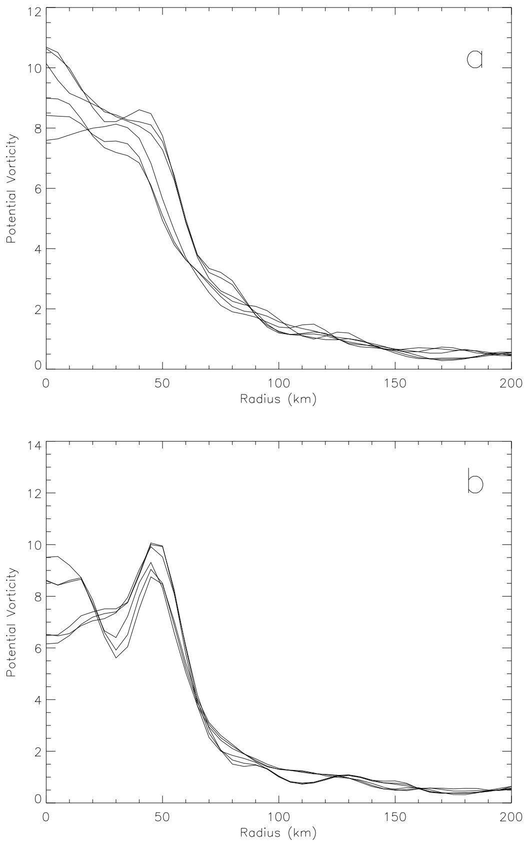

Fig. 2 The radial profile of PV at the minimum TW period (a) and at the maximum TW period (b).

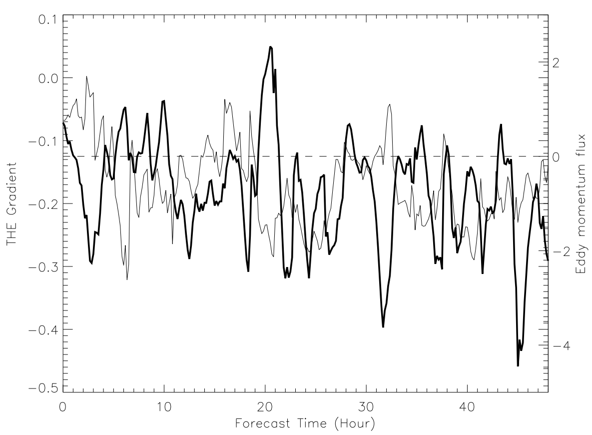

Fig. 3 The equivalent potential temperature gradient (thin line) and the eddy momentum flux convergence (thick line) at the RMW. Positive means eddy momentum flux convergence.

4. Conclusions

The mechanisms of changing hurricane core structure are investigated using the PSU/NCAR MM5. The model simulation not only reproduces features of the hurricane core structure shown in previous studies but also simulates the PV maximum rebuilding process in the hurricane eyewall. The numerical simulation also shows that these PV structures in the hurricane core are well correlated with the change of the hurricane intensity.

The hypothetical mechanism of the complete hurricane core structure oscillation suggested in this study is as followings; When the horizontal gradient of PV exceeds the critical value, the barotropic instability begins to form vortex Rossby wave and mixes PV into the center of the hurricane. After locating PV maximum in the center, the barotropic instability can not be activated because of dissatisfying the Rayleigh-Kuo necessary condition. Instead of the barotropic instability, the baroclinic instability can activate then, the eddy momentum convergence occurs by the baroclinic instability and forms the ring of maximum PV ring around the eyewall.

Acknowledgement: This work was supported by the long-term fellowship program for oversea study of Korean government**.**

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