Interaction between Concentric Eyewalls in Super Typhoon Winnie (1997)

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1 Introduction

During the period 05-23 August 1997, super typhoon Winnie formed at low latitudes in the Marshall Islands, moved across the western North Pacific, over Okinawa, and later made landfall on the east coast of China. As Winnie moved towards Okinawa on August 16, the inner eyewall cloud began to dissipate and a larger outer eyewall rainband with an inner diameter of 370 km began to circle the eye and its pre-existing eyewall cloud (Lander 1999, JTWC 1997). Sooner after the outer cloud eyewall became well defined, Winnie did not appear to undergo an eyewall replacement (Lander 1999). The large outer wall cloud was not contracted and replaced the inner eyewall, instead of that, the inner eyewall was recovered with a diameter around 18 km. Thus Winnie retained its concentric eye structure until it landed on Mainland China at 1132 UTC 18 August. The lifetime of the concentric eye structure lasted near 48-h. During this period, the relative echo free moat between the outer and inner eye wall was about 150-km in width, and the spiral rainbands were observed by satellite in the moat (Shi 2001). How and why inner eyewall was recovered after a huge outer convective ring was formed in Winnie? And what is the role of the spiral rainband between them? Spiral rainbands near hurricane eyewall are explained by vortex Rossby wave theory (Guinn and Schubert 1993, Montgomery and Kallenbach, 1997). Is spiral rainband in the moat of Winnie driven by vortex Rossby wave?

2 Experiment design and Model verification

Winnie is successfully simulated using the Penn State/NCAR MM5 model, with 3 km horizontal spacing grids that take the triple-nested grids' (81 km/27 km/9 km) 24-hour forecast as its initial fields. All grids have 32 levels in the vertical. The simulations for D01, D02 and D03 are initialized at 1200 UTC 15 August 1997, and integrated for 99 hours. The 3-km grid D04 simulation is run in one-way-nesting mode, driven by the 9 km grid D03 output.

The simulated outer eyewall matches well with the observation in terms of size and the simulated track follows closely the best track except 6 hours delay. Tangential wind maxima are associated with the outer and inner eyewalls. These structures compare favorably with satellite and radar observations and previous hurricane studies. The four-dimensional, dynamically consistent model output provides an opportunity for us to study this typhoon in greater details.

3 PV evolution and vortex Rossby wave verification

Observed T_{bb} from satellite showed the concentric eyewalls possesses a distinct life cycle (not shown): First, the inner convective core is connected to the outer convective ring by a spiral rainband. And then the spiral rainband is broken before the inner convective eyewall is intensified. Finally main part of inner convective core is attracted to the outer convective ring, leaving a weak convective core in the center. The outer convective ring contracted. The model simulation also captures this cycle. The phase propagate speed of spiral rainband was found to match with the theory of vortex Rossby wave(Montgomery and Kallenbach 1997).

Azimuthal mean PV show that there is a gap radius of PV gradient in the moat at the initial time at lower level (left panel in Fig.1), which varies from 100 km to 150 km from the center of Winnie later. Inward vorticity gradient exists outside that gap radius and outward vorticity gradient control the inside of it. At middle level, the outward vorticity gradient is much stronger than inward gradient (middle panel in Fig.1). Two kinds of vortex waves have been identified. One is outward propagating wave, which is wave number 1 that dominates the middle and upper levels. While another one is inward propagating wave that only exists at the lower level. The outward propagating wave is associated with a spiral deep convective rainband, which connects the two concentric eyewalls. Shallow convective spiral rainbands are found to

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correspond to the inward propagating waves at lower level. The inward wave moves faster than outward wave both in radius and azimuthally direction. When the inward wave catch up the outward wave at t = 6-9 h, the connecting deep rainband between two concentric eyewalls is broken. After t = 18 h, when the outward vorticity gradient at the outer edge of inner eyewall is two times stronger than that of inward gradient at inner edge of outer eyewall at the lower level, the outward propagating vortex Rossby wave dominates the whole layer and the inner convective core, as a whole, is attracted to the outer convective ring. The outer convective ring shrinks in size by 50 km after its merging with the inner convective core at t = 36 h.

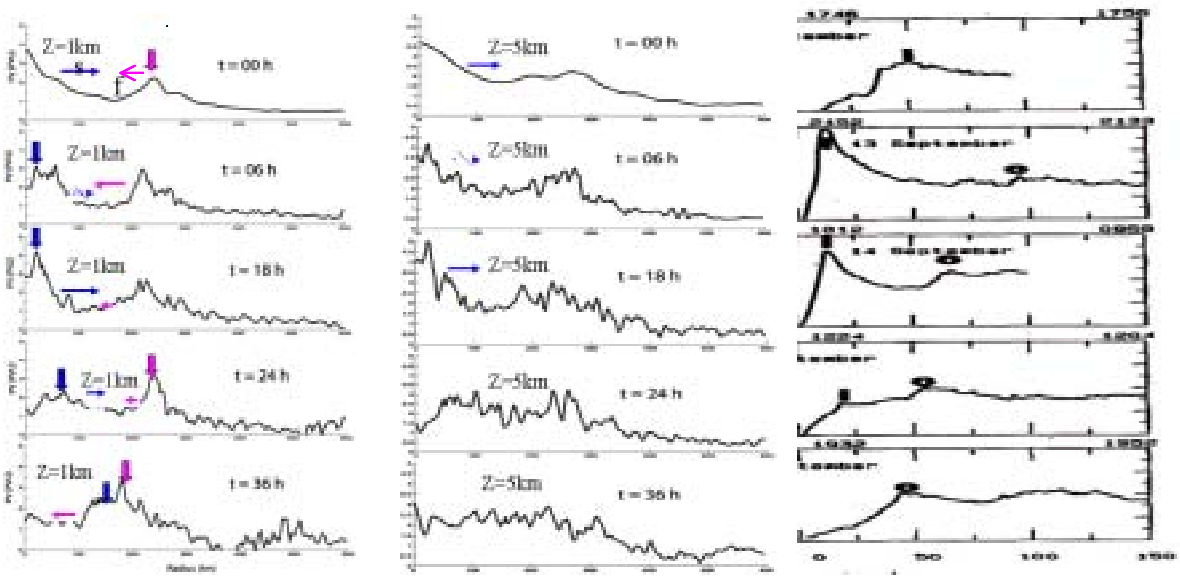

Figure 1 Simulated azimuthal mean PV at 1 km (left panel) and 5 km (middle panel) altitude of Winnie 1997 and Wind observed by aircraft near 900 hPa of Hurricane Gilbert 1988 (after Black and Willoughby 1992) at right panel.

4 Summary

The vorticity gradient between concentric eyewalls could drive vortex Rossby wave, whose propagation would result in spiral rainband in the moat. The convective heating caused by spiral rainbands can also change the vorticity distribution and therefore influents the intensity of concentric eyewalls. Inward wave in the lower level tend to transport flux eddy inside to reinforce the inner eyewall. Outward wave in the upper level tend to transport vorticity outside to intensify the outer convective ring. When the inward wave dominates the moat, inner eyewall would intensify, and intensified inner eyewall will result outward PV (rain) band. While if the outward wave control the moat, outer eyewall would be strength, which in turn generate the inward PV (rain) band. In other words, concentric eyewalls interact with each other through PV (rain) band between them.

Concentric eyewall cycle of hurricane Gilbert 1988 has been studied by Black and Willoughby (1992) (right panel in Fig. 1). Despite the left and right panel of figure 1 represent different variables and they are in difference scale of horizontal coordinate, the evolution of two concentric eyewalls appears to be superficially analogous in general. Although this can be explained as eyewall replacement in Black and Willoughby (1992), it is also useful to explain it as Vortex Rossby wave propagation in this study.

reference

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