16C.7

Structure and Maintenance of Concentric Eyewalls in Simulated Typhoon Bolaven (2012)

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1. Introduction

Tropical cyclone (TC) occasionally has some eyewalls which are called as concentric eyewalls. Striking concentric eyewalls of some hurricanes are studied by airborne radar observations and numerical simulations. Houze et al. (2007) observed the concentric eyewall (CE) of Hurricane Rita (2005), using the air-bone Doppler rador. They indicated the structure of Rita's CE. Previous studies indicate that the eyewall replacement cycle (ERC) often occurs once concentric eyewalls are formed. The eyewall replacement is a process that the inner eyewall gradually decays and the outer eyewall moves into the position of the inner (old) eyewall. In addition, the wind speed of TC rapidly varies during the replacement. It is important for prediction of TC's intensity to understand the process of the eyewall replacement. However, typhoon Bolaven, which passed in main Okinawa island in 2012, had stationary concentric eyewalls for very long time. Moreover, the replacement of Bolaven's concentric eyewalls did not occur (Fig. 1, 2). It is clear from observation by Doppler radars of the Japan Meteorological Agency (JMA). It shows that the eyewall replacement does not always occur even if concentric eyewalls are formed. The process of the eyewall replacement are not fully known.

In this study, we investigate the difference of CE with and without replacement. First, we conduct numerical simulation of Bolaven and indicate that Bolaven's CEs did not satisfy the necessary condition for ERC through water budget and trajectory analysis. Next, we focus on the relationship between structure and maintenance of Bolaven's CEs, and construct a hypothesis of maintaining CEs in TCs (i.e. without ERC). Finally, we test our hypothesis thorough some idealized experiments.

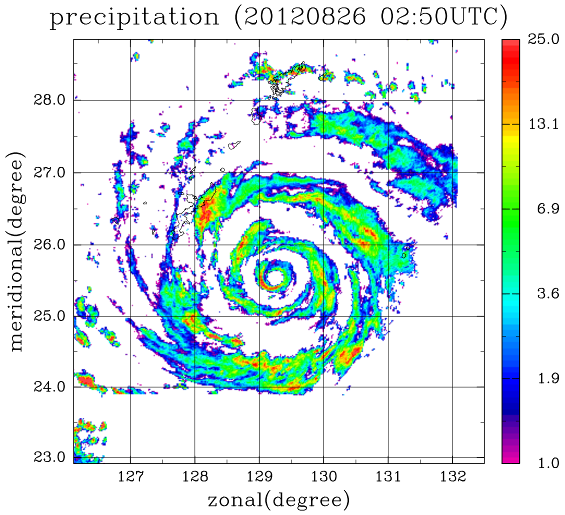

Fig:1 Precipitation intensity of Bolaven's CEs observed by the JMA Doppler radars. (Unit is mm h^{-1}.)

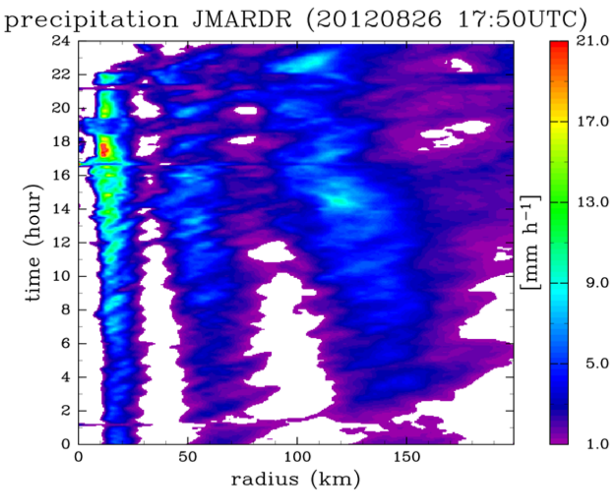

Fig:2 Time series of azimuthal mean precipitation in Bolaven observed by the JMA Doppler radars. (Unit is mm h^{-1}.) Initial time is Aug. 25, 2012, 12 UTC.

2. Numerical experiment

In this study, each experiment is performed with the Cloud Resolving Storm Simulator (CReSS) which is a three-dimensional, nonhydrostatic model (Tsuboki and Sakakibara, 2007). According to some previous studies for concentric eyewalls of hurricanes, concentric eyewalls has horizontal scale of about 10 km (e.g. Terwey and Montgomery, 2008; hereafter TM08). In order to simulate the concentric eyewalls of Bolaven, it suggests that we conduct numerical experiment with horizontal resolution of about 1 km. First, we perform the experiment with 5 km horizontal resolution whose initial and boundary conditions are given by the initial data of the Global Spectral Model (GSM; 0.5 degree horizontal resolution) provided by JMA. Second, we perform the experiment with 2.5 km horizontal resolution based on the output data of 5 km horizontal resolution. Finally, we perform the experiment with 1 km horizontal resolution based on the output data of 2.5 km horizontal resolution.

Water budget equation in a cylinder region with the center of TC is :

$$\frac{\partial Q}{\partial t} = \mathrm{ADV.} + \mathrm{Evap.} + \mathrm{Prec.} \tag{1}$$

"ADV." is horizontal advection of water vapor due to lat-

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eral side of a cylinder. "Evap." and "Prec." are evapolation and precipitation in the bottom of the cylinder.

3. Result

We could simulate the striking concentric eyewalls which were located within about 100 km radius from Bolaven's center with 1 km horizontal resolution (Fig. 3). Simulated outer eyewall started to form at 15 hours. However, the innermost eyewall observed did not simulate. The track and intensity of simulated Bolaven is the most of the same as the JMA best track data (not shown). Simulated concentric eyewalls are stationary for over one day. It substantially exceeds the time required for the eyewall replacement (Fig. 4). Moreover, the simulated concentric eyewalls have the moat regions, which is very dry and weakly descending.

The water budget analysis indicates that supplied amount of water vapor into the inner eyewall due to the lateral advection did not change before and after forming CE (Fig. 5).

The backward trajectory analysis indicates that the air parcel, which arrived at the inner eyewall, existed beyond the outer eyewall, originally. The most air parcel passed throughout the outer eyewall with low-level inflow in PBL (Fig. 6). Thus, the supplied amount of water vapor into the inner eyewall did not change.

Simulated Bolaven's outer eyewall is outward tilted and has weak updraft, relative to the inner eyewall (Fig. 7). The weak updraft in the outer eyewall is consistent with the result of trajectory analysis. We consider that the structure in the outer eyewall is character of maintaining CE (i.e. CE without ERC).

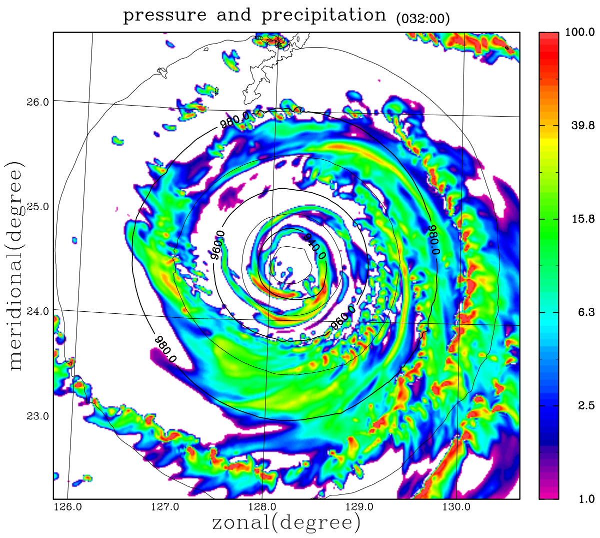

Fig:3 Precipitation (shade) and sea level pressure (contour) of simulated Bolaven's CEs. (Units are mm h^{-1} and hPa.)

4. A hypothesis of maintaining CE

We construct a hypothesis of CE without ERC, on the basis of the Sawyer-Eliassen response. Rossby deformation radius R is proportional to vertical stability (N)

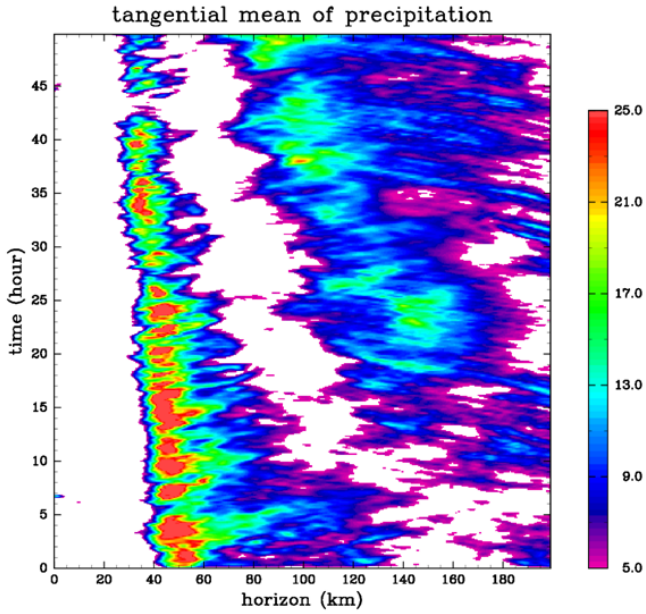

Fig:4 Time series of azimuthal mean precipitation in simulated Bolaven. (Unit is mm h^{-1}.) Initial time is Aug. 24, 2012, 12 UTC.

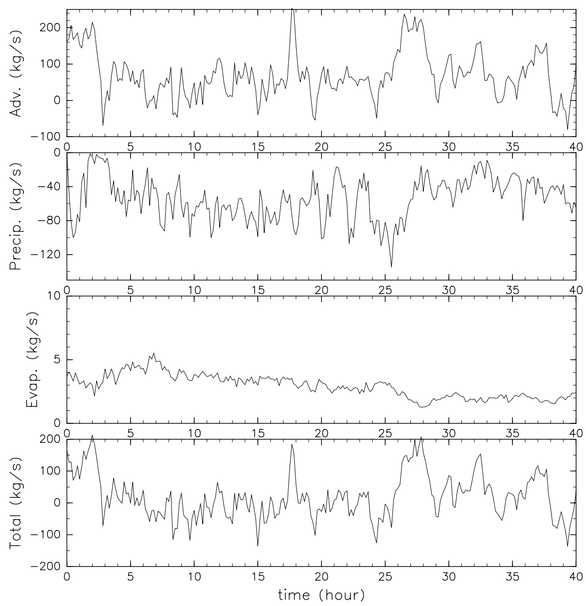

Fig:5 Time series of each term of Eq.(1). The bottom figure is $\partial Q/\partial t$ in eq. (1). (Unit is $\times 10^6$ kg s^{-1}.)

and inverse of horizontal stability (I). Moreover, I is proportional to tangential wind of TC and inverse of distance from the TC's center. Then, If R is large (small), the secondary circulation for the point source is spread (narrow) horizontally. We assume that eyewall is composed of the superposition of point sources. This spread (narrow) circulation is related to the outward tilted (upright) eyewall. Moreover, This spread (narrow) circulation is corresponding to weak (strong) updraft in the eyewall. According to the result of our trajectory analysis, the eyewall replacement does not occur in the outer eyewall with the weak

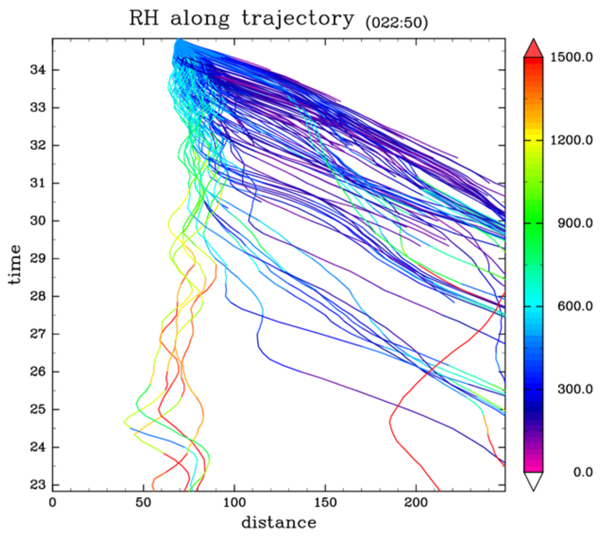

Fig:6 Time series of the distance of trajectory parcels from the center of TC. Color solid lines show height (m) of each parcel.

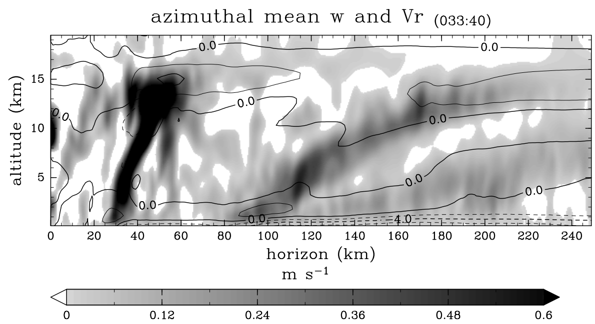

Fig:7 Vertical cross section of azimuthal mean vertical (shade) and radial (contour) velocity in Bolaven's simulation after forming CEs.

updraft. Thus, we consider that the eyewall replacement is hard to occur when the R in the outer eyewall is large. This hypothesis suggests that CE is maintained (i.e. ERC is not occurring) when the environmental condition is relatively stable around the outer eyewall or the position of the outer eyewall is far from the center of TC.

5. Idealized experiment

In order to evidence our hypothesis, we conduct idealized parameter sweep experiments of ERC, using CReSS model. The model setting is the following :

- Initial vortex is weak axisymmetric vortex of TM08.
- Horizontal grid is 2 km.
- Initial thermodynamic field is the tropical sounding data of Jordan (1958).
- SST is set by 302 K (constant value).
- Coriolis parameter is constant value in 15 ° N.

In this experiment, the sweeping parameter is sounding temperature. "CTL" experiment is the original sounding data (Jordan, 1958). "ST302" experiment is the sounding data which warms the original sounding data by 3 K, uniformly. We define vertical stability as $(T_0 - SST)$. T_0 is temperature of tropopause. Then, ST302 is more stable than CTL because SST is a constant value of 302 K in both of CTL and ST302. In CTL, the clear ERC occurred. However, in ST302, ERC did not occur and CEs was maintained for a long time (Fig. 8). In CTL, the slope of the outer eyewall was comparable with that of the inner eyewall. On the other hand, in ST302, the outer eyewall was outward tilted, relative to the inner eyewall. Moreover, updraft of the outer eyewall was weaker than that of the inner eyewall (Fig. 9). In addition, the position of the outer eyewall is far from the center of TC. These results agree with our hypothesis and Bolaven's simulation.

6. Summary

We conducted numerical experiment of Bolaven, using CReSS model. Simulated Bolaven had the striking CEs. Moreover, the CEs maintained for over one day (without ERC). Water budget and trajectory analysis indicated that continuous supply of water vapor into the inner eyewall from the outside of the outer eyewall On the basis of the Sawyer-Eliassen response, we constructed a hypothesis of CEs without replacement. This hypothesis suggests that CE is maintained (i.e. ERC is not occurring) when the environmental condition is relatively stable around the outer eyewall or the position of the outer eyewall is far from the center of TC. We tested our hypothesis throughout idealized experiments. We consider that these results support our hypothesis because the characteristic structure of idealized CEs has the same as that of Bolaven's CEs.

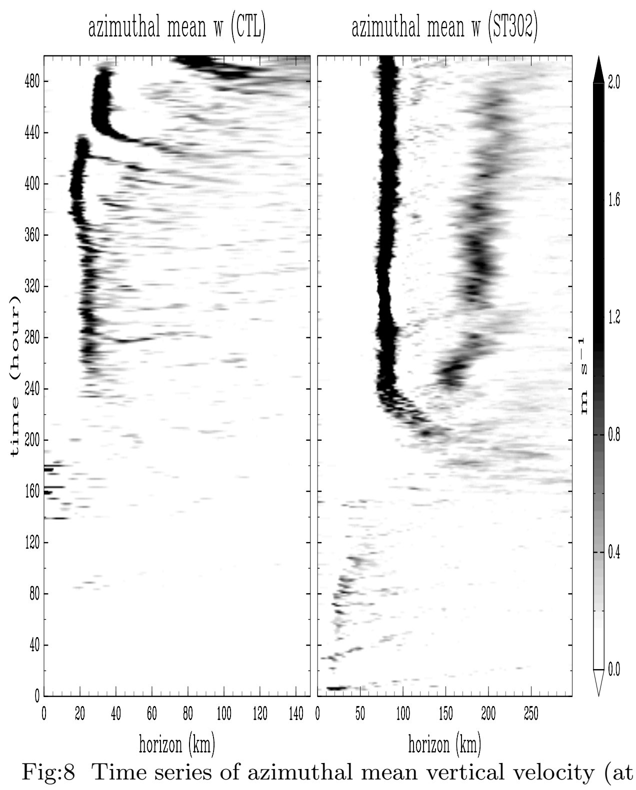

Fig:8 Time series of azimuthal mean vertical velocity (at about 5000 m height). Left figure is CTL, right figure is ST302.

Reference

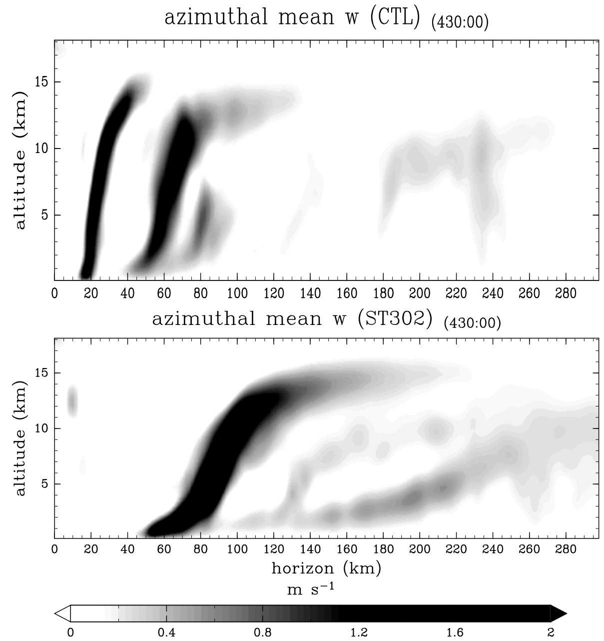

Fig:9 Vertical cross section of azimuthal mean vertical velocity (at 400 hours) in idealized experiments. Top figure is CTL, bottom figure is ST302.

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