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Relationship between structure and replacememt of concentric eyewalls in idealized tropical cyclones

TSUJINO, Satoki[1*] ; TSUBOKI, Kazuhisa[1]

[1]HyARC, Nagoya University

Eyewall is a ring of convective clouds that encircles the eye of a tropical cyclone (TC) such as typhoon and hurricane. TC occasionally has some eyewalls which are called as concentric eyewalls. Once concentric eyewalls are formed, eyewall replacement often occurs. 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. The wind speed of TC rapidly varies during the replacement (Willoughby, 1987). However, the eyewall replacement does not always occur even if concentric eyewalls are formed and the process of eyewall replacement is not fully known. Tsujino and Tsuboki (2013; the Fall Meeting of the Meteorological Society of Japan) indicated that, on the basis of some analyses of Typhoon Bolaven (2012), the vertical flow of the outer eyewall is weaker than that of the inner eyewall and the outer eyewall tilts relative to the inner eyewall in the long-lived concentric eyewalls. Therefore, we suspect that the eyewall replacement is related to the structure of the concentric eyewalls of TC.

In this study, we investigate the relationship between structure and replacement of concentric eyewalls in some idealized TCs. We conduct some parameter experiments for structure of concentric eyewalls in TC, using the Cloud Resolving Storm Simulator (CReSS; Cloud Resolving Storm Simulator, Tsuboki and Sakakibara, 2007) which is a three-dimensional, nonhydrostatic model. And we investigate the structure of concentric eyewalls in these experiments. In our experiments, the initial wind field was axisymmetric and cyclonic vortex, which is hydrostatic and gradient wind. This wind field was based on the eq. (2) and (3) of Terwey and Montgomery (2008, hereafter TM08). The initial thermodynamic field was given by Jordan (1958; hereafter J58). The horizontal grid spacing was 2 km. The number of vertical grids was 45 and the vertical grid interval on the lowest layer was 100 m. The calculating domain had 2000 km x 2000 km x 22.5 km. The simulation time for each experiment was 500 hour. For each experiment, SST value was constant, horizontally uniformed and did not change during the simulation. We considered that structure of concentric eyewalls varies with the radial profile of the tangential wind of TC, on the basis of TM08. Therefore we conducted some parameter experiments for SST and vertical instability in the atmosphere. Because these parameters are sensitive for the maximum tangential wind of TC (Rotunno and Emanuel, 1987). We had four experiments: (1) SST = 301 K, thermodynamic field was J58, (2) SST = 302 K, thermodynamic field was J58, (3) SST = 302 K, thermodynamic field was J58 + 3 K, (4) SST = 300 K, thermodynamic field was J58 + 1 K. Here “ J58 + 3 K ” means that 3 K was uniformly added to the potential temperature profile of J58, and “ J58 + 1 K ” was the same of “ J58 + 3 K ” but except for the added value of 1 K. We named experiments of (1) - (4) as “ CTL ”, “ S302 ”, “ ST302 ”, “ ST300 ”, respectively.

In CTL and S302, eyewall replacements occurred on several occasions during the last 100 hours. On the other hand, in ST302, clear concentric eyewalls were formed. However, eyewall replacement did not occur over 500 hours. In ST300, concentric eyewall was not formed. In CTL and S302, the outward slope associated with height of the outer eyewall was similar to that of the inner eyewall. Moreover, the vertical wind speed in the outer eyewall was comparable with that in the inner eyewall. The other hand, in ST302, the outward slope of the outer eyewall was more gradual than that of the inner eyewall. For the vertical wind speed, it was weaker than that of the inner eyewall.These characters is also indicated in the simulated Typhoon Bolaven (2012) of Tsujino and Tsuboki (2013). Thus, we think that the occurrence of eyewall replacement is related to the similar extent of the slope between the inner and outer eyewall associated with height.

Keywords: tropical cyclone, concentric eyewall, eyewall replacement, vortex dynamics