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Dynamic energy efficiency of tropical cyclones with long-lived concentric eyewall in numerical simulation

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"Eyewall" is a ring of convective clouds that encircles the eye of a tropical cyclone (TC) such as typhoon and hurricane. Multiple eyewalls, named "concentric eyewall", are observed in some TCs, and "eyewall replacement cycle" is also observed after the formation of concentric eyewall. In the process of an eyewall replacement, the inner eyewall gradually disappears while then the outer eyewall moves towards the TC center in closing to the previous inner eyewall. During the period of a replacement cycle, the TC intensity changes drastically. 24 percentages of TCs with concentric eyewalls maintained in a long time (over 20 hours) in satellite observations (Yang et al., 2013). The result suggests that a TC with concentric eyewall does not always undergo the replacement cycle. There are very few studies of long-lived concentric eyewall. Moreover the maintenance mechanism of long-lived concentric eyewall is also not clear.

To understand the maintaining mechanism of concentric eyewall, we employ dynamic energy efficiency in considering the change of kinetic energy (KE) and available potential energy (APE) due to the internal dynamics of a TC. We focus on a parameter of dynamic energy efficiency, which is proposed as an index of conversion efficiency of potential energy to KE. In this study, dynamic energy efficiency of idealized TCs with replaced and long-lived concentric eyewall, and then, real typhoon Bolaven (2012) with long-lived concentric eyewall was investigated, using numerical simulation results which were performed by Tsujino and Tsuboki (2013, 2014). TC simulation data in this study were supported by an atmospheric numerical model of a three-dimensional, non-hydrostatic and full-physics, which is called by CReSS (Cloud Resolving Storm Simulator; Tsuboki and Sakakibara, 2007).

The formula for the dynamic energy efficiency of heat and of momentum in balanced vortex, whose the primary circulation is gradient wind balance, and the secondary circulation is induced due to convective heating and surface friction, was derived by Kuo et al. (2013). The dynamic energy efficiency of heat and of momentum is determined by the solution of the Eliassen transverse circulation equation with the radial temperature gradient instead of the radial heating gradient. They showed that dynamic energy efficiency enables to explain intensity change of TC through diabatic heating and friction with analytical profile of idealized TCs. The dynamic energy efficiency of an idealized TC with replaced concentric eyewall was increasing drastically during the replacement cycle, and the value of dynamic energy efficiency had maximum when inner eyewall dissipated. Low (high) dynamic energy efficiency indicates that conversion of APE to KE is inefficient (efficient) for TC's intensification. The tendency of dynamic energy efficiency of TC with replaced concentric eyewall was consistent with the TC's intensity change during the replacement cycle. On the other hand, the dynamic energy efficiency of the idealized TC with long-lived concentric eyewall did not increase apparently after the outer eyewall formed. The result suggests that the conversion of APE to KE in the outer eyewall does not control much the TC intensity change. The tendency of dynamic energy efficiency resembled that of a typical TC with single eyewall which was shown by Kuo et al. (2013). Moreover, in typhoon Bolaven (2012), the tendency of dynamic energy efficiency also resembled that of the idealized TC with long-lived concentric eyewall. These results imply that the dynamic energy efficiency of TCs with long-lived concentric eyewall may describe one of the universal characters of a TC development process.

Keywords: Eliassen transverse circulation, concentric eyewall, tropical cyclone