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Large Eddy Simulation of Entire Tropical Cyclone

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Current numerical models of a tropical cyclone do not have a resolution to explicitly simulate turbulent eddies, and their effects have to be usually parameterized. However, such parameterizations are known to introduce significant uncertainties. Owing to the K computer, which is the Japanese most powerful supercomputer, we can perform a large eddy simulation (LES) in which a horizontal grid spacing is taken to be fine enough to reliably simulate large eddies over the computational domain covering an entire tropical cyclone. Such an LES contributes to understand roles of micro-scale processes in a tropical cyclone, and reduce the uncertainties due to the parameterizations.

In the present study, JMA-NHM (Japan Meteorological Agency's Non-Hydrostatic Model) is used as a LES whose horizontal grid spacing dx is 100 m everywhere. The computational domain covers 2000 km by 2000 km in the horizontal and 23 km in the vertical directions, and horizontal boundary conditions are doubly cyclic. The grid number is 20000 by 20000 in the horizontal directions, and 60 in the vertical direction where grid spacing increases with increasing height. The LES has been conducted using 9216 nodes of the K computer, which is believed to be the hugest computation in the current facility. Before starting the LES, a preliminary run with JMA-NHM with dx=2km is made. In this preliminary run, a tropical cyclone develops from an initial weak vortex to a mature stage after 120 hours integration. The grid point values of this mature stage are interpolated to prepare the initial condition for the LES. The time integration of the LES is performed for 10 hours.

A comparison of the results of the LES with those of the preliminary run at the same instants shows that the minimum surface pressure and the maximum surface winds are nearly the same. However, the radius of the eye-wall is smaller and the radial flow near the surface is stronger in the LES.

Horizontal rolls whose horizontal scale is less than or close to 2 km are found near the surface in the LES. There are two different types of rolls: Type-A rolls occur outside of the radius of the maximum wind (RMW) and have their axis nearly directed in the tangential direction with slightly deflection to the center of the cyclone; Type-B rolls are found near the RMW, and have their axis slightly deflected to the outside of the cyclone.

Type-A rolls appear to be caused by the inflection point instability of the Ekman layer as in the previous idealized LES study. They enhance turbulence mixing in the Ekman layer to cause stronger radial inflows, which may have contributed to shrink the radius of the eye-wall in the LES. Type-A rolls lead to updrafts that form eye-wall cumulus clouds.

On the other hand, Type-B rolls appear to be due to a parallel instability that only occurs under a strong rotation. This instability appears to be possible only near the RMW where large centrifugal force operates as if Coriolis force is strengthened. Local maximum surface winds in the tropical cyclone occur at the downdraft regions of the rolls where the momentum is transported downward. Unlike Type-A rolls, the circulation of Type-B rolls is confined to the boundary layer .

The LES is also used to evaluate the gust factor, which is defined by a ratio of three-second mean to 1-minute mean wind speed . WMO guideline (Harper et al., 2010) suggests that it is nearly 1.1 for a tropical cyclone over a sea. The LES results at each grid point shows that the gust factor of the guideline seems to be reasonable. However, it reaches 1.5 near the RMW where Type-B rolls prevail.

Keywords: tropical cyclone, large eddy simulation, turbulent Ekman layer, inflection instability, parallel instability, gust factor