Multi-scale Structure of Meso-beta-scale Vortex Associated with a Maritime Extratropical Cyclone

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A sudden gusty wind caused by a meso-β-scale (MBS) vortex of 30km diameter occurred in the Tsushima Strait at the southwest part of the Sea of Japan between 0300 and 0400 JST (Japan Standard Time) on 1 September 2015. It upset 6 fishery boats, causing 5 fatalities and 1 missing person. Some of the survived fishermen reported that they were hit by a waterspout. The MBS vortex was located northeast of the center of a maritime extratropical cyclone. A C-band Doppler radar of Japan Meteorological Agency (JMA) detected a spiral-shaped reflectivity pattern associated with a convective system to the east of Tsushima island at around 0300 JST. At 0320 JST, a couplet of positive and negative Doppler velocities exceeding 50 m s⁻¹ started to be observed near the center of the spiral-shaped reflectivity pattern, which later transformed into a circular reflectivity pattern with an eye-like weak echo region at the center by 0400 JST. To clarify the multiscale feature of the MBS vortex, we perform numerical simulations using JMA non-hydorostatic model (JMANHM).

A numerical simulation with horizontal resolution of 2km and 50 vertical levels successfully reproduced the MBS. The simulated MBS vortex had a vertical shallow structure (< 3 km) and its vertical vorticity was largest near the surface. A vorticity budget analysis shows that the tilting of horizontal vorticity due to vertical shear of westerly and the stretching of vertical vorticity at 1-1.5km height largely contribute to the formation and early development of the vortex, while the stretching of vertical vorticity near the surface is dominant for the later development of the MBS vortex. A Lagrangian analysis for circulation clarifies that the strong near surface vorticity originates from the horizontal shear between east-southeasterly and northeasterly.

A triply-nested numerical simulation with horizontal resolution of 50m and 100 vertical levels has been performed to clarify a finer structure that caused the damaging gusty wind. The simulation well reproduced MBS vortex with spiral-shaped precipitation system and micro-scale (< 1km diameter) vortices within the MBS vortex. The tornado-like vortices with maximum vorticity exceeding 1 s⁻¹ grew and decayed repeatedly near the surface in the west of the MBS vortex center, where strong horizontal shear exits. It is suggested that these vortices were strengthened by the shear instability. In addition, the intensification of the vortices was accompanied by strong updrafts exceeding 25 m s⁻¹ at 300-500 m height. The maximum of wind speed near the surface occasionally exceeded 50-55 m s⁻¹ during the simulation.