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Tornado-like Vortices in a Meso-β-scale Vortex Associated with a Maritime Extratropical Cyclone: A Numerical Study

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A sudden gusty wind caused by a meso-β-scale (MBS) vortex of $\sim$30km diameter occurred in the Tsushima Strait at the southwestern part of the Sea of Japan between 0300 and 0400 JST (Japan Standard Time; UTC+9 hour) 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 meso-β-scale vortex was located in the northeast of the center of a meso-α-scale extratropical cyclone. A C-band Doppler radar of Japan Meteorological Agency (JMA) detected a spiral-shaped reflectivity pattern associated with the MBS vortex 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 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.

A triply-nested numerical simulation using JMA non-hydrostatic model was performed to clarify the fine structure of the MBS vortex that caused the damaging gusty wind. The simulation with the finest horizontal resolution of 50m and 100 vertical levels successfully reproduced the MBS vortex with spiral-shaped precipitation system and associated tornado-like micro-scale (< 1km diameter) vortices within the MBS vortex. The simulated MBS vortex had a vertical shallow structure (< 3 km) and its vertical vorticity was largest ear the surface. The tornado-like vortices with maximum vorticity exceeding 1 /s 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 at 300-500 m height. The maximum of wind speed near the surface occasionally exceeded 50-55 m/s during the simulation, which is comparable to Japanese Enhanced Fujita scale of 1$\sim$2.