Numerical simulation of tornado-producing supercell storm and tornado associated with Typhoon Shanshan (2006)

Wataru Mashiko
Meteorological Research Institute, JMA, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052, Japan
(E-mail : wmashiko@mri-jma.go.jp)

1. Introduction

On 17 September 2006, three tornados hit the Miyazaki Prefecture, western Japan, during the passage of the rainband of Typhoon Shanshan. The tornado which hit Nobeoka city caused most severe damage and was assessed with F-2 scale. In order to reveal the environmental field and the storm which spawned the tornados, the numerical simulations were conducted. Moreover, the high-resolution simulation with the horizontal grid spacing of 50 m was attempted to reproduce the tornado explicitly.

2. Numerical model

The numerical model used in this study is the fully compressible nonhydrostatic model developed by Japan Meteorological Agency (JMANHM; Saito et al. 2006). We employed the bulk-type cloud microphysics scheme with six water species (water vapor, cloud water, rain, cloud ice, snow and graupel) and the turbulent closure scheme that predicts the turbulent kinetic energy. As to the surface boundary condition, exchange coefficients of surface fluxes are determined from the formula by Kondo (1975) over the sea and they are based on Monin and Obukhov's similarity law over the land, depending on the roughness and temperature. To conduct the high-resolution model integration, four telescoping one-way nested grids (Horizontal grid spacing 5 km; NHM5km, 1km; NHM1km, 250 m; NHM250m; 50 m; NHM50 m) were used. The vertical coordinate is terrain-following and contains 50 levels with variable grid intervals of Δz = 40 m near the surface to 904 m at the top (NHM1km and NHM250m), and 90 levels with Δz = 40 m to 304 m (NHM50m). The initial and boundary conditions of NHM5km are provided from the operational regional analysis of JMA.

3. Simulated environmental fields around the outer rainband

NHM1km reproduced the outer rainband about 300 km away from the typhoon center in the right-front quadrant of translating Shanshan. The wind hodograph around the rainband shows that the strong vertical shear with veering existed below 2 km AGL. The distribution of storm-relative helicity shows the peak with more than 750 $m^2 s^{-2}$ but that of CAPE is not related to the location of the rainband.

4. Simulated mini-supercell structure by the NHM250m

Figure 1a presents the simulated rainband by the NHM250m. The rainband consists of a number of isolated active convective cells. Some convective cells have the hook pattern and bounded weak region of hydrometeors at the southern tip of them (Fig. 1b). The maximum vertical vorticity is about 7 x 10^{-2} s^{-1} and upward motion is more than 30 m s^{-1} around 1 km and 3 km above AGL (Fig. 1c). The vertical and horizontal scale is small compared to the typical supercell storm over the Great Plains of the United States. These features are identical to the mini-supercell as showed in many previous studies (eg., Suzuki et al. 2000). Another noteworthy feature is that the gust font near the surface boundary is distinguishable by the wind field and vertical vorticity, however, the horizontal gradient of temperature across it is weak. As this storm approached the land, the mesovortices at low-level intensified significantly.

5. Simulated tornado structure by the NHM50m

Figures 2a and 2b show the successfully simulated tornado spawned by the mini-supercell noted above. Note that this simulation includes full-physics processes and free-slip surface condition is not used unlike the other previous studies. The tornado was generated on the gust front and moved with the rapid translation speed of about 100 km h^{-1} over the sea. The vertical vorticity reached 0.7 s^{-1} and surface pressure drop was about 12 hPa. The diameter of the vortex near the surface is about 500 m. The tornado exhibited the asymmetric structure with strong winds of more than 50 m s^{-1} only on the right side and tilted northwestward vertically.

Further analytical and numerical studies are being conducted focusing on the evolution of the mini-supercell storm and the tornadogenesis process.

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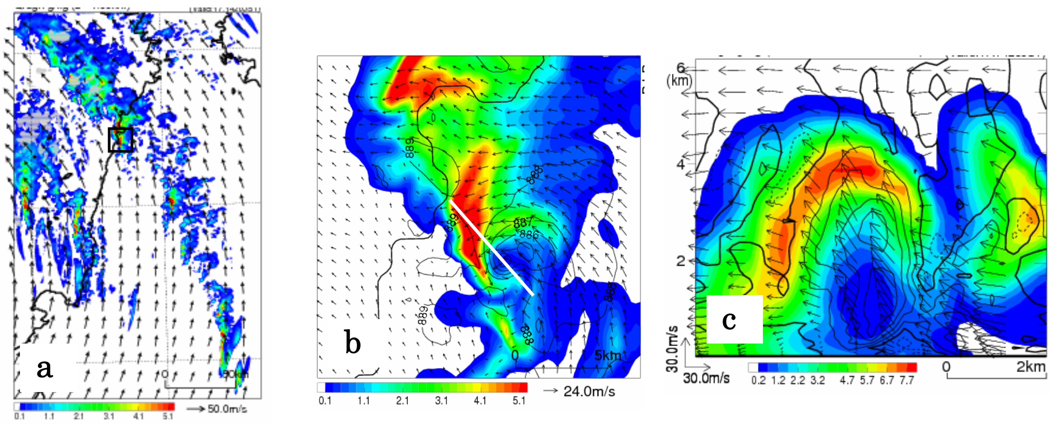

Fig. 1. (a) Horizontal distribution of hydrometeors and wind vectors at a height of 1 km by NHM250m. (b) Enlarged illustration of the square box in (a). Contour lines denote the pressure with 1 hPa interval. Arrows show the storm-relative wind. (c) Vertical cross section along the line in (b). Contour lines denote vertical vorticity with 0.015 s^{-1} interval.

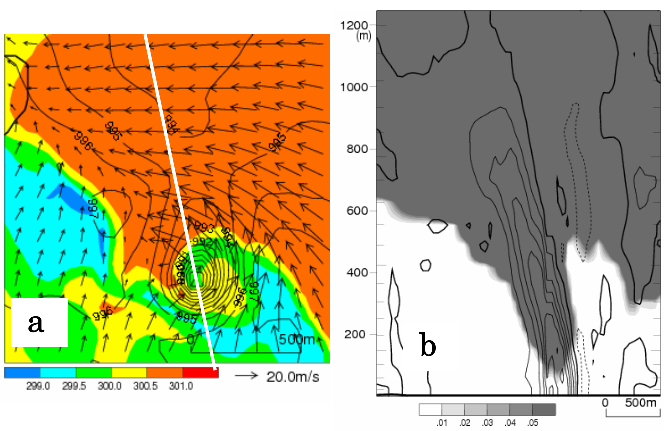

Fig. 2. Simulated tornado structure by NHM50m. (a) Potential temperature with the wind vectors at 20 m AGL. Contour lines denote the surface pressure with 1 hPa interval. (b) Vertical cross section of cloud water along the line in (a). Contour lines denote vertical vorticity with 0.1 s^{-1} interval.