NUMERICAL SIMULATION OF TORNADO-SCALE VORTICES OCCURRED IN A WINTER COLD-AIR OUTBREAK OVER THE SEA OF JAPAN

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I. INTRODUCTION

Tornado-scale intense vortices are called "tatsumaki" in Japanese. Both tornado and waterspout are called as tatsumaki in Japan. It occurs below intense convective clouds. Niino et al. (1997) showed that a majority of tornadoes occurs in coastal regions of Japan and that about 12 % of tornadoes are associated with winter monsoon. When a cold-air outbreak occurs over the Sea of Japan, shallow convective clouds develop over the sea. They are usually ordinary cells and have short life time. Two major types of tornado-genesis are known; one is a supercell type and the other is non-supercell type along a meso-front. The mechanism of tatsumaki is unknown. Since a tatsumaki in the winter monsoon occurs over the sea and its life time is short with their small scale, there are almost no reports about tatsumaki in the coastal regions of the Sea of Japan except Kobayashi et al (2007). They observed a tatsumaki in the coastal region using a Doppler radar and photograph and showed its horizontal scale is 150 m at a height of the cloud base. Although a tatsumaki occasionally causes severe disasters along the coastal region, its characteristics and structure have been unknown for long time.

On 25 December 2005, a train-accident occurred in the coastal region owing to a strong gust wind and 5 people were killed. Since the gust wind associated with snowstorm has not been studied well in the region, its mechanism was not identified. A tatsumaki is most possible phenomenon for the gust wind. Even though the tatsumaki frequently occurs when the cold-air outbreak of the winter monsoon occurs over the sea, it is still a mistily in a snowstorm. Observation is very difficult because of its small scale and short life time. A high-resolution numerical simulation is a possible approach to clarify characteristics and structure of the tatsumaki in snowstorm. Since the horizontal scale is an order of 100 m, a very high resolution of a several 10 m is necessary and the computation is very large. The huge parallel computer named the Earth Simulator makes it possible such huge simulation of tatsumaki.

For simulations of high-impact weather systems, we have been developing a cloud-resolving model named CReSS (the Cloud Resolving Storm Simulator) (Tsuboki, 2004; Tsuboki and Sakakibara, 2001, 2002). The purpose of the present study is to clarify characteristics and structure of the tatsumaki associated with the snowstorm of winter monsoon in the coastal region using the cloud-resolving model.

II. NUMERICAL MODEL AND EXPERIMENTAL DESIGN

The basic equations of the CReSS model are the non-hydrostatic and compressible equations. Terrain following coordinate is used for the vertical coordinate. Time integration is performed by the mode-splitting technique. Cloud microphysics is a bulk method of cold rain. One-dimensional model is used for the computation of the surface temperature.

In the present study, one-way triple-nesting technique was used for the high-resolution simulation of intense vortices of tatsumaki with 3 different horizontal resolution of 2000 m, 250 m and 50 m. The initial and boundary conditions were provided by the forecast model output data of JMA (the Japan Meteorological Agency). The initial time is 00 UTC, 25 December 2005. The domains are shown in Fig.1.

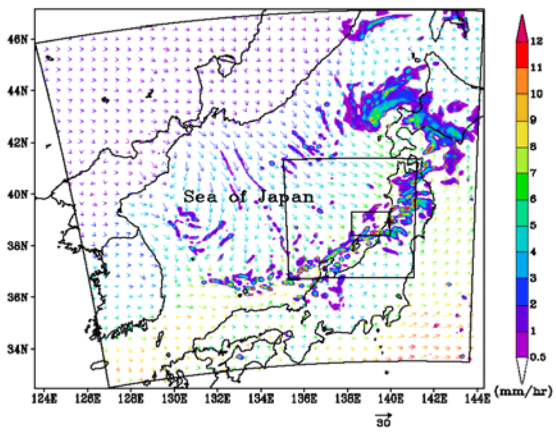

FIG. 1: Computational domains for the triple-nested simulation experiments. The outermost, middle and innermost regions are those of 2000 m, 250m and 50 m resolution simulations.

III. RESULTS AND CONCLUSIONS

The simulation of 50 m resolution was performed for 2.5 hours. The cold-air outbreak occurred over the Sea of Japan. The front of the cold air pushed the warm and moist southwesterly toward the southeast. Shallow convective clouds developed in the cold air of the winter monsoon. A large number of intense vortices were simulated in the domain of the 50 m simulation. We found both positive and negative vortices of tatsumaki in the simulation. Typical vortices of positive and negative tatsumakis are shown in Figs. 2 and 3, respectively. Both tatsumakis have absolute value of vorticity of about 0.3 s^{-1} and maximum wind speed reaches about 30 m s^{-1}. Their horizontal scale is about 200 m. This is almost the same scale that the observed winter tornado observed by Kobayashi et al. (2007)

The surface data were output every 20 seconds and used for traces of each vortex. The minimum absolute value of vorticity is 0.2 s^{-1} for a tatsumaki vortex and 10 km regions (200 grids) from the inflow boundary were excluded from the analysis. The total number of vortices is 418. Positive and negative vortices are 58 and 42 %, respectively. Histogram of vorticity (Fig. 4) shows that most tatsumakis have vorticity between 0.2 and 0.3. The number decreases significantly with increase of vorticity. A small number of tatsumaki were found with vorticity larger than 0.3 s^{-1}.

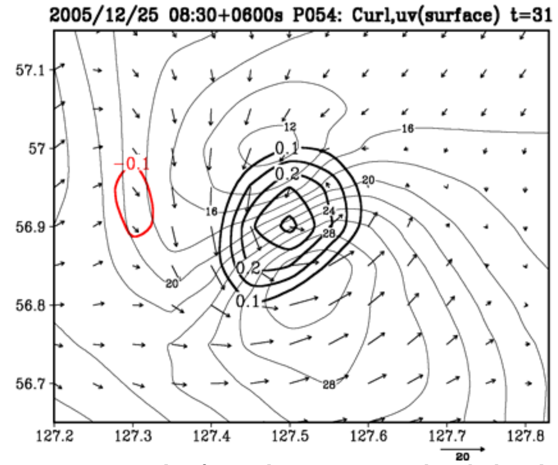

FIG. 2: An example of typical positive tatsumaki. Thick and thin contours are vorticity and wind speed at the surface, respectively. The arrows are horizontal wind vectors at the surface.

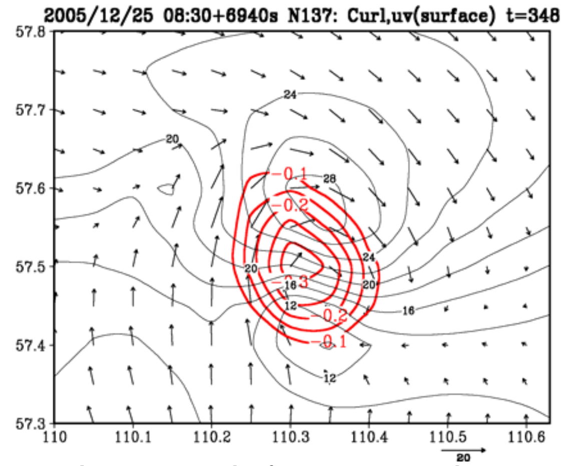

FIG. 3: The same as Fig. 2 but for a negative tatsumaki.

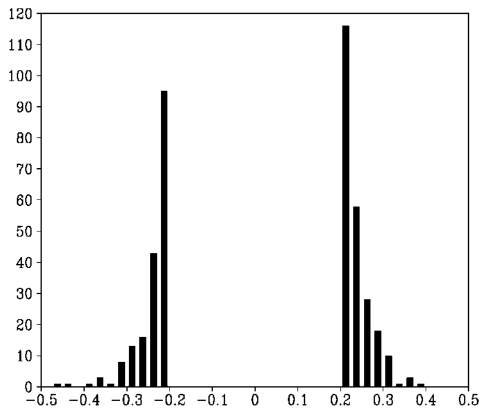

FIG. 4: Histogram of vorticity of tatsumaki obtained in the 50 m simulation. Vorticity between -0.2 and 0.2 s^{-1} are not counted.

The velocity field of both positive and negative tatsumakis is balanced with the pressure field (the cyclostrophic balance). Both positive and negative vortices of tatsumaki are accompanied with negative pressure deviation. Figure 5 shows a scatter diagram of vorticity and pressure deviation. The increase of vorticity roughly corresponds to the increase of pressure deviation. Its maximum deviation reaches about 4 hPa.

Both positive and negative tatsumakis accompany intense wind of 30-35 m s^{-1}. The maximum wind speed reaches 40 m s^{-1}. The relationship between vorticity and wind speed is not clear (figure is not shown).

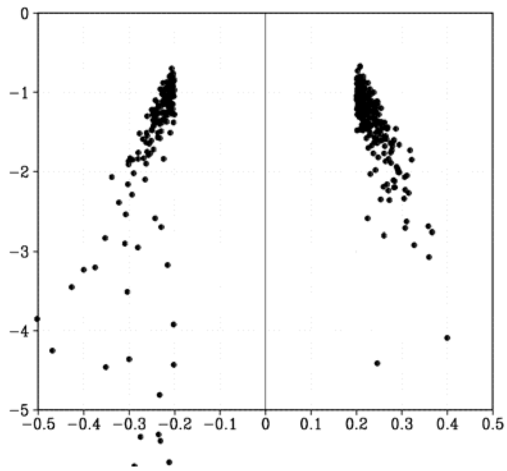

FIG. 5: Scatter diagram of vorticity of tatsumaki vs. pressure deviation at the surface obtained in the 50 m simulation. Data of vorticity between -0.2 and 0.2 are excluded.

IV. AKNOWLEDGMENTS

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