P4A.7 DOPPLER RADAR OBSERVATION OF WINTER TORNADOES OVER THE JAPAN SEA

Fumiaki KOBAYASHI*
National Defense Academy, Yokosuka, Japan

1. INTRODUCTION

Tornadoes (supercell tornadoes, landspouts and water spouts) often occur in Japan. According to the geographical distribution, many tornadoes occurred along the coastline of the Pacific Ocean. On the other hand, tornadoes also reported on the Japan Sea Coast. Ishikawa Prefecture is the highest value of “the tornado probability” which is larger than that of several Prefectures on the Pacific side.

Supercell tornadoes often occurred in Japan (e.g., Kobayashi et al., 1986; Niino et al., 1993; Suzuki et al., 2000). However, the structure, morphology or mechanism of the tornadoes, which occurred over the Japan Sea in winter, is unknown until now. We call the tornadoes generated over the Japan Sea in winter season as “winter tornado” or “tornado with snowcloud”. In this paper, we would introduce case studies of winter tornadoes observed at the Hokuriku Coast.

2. DOPPLER RADAR OBSERVATIONS

Doppler radar observations were carried out from the middle of December to the end of January for recent five years at the Hokuriku Coast to investigate winter thunderclouds, heavy snowfall and high winds. In specially, the observation project of Winter MCSs Observations over the Japan Sea (called as “WMO” project, Yoshizaki et al. (2002)) was carried out using Doppler radars, GPS sondes, and wind profilers and so on in January 2001-2003.

* Corresponding author address:
Fumiaki Kobayashi, Dept. Geoscience, NDA,
Yokosuka, Japan 239-8686;
e-mail: kobayasi@nda.ac.jp

7 mobile Doppler radars were set up along the coastline. Some GSP sonde and wind profiler points made up the routine upper air observations. Also, missions of observation ships and aircrafts were planned during the core observation period. Figure 1 shows the observation area at Mikuni Town, Fukui Prefecture. The NDA Doppler radar was set up at the coastline to make clear the fine structure of MCSs and the precipitation process at the landing of snowclouds. GPS sonde was launched at every 3 or 6-hour intervals. Surface weather stations were set up. Moreover, the Boundary Layer Radar and the cloud radar (Kyoto Uni.), the C-band dual-polarization Doppler radar (Hokuriku Electric Power Company) and the UHF Interferometer to observe lightning strokes (Osaka Uni.) were also set up at the same area.

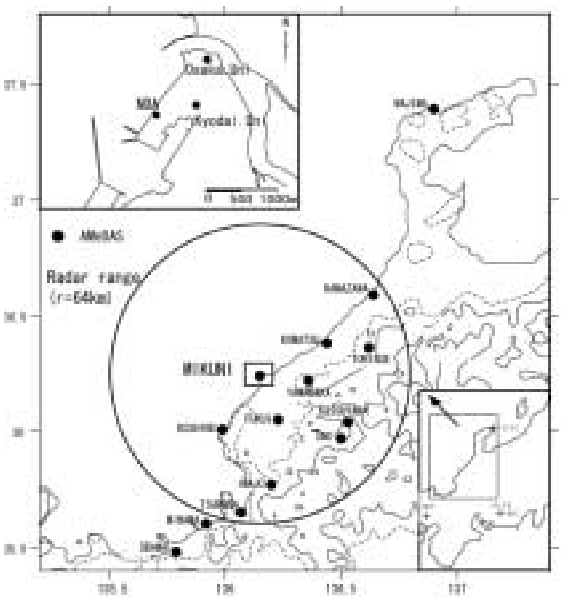

Fig.1 Observation area at Hokuriku Coast.

We would introduce the structure of a winter tornado, which occurred close to the radar site in the special observation period.

3. "MIKUNI" TORNADO

3.1 FUNNEL CLOUD

Figure 2 shows a photo of "Mikuni tornado" just before the touch down on 18 January 2001. Two fixed video cameras and handy cameras took the shape of the funnel cloud. Life time of the funnel cloud was 7 minutes (1048JST〜1055JST (Japan Standard Time)). The generation of the funnel cloud was corresponded with the landing of one snowcloud under the winter monsoon. The diameters of the funnel were estimated from the images. Funnel diameter was about 100 m at the cloud base and 20〜30 m near the sea surface. The direction of rotation was cyclonic. The height of the cloud base was 300 m and cloud top was 3000 m from GPS sonde observation at 09 JST.

3.2 SCALE OF THE TORNADO

Figure 3 shows the path of the Mikuni tornado. The tornado generated about 3 km offshore, close to the radar site (● in the figure). The tornado moved towards ENE direction and disappeared at the mouse of the Kuzuryu River. The length of the path was corresponded with P1 scale (3 km). There was no damage on the ground or ships. Maximum

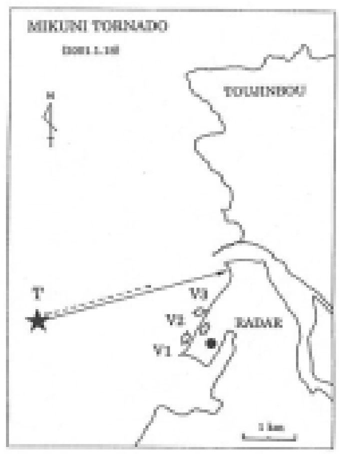

Fig.3 Path of Mikuni tornado. V1〜V3 denote directions of the video cameras. Broken line shows a limit of the tornado vortex observed by the radar.

wind speed was estimated to 30 ms^{-1} (F0 scale) from the video images, which value was supported by the Doppler radar observation. No strong wind accompanied with the tornado was observed at the radar site.

3.3 DOPPLER RADAR OBSERVATION

Radar data were taken by CAPPI (10 elevations) and RHI modes at every 6-minute interval. The tornado vortex was caught by PPI scan from 1048JST (elevation 1°) to 1051JST (19°). Figure 4 shows Doppler velocity patterns at 10:49 JST. The couple of positive (5 ms^{-1}) and negative

Fig.2 Tornado funnel at 1051JST 18 January 2001. The photo is looking towards WNW direction, just before the touch down.

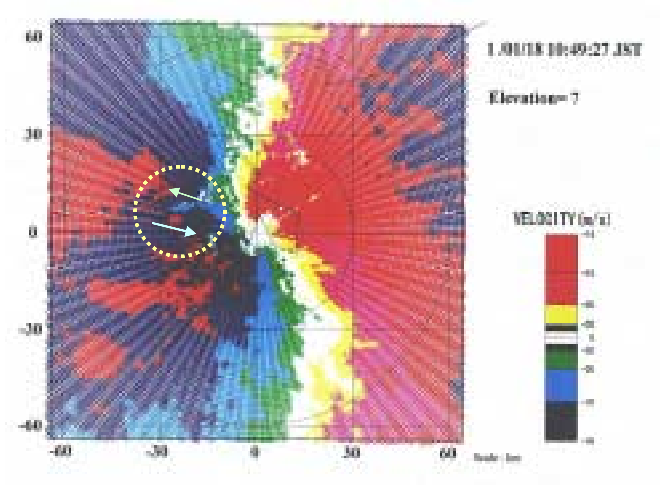

Fig.4 Doppler velocity patterns at 7° elevation on 10:49JST. A circle shows the position of tornado vortex.

(21 ms^{-1}) peaks of the Doppler velocity indicate the presence of a circulation which diameter was about 200 m. This signature means the existence of a vertical vortex (tornado funnel) under the strong winter monsoon wind.

Figure 5 shows vertical distributions of the tornado vortex diameter and vorticity observed by the Doppler radar. The diameter of the vortex varied at three different altitudes; 30 m near the surface, 200m below the cloud base and 400m～800m in the cloud, which corresponded with that of the funnel cloud as shown in Fig.2. Remarkable changes in the vortex diameter occurred at the cloud base, which means existence of the tornado funnel below the cloud base and a misocyclone in the cloud. The vorticity reached 10^0 orders near the surface (funnel), was uniform (10^{-1} order) near the cloud base and in the cloud (misocyclone). The angular momentum was quite uniform (～1000 m^2s^{-1}) at all altitude (not shown), which indicates the conservation between the misocyclone in the cloud and the tornado funnel below the cloud base. Also, the movement of the tornado vortex observed by the radar corresponded well with the path of the funnel (Fig.3).

3.4 MECHANISM

Two mechanisms of winter tornadoes would be considered: one is horizontal wind shear near the surface; another is vertical wind shear below cloud base. Over the Japan Sea, mesoscale disturbances form in Japan Sea Convergence Zone (JPCZ). Nagata (1993) simulated meso-β-scale vortices developing along JPCZ cloud band. Balotoropic shear instability is one important mechanism for generation the vertical vortex. On the other hand, vertical wind shear in sub-cloud layer was dominant in this case ($35x10^{-3}$ sec^{-1}, see Fig.6). The vertical wind shear related horizontal vortex would be tilted by updraft of developing snowclouds like non-supercell tornado. The mechanism of the Mikuni tornado formation was guessed that the vertical wind shear of sub-cloud layer made the vertical vortex.

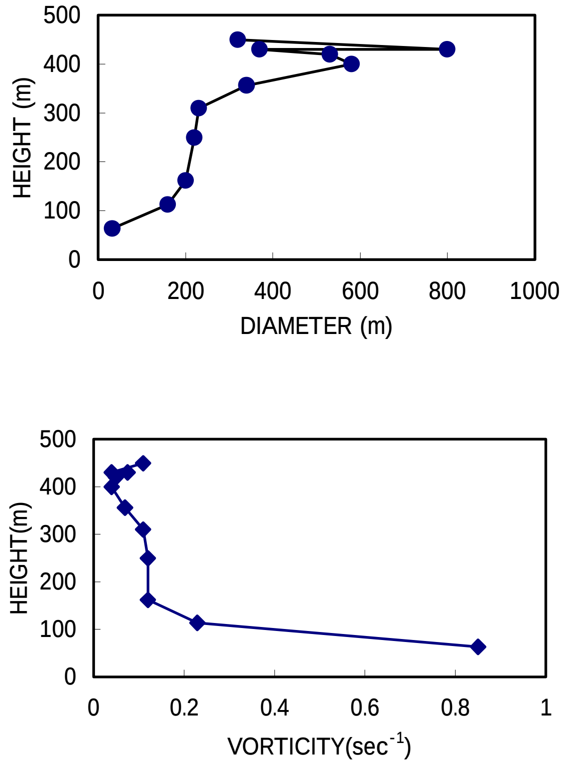

Fig.5 Vertical distributions of tornado diameter (top) and vorticity (bottom) calculated from Doppler velocity.

"Steam devils" development over Lake Michigan was reported under the cold air outbreak (Lyons and Pease, 1972). Thermal instability is also necessary condition over the Japan Sea in winter. Further studies are needed to accumulate environmental condition data favored for tornado generation, such as stability, wind shear and local wind fields.

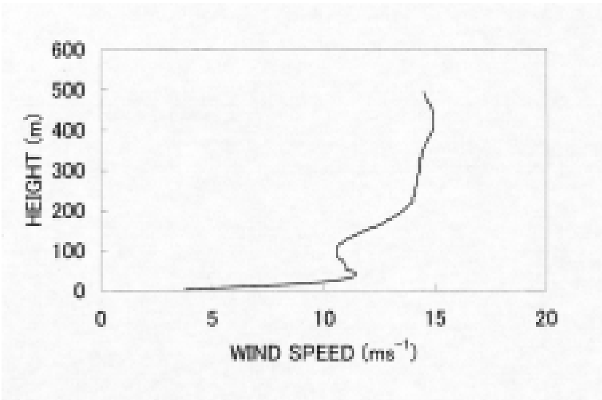

Fig.6 Vertical wind profile at Mikuni tornado (09JST, 18 January 2001).

4. MORPHOLOGY OF THE TORNADOES

Tornadoes, which landed or caused considerable damage, often occurred in Hokuriku Coast. For example, Kanazawa tornado (11 December 1991; Kobayashi et al. (1992)) caused damage to more than 200 houses and corresponded with F3 scale. The tornado was associated with a hook echo (mesocyclone) which developed near the center of a meso-β-scale vortex over the Japan Sea. It is recognized that "mini-supercell" like tornadoes exist over the Japan Sea in winter. There are many types of mesoscale vortices over the Japan Sea. Ninomiya et al. (1996) pointed out the multi-scale features of the cold air outbreak. However, meso-γ-scale or microscale structures of the disturbances have not been clear until now.

In fact, several tornadoes were observed at each radar site during the special observation period (WMO). Generally, few watchers are looking at the snowclouds under the strong winter monsoon period at the coastline. The tornado probability may increase if we will survey winter tornadoes along the coastline. In other words, many tornadoes may generate over the Japan Sea Coast in cold air outbreak more than our expectation.

5. SUMMARY

Some characteristics of winter tornadoes, which formed near the Hokuriku Coast over the Japan Sea, were pointed out. The Mikuni tornado was non-supercell tornado formed under the winter monsoon. The tornado was accompanied with a misocyclone near the cloud base and single funnel cloud. On the other hand, "supercell" tornado accompanied with a mesocyclone also exists in winter. These observation results indicate a possibility of so many "winter tornadoes" generation over the Japan Sea. Further observations must be needed to accumulate case studies and make clear the structure of winter tornadoes.

6. ACKNOWLEDGMENTS

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