Tornado Generation in a Narrow Cold Frontal Rainband
—Fujisawa Tornado on April 20, 2006—

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Abstract

At noon on April 20, 2006, a wind storm occurred in Fujisawa City, Kanagawa Prefecture, Japan with a F0-P1-P1 rank on the Fujita-Pearson-scale (FPP-scale). Damage to over 40 residential buildings was observed. The damage covered an area 2 km by 50 m. The strong winds were accompanied by the passage of a cold front. Eyewitness accounts of a dust column and the recording of a pressure drop (1.5 hPa) indicate the existence of a tornado vortex. A hook-shaped radar echo (5 km in diameter) was observed in the narrow cold frontal rainband, with strong horizontal wind shear above the damage area. The Doppler velocity pattern indicated a misocyclone, which had a diameter of 2 km and a vorticity on the order of $10^{-2}$ s$^{-1}$. The wind storm may have caused the tornado, which formed in the cold frontal wind shear zone.

1. Introduction

In Japan, tornadoes and tornado-related disasters can occur all year round. Tornadoes are also commonly accompanied by extratropical cyclones, typhoons and heat thunderstorms. Supercell tornadoes that accompany mesocyclones in the parent cloud are often reported in Japan (e.g., Niino et al. 1993; Kobayashi et al. 1996). Suzuki et al. (2000) described a supercell type (mini-supercell) tornado within the rainband of a typhoon. Many waterspouts (non-supercell tornadoes) have occurred near the coastline of Japan (e.g., Kobayashi et al. 1997). Although many tornadoes were accompanied by a developing synoptic low or cold front (Niino et al. 1997), the mechanism and structure of tornadoes that occurred in the cold frontal rainband have been unsolved until now.

At noon on April 20, 2006, a wind storm occurred in Fujisawa City, Kanagawa (Tokyo District Meteorological Observatory 2006). A tornado caused damage to over 40 residential buildings. Doppler radar observation was carried out at Yokosuka, near Fujisawa during the passage of the cold front. In this paper, we document the tornado, which was generated in the narrow cold frontal rainband.

2. Synoptic situation

The weather map at 12:00 JST (Japan Standard Time) on April 20, 2006 shows a cold front extending from the 992 hPa low to the Pacific Ocean (Fig. 1). This implies that the synoptic low moved slowly towards the southeast as the cold front passed over Fujisawa City, Kanagawa Prefecture. Figure 2 shows the geostationary meteorological satellite (GMS) MTSAT-1R infrared image at 11:30 JST. Convective activity around this cold front was active. The damage caused in the Fujisawa region by the wind gust recorded after 12:00 JST on April 20, 2006 was accompanied by a band of cumulonimbus clouds that had formed in the cold front. Figure 3 shows that line-shaped strong radar echoes with a width of 10 km and a top height of over 10 km observed over the Pacific Ocean. The strong echo corresponds to a precipitation intensity of over 30 mm h$^{-1}$.

3. Surface damage and meteorological observation data at Fujisawa

In Fujisawa City, at approximately 12:05 JST on 20 April, 2006, a strong gust of wind occurred that caused damage in both Fujisawa City and the southwestern part of Yokohama City. Figure 4 is a damage map drawn up after a 2-day field survey, which shows the locations of damaged residential houses and non-residential structures, such as wooden roofs, plastic greenhouses, and trees. Damage to over 40 residential and non-residential houses was observed, with the affected area covering 2 km by 50 m. The damage rank
was estimated to be F0-P1-P1 on the Fujita-Pearson-scale (FPP-scale). F scale was determined by the features of overall damage. Distinct features of the damage included that: 1) the damage area was practically in a straight line, and 2) there were indications of cyclonic (rotary) winds, determined by tracing debris, flying debris and surveying surface damage patterns. These features suggested that the damage was caused by a tornado. Although there were many eyewitness accounts of the rotating wind of a “dust column” near the surface, there were no eyewitness accounts of a funnel.

Figure 5 shows the change of each meteorological element with respect to time for the locations that were close to the damage area, as well as for locations 100 m east of the damage (shown as a triangle in Fig. 4). A pressure drop of 1.5 hPa was recorded after 12:00 JST, indicating the passage of a tornado or its parent cloud (misocyclone). The tornado occurred at the passage of the cold frontal rainband.

4. Doppler radar observation of parent cloud

X-band Doppler radar (wavelength of 3 cm) located at the Yokosuka, National Defense Academy (100 m AGL), which will be referred to as the NDA radar, was used to acquire the radar echo reflectivity and Doppler velocity data. The range of the NDA radar was a circle with a radius of 64 km. Plan position indicator (PPI)
volume scans of 20 steps, from an elevation (EL) of 0.5° to 20.5°, and a range height indicator (RHI) scan, azimuth of 355°, were carried out at 8 minute intervals.

Figure 6 shows the NDA radar echo pattern (intensity) of the CAPPI (Constant Altitude PPI) at 1 km AGL, calculated from 12:12 JST to 12:18 JST. A strong echo area greater than 36 dBZ denotes the meandering line echo pattern. A hook-shaped (or ring-shaped) echo was observed northeast of the damage area. The diameter of the hook-shaped echo was about 5 km. On the other hand, the tornado vortex signature was captured by the PPI volume scans from 12:12 JST (EL = 0.5°) to 12:15 JST (EL = 4.5°). Figure 7 shows the Doppler velocity patterns at 12:12 JST (EL = 0.5°, about 310 m AGL at Fujisawa City) just after the generation of the tornado. The positive and negative opposite peak winds in the Doppler velocity, which were located about 3 km northeast of the damage area, indicate the presence of a circulation 2 km in diameter. These observations suggest the existence of a vertical oriented vortex tube, which implies that a misocyclone formed in the southwest quadrant of the hook-shaped echo.

Figure 8 summarizes the time-height section of the vorticity calculated from tornado vortex signatures. The vortex signature reached a height of 2 km (from EL = 0.5° to EL = 4.5°). The vorticity, calculated by peak to peak Doppler velocity assuming axially symmetric vortex, was $4.9 \times 10^2$ s$^{-1}$ near the surface and decreased as the altitude increased. The lifetime of the misocyclone was the same as that of the surface tornado vortex (about 5 minutes of the dust column), as no vortex signature was observed in the next volume scan data of the Doppler radar once the tornado vortex signature had disappeared. The hook-shaped echo and the misocyclone, which were observed during one volume scan (from 12:12 JST to 12:18 JST), appeared just as the tornado touched down (12:05-12:10 JST). In this case, the tornado (surface dust column) and misocyclone would have formed simultaneously. The misocyclone, which had a diameter of 2 km, lasted about 5 minutes. No mesocyclone was accompanied with the hook-shaped echo, but a misocyclone was generated in the center of the hook-shaped echo.

5. Summary and discussion

At noon on April 20, 2006, a tornado occurred in Fujisawa City, Kanagawa Prefecture, Japan. The damage extended over an area 2 km by 50 m and had a
The tornado was accompanied with the passage of a cold front. The hook-shaped radar echo (5 km in diameter) was observed in the narrow cold frontal rainband. The Doppler velocity pattern indicates the existence of a misocyclone, which had a diameter of 2 km and a vorticity on the order of $10^{-2} \text{s}^{-1}$. The wind storm may have been caused by a non-supercell tornado, which formed in the cold frontal wind shear zone.

Wakimoto and Wilson (1989) described a formation mechanism for non-supercell tornadoes that formed along the shear line in the vicinity of Denver, USA. In the present case, the horizontal wind shear in the narrow cold frontal rainband caused a vertical oriented vortex tube, which may have been stretched by the surface convergence. Strong convergence and stretching may occurred between updraft at the ground and cloud base.

Carbone (1982) pointed out the possibility of tornado generation in the frontal zone horizontal shear. Recently, Arnott et al. (2006) showed that misocyclones are associated with vertical velocity maxima in convergence along the cold front. Friedrich et al. (2005) discussed characteristics of misocyclones generated in the gust front and relationship between horizontal wind shear and convection initiation. However, few tornadoes generated in the narrow cold frontal rainband have been reported using Doppler radar. Further studies are needed in order to clarify the fine structure of narrow cold frontal rainband that causes tornadoes.

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1. Photos of the damage at Fujisawa are shown in the Supplement 1.

References


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SOLA: http://www.jstage.jst.go.jp/browse/sola/