X-band Phased Array Weather Radar Observations of a Mesocyclone in the Tokyo Urban Area

*Shigeharu Shimamura[1,3], Kazuomi Morotomi[1,3], Saori Kurihara[1], Fumiaki Kobayashi[2], Toshiaki Takano[3], Atsushi Higuchi[3], Hisato Iwashita[4]

1. Japan Radio Company, Ltd., 2. National Defense Academy of Japan, 3. Chiba University, 4. Meisei Electric Co., Ltd.

In summer, around Tokyo urban area in Japan, localized heavy rainfall, downburst, and lightning sometimes threatens lives. These severe weather events can be brought down from cumulonimbi which grows rapidly in several ten minutes. After the evening on August 27, 2018, a mesoscale convective system had been growing in Kanto region, bringing down heavy rains and winds, and causing floods, fallen trees, and electric outage in Tokyo urban area. Ground-based observation results in Nerima-ku show ground-based rainfall amount of 74 mm/h accompanied with hail from 19:30 to 20:30 JST, and the north wind of 25.1 m/s in maximum velocity on 19:46 JST. The sudden wind on ground level was reported that it was generated from downbursts fallen down from the cumulonimbus above. This type of convective system represented by cumulonimbi grows firstly, which implies that convective radars equipped with parabolic antenna cannot detect their growing process.

Japan Radio Co., Ltd. has independently developed a single polarization X-band PAWR, capable of detecting precursors of extreme weather events such as localized heavy rain and hazardous microburst. The developed X-band PAWR was installed in 2015 in Chiba city for continuous observation. The PAWR needs only 30 seconds to complete volume-scanning within 80 km in radius and 20 km at height. Transmitting horizontally-polarized wave from 16 slot antenna elements and receiving echo by 126 slot antenna elements, the PAWR relies on digital beam forming (DBF) process on received IQ signals in order consequently to obtain single polarization radar products such as radar reflectivity, the Doppler velocity, and spectrum width with high spatial resolution of 50 meters.

Regarding to the case in Nerima-ku on August 27, 2018, the observation results by the PAWR indicates that the convective cloud had attributes peculiar to mesocyclones. Figures 1, 2, and 3 show the cloud’s characteristics on horizontal section, vertical section, and 3D image, respectively. Figure 1 displays horizontal distributions of radar reflectivity and the Doppler velocity at 5 km height by the PAWR on 19:34:00 JST. The figure shows attributes of a mesocyclone, in particular, a ring shape of radar reflectivity in the solid black circle and a couple of positive and negative Doppler velocities in the dotted black circle. In the Doppler field, positive regions indicate precipitation particles moving away from the PAWR, whereas negative regions indicate them moving towards to the radar, which implies the couple of velocities here suggests the vortex’s rotation was counterclockwise. Figure 2 shows a vertical cross section of the convective system which moved roughly from left to right. A vault-like shape of radar echoes that strong radar echo areas (red or yellow colored) are surrounding the upper side of weak echo area (green colored area) are shown. The boundary of the areas is indicated by the dashed white line. This echo shape implies that strong updrafts blowing up from the front-side of the system existed at the weak echo region in the vault. Figure 3 shows a 3D image of the twisted cloud echo looking from the south side on 19:43:30 JST, revealing that the convective cloud had approximately 18 km of 20 dBZ echo top height at maximum and three-dimensionally tornadic form. At that time, in the cloud, both updraft and downdraft co-existed, which were separated and had skew positions each other. Because of the twisted form, they did not cancel out each other, and convective growth and precipitation core’s descending co-existed in the same system. In these results, the convective cloud, bringing downburst onto the ground, can be referred to as a mesocyclone.

A relationship between vertical vorticity structure and growth of the convective cloud observed by the PAWR is introduced. To investigate time-height structure of the mesocyclone, we derived time-height sections of pseudo vertical vorticities of the vortex calculated individually from the PAWR Doppler data. Figure 4 shows time series of echo top height on each radar reflectivity and the echo top growing rate line only at 50 dBZ as well as time-height sections of vorticity. Since the 30 dBZ echo top height (solid blue) reached at approximately 17 km and even the 50 dBZ echo top height (solid red) came up at over 14 km, the mesocyclone can be estimated that it was one of the most intense localized weather phenomena in these years in Japan, as hazardous as “Nerima Heavy Rain” in 1999. Furthermore, the 50 dBZ echo top growing rate (dashed red) reached to approximately 800 m/min. on 19:30:00 JST. This growing rate also implies growing process of the cloud cell was extremely rapid and the process cannot be detected by conventional weather radars equipped with parabolic antennas whose temporal resolutions are 5 to 10 minutes. On the other hand, the cell had strong vertically-successive vorticities over 0.02 s^{-1} which probably played a role to roll up precipitation particles and water vapor around it and to promote its growth. Focusing on a relation between echo top growing rate and vorticity, at the three times on the local maximums of the growing rate, 19:30:00, 19:38:00, and 19:44:00 JST, strong vorticities were continuously detected. Consequently, this relation suggests that vertical vorticity can be related to growth of convective clouds.

This paper reports three-dimensional analysis on the mesocyclone around the Tokyo urban area on August 27, 2018. Spatial structures of the vortex and its rapid growing process were revealed by the PAWR’s three-dimensional rapid scanning.

Keywords: phased array, mesocyclone, downburst, microburst, tornadic storm, vorticity

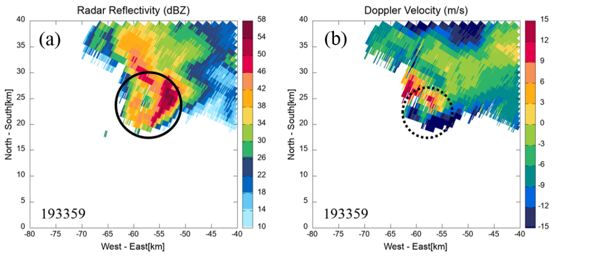

Fig. 1. The PAWR reflectivity and Doppler velocity field on 19:34. (a) Reflectivity (Solid black circle indicates the ring shape echo), and (b) Doppler velocity (Dotted black circle indicates the couple of positive and negative Doppler velocity).

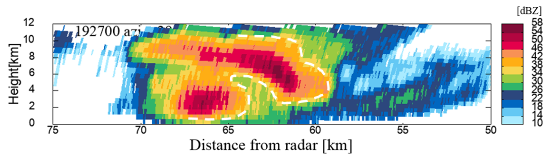

Fig. 2. The vertical section of the PAWR reflectivity on 19:27 for an azimuth angle of 295° (Dashed white line indicates the boundary of strong echo and weak echo areas).

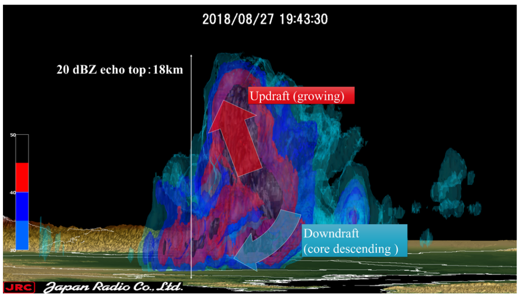

Fig. 3. The 3D reflectivity image of the mesocyclone on 19:43:30.The red arrow and the blue arrow indicates the locations of updraft and downdraft, respectively.

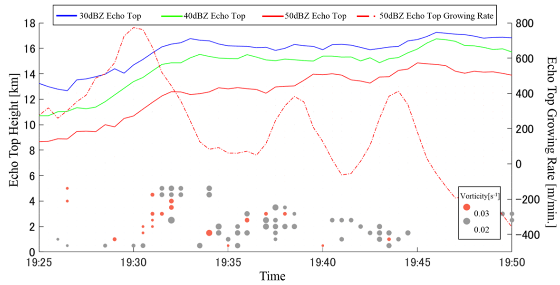

Fig. 4. The time-height sections of vorticity and the time series of the PAWR echo top height on 30, 40, and 50 dBZ, and echo top growing rate on 50 dBZ.