First Radar Echo Formation of Summer Thunderclouds in Southern Kanto, Japan

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Abstract Radar observations of heat thundercloud generation in southern Kanto, Japan for two summer seasons, are analyzed in order to clarify the characteristics of cloud formation. First radar echoes, detected using a X-band Doppler radar for the first time in southern Kanto, are found to occur in both mountain and plain areas. First echoes were generated with high frequency on the Boso Peninsula and at the foot of the Tanzawa mountains early in the afternoon, and with lower frequency over the Tokyo metropolitan area. The period of highest activity was between 11JST and 17JST, and while most first echoes were generated at an altitude of around 2 km in mountain areas, first echoes occurred at much higher altitudes (~5 km) over the metropolitan region.

Key words: Heat thunderclouds, first echo, radar observation

1. Introduction

The mountain areas in northern Kanto, Japan, are typified by frequent summertime thunderstorm activity, with that around Mt. Akagi and Mt. Haruna being famous examples. Through statistical analysis, Saito and Kimura (1998) revealed that the diurnal change in convective precipitation around the Kanto area includes an afternoon peak in convective precipitation around the mountains proper, and an evening peak at the foot of the mountains. In contrast, the Kanto plain itself experiences relatively few thunderstorms (e.g., Horie and Tomine, 1998). However, heavy rainfall occurs occasionally in the greater Tokyo metropolitan area, with notable examples being peak hourly rainfalls of 80 mm at Yokohama on 30 July 1998, 131 mm at

Many studies of heat thunderclouds in Kanto have been presented using JMA (Japan Meteorological Agency) radar data (2.5km x 2.5km mesh) or AMeDAS precipitation data of JMA (spatial resolution of about 20km). However, those resolutions are not so fine enough to analyze thundercloud formation. In order to detect the formation of thunderclouds (first radar echoes), higher resolution (100m order) radar data is needed. Suzuki et al. (2000) indicated the first echo distribution around northern Kanto region from case studies of X-band Doppler radar observational data (see Fig.1).

Fig. 1 Geographical features of the Kanto area. Circles show 64 km ranges of the NDA radar and Maebashi radar in 1997, respectively.

2. Observations

The NDA radar was set up on top of a building (100 m above mean sea level) of the NDA, Kannonzaki, Yokosuka, in March 1999. Figure 1 shows the geographical features and radar ranges in our studies (NDA radar and Maebashi radar). In this study, a 64 km range was chosen in order to obtain data with higher spatial resolution. This range encompasses the Tokyo urban area, Boso Peninsula, Tanzawa mountains, Tokyo Bay, and Sagami Bay. Specifications of the NDA radar are followings:

- Frequency; 9.7 GHz
- Wavelength; 3 cm
- Beam width; 1°
- Minimum range (intensity); 13 dBZ
- Spatial resolution (radial direction); 125 m

Doppler radar observations were carried out during summer (July to September) by plan position indicator (PPI) volume scans (11 elevations, from 0.5° to 20.5°) and range height indicator (RHI) scans at 10 min intervals. There are no obstacles around the radar site, giving unobstructed radar detection. Video and 35 mm still photography corresponding to the periods of cumulus development were also captured.

3. Characteristics of the first echo generation

3.1 Definition of first echo

On a summer afternoon, many convective clouds (Cu or Cb) form and dissipate in the mountain and plain regions of Kanto. As heat thunderstorms usually only occur when a Pacific high is situated over the mainland (Honshu), analysis was performed on “mid-summer days” meeting this criterion. Days for analysis in the present study were selected based on the criteria of maximum daily temperature exceeding 30 °C at Otemachi to ensure sufficient sunshine, and a wind speed at 12JST at Otemachi of less than 2.5 ms⁻¹ to allow for the onset of local circulation (sea breeze).

Fig. 2 Example of convective cloud photo and corresponding radar echoes in the same time (12:28JST, 9 August 2000). Bottom figure shows successive development of radar echo “b”.

Fig. 3 Three-hourly distribution of the first echoes during two summer seasons (1999-2000).

The first convective clouds that later develop into thunderclouds are expected to possess characteristics that may be useful for the analysis of thundercloud generation. However, as the visibility for video and still photography was limited, and the period between first cloud formation and the first radar echoes was quite short (see Fig. 2), visualization of this period of formation is not included in the present analysis. Instead, the initial convective echoes observed by the radar are discussed in this study.

“Thundercloud echoes” were defined as convective radar echoes of greater than 28 dBZ intensity in the mature stage in this study. These thundercloud echoes were traced back to the formation echoes or initial convective echoes, defined here as “the first echoes of the thunderclouds” at an echo intensity of 13 dBZ (minimum detectable intensity). But, secondary radar echoes generated near older cells (within a radius of 10 km) were discarded in this study.

Figure 2 shows an example of a first echo image, with the corresponding photo. Three developing cumuli or cumulonimbi were recognized, each in different stages of development. Cloud “A” is a precursor of a thundercloud and corresponds to the developing single radar echo cell “a” in the same time, representing the stage just after first echo generation. Cloud “C” is also a nucleating thundercloud, and corresponds to the first echo cell “c”. Cloud “B” is well-developed and corresponds to a multicell “b”. First echo “b” generated at 11:51 JST and developed rapidly (Fig.2, bottom).

A total of 5 days in 1999 and 20 days in 2000 fit the above criteria of mid-summer day. First echoes were observed in the range for 10 days among total 25 mid-summer days. The number of total “first echoes” was about 350 in these 10 days.

3.2 Temporal and spatial distributions of first echoes

Figure 3 shows 3-hourly distributions of the first echoes from 09JST to 24JST during the period when first echoes were observed. First echoes were generated before noon, and many first echoes were observed on the Boso Peninsula and at the foot of the Tanzawa mountains early in the afternoon. It is remarkable that first echoes were also generated over the plain encompassing the metropolitan region and Tama area (west Tokyo). A few first echoes were generated on the Miura Peninsula in the whole day and Boso Peninsula after 18JST. First echoes were also generated in Tokyo Bay and Sagami Bay in the evening.

Fig. 4 Number of first echoes generations per hour. Shaded area denotes first echo generated in the metropolitan area.

Fig. 5 Number of first echo generations in 1-km height intervals. CH: Plain in Chiba Prefecture. KN: Plain in Kanagawa Prefecture. TM: Tama area (west Tokyo). BS: Boso Peninsula. TZW: Tanzawa mountains area. MET: metropolitan area. BAY: Tokyo Bay. SEA: other bay or sea.

Figure 4 shows a histogram of first echo occurrences during the day. The most active period of first echo generation was between 11JST and 17JST. In the evening, the frequency of first echoes dropped by half, and became relatively rare after 21JST. First echoes in the metropolitan region were observed between 09JST and 21JST.

3.3 Height of the first echo

The height distribution of first echoes in 1-km increments based on constant altitude PPI (CAPPI) images is shown in Fig. 5. First echoes were generated between 2 and 6 km above ground level (AGL), with 75% generated in the 2-3 km height interval. Also in this interval, 45% of first echoes occurred around the Tanzawa mountains, 20% on the Boso Peninsula and Tama area, and 35% over the plain and sea. The numbers were decreased abruptly above 3 km height and the ratio was changed remarkably. The proportion of occurrences on the Boso Peninsula increases in the 3-5 km height interval, and the number of echoes over the metropolitan region halved above 5 km.

4. Discussion

Many studies on the altitude of first echoes have been reported for American examples. First echoes are primarily generated 6-8 km AGL (-10 to -20 °C) in New Mexico (Workman and Reynolds, 1949), Alberta (Chisholm and Renick, 1972) and Colorado (Knight et al., 1983). This is also the case in Ohio (Battan, 1963), Arizona (Braham, 1958), Texas (Clark, 1960) and Missouri (Braham et al., 1963), where this altitude corresponds to -2 °C. In northern Kanto, first echoes are generated between 3 and 7 km AGL, and most frequently in the 4-5 km interval, which corresponds to 0 °C (Suzuki et al., 2000). The result of 2 km for the mountain area in southern Kanto is quite different from that in America and northern Kanto.

In southern Kanto, sea breeze enters to inland after 09 JST (Kurita et al., 1988). Cumulus clouds generate around the Tanzawa mountains and on the Boso Peninsula early in the afternoon at lower altitude (2-3 km AGL). Generally, the 0 °C level occurs at a height of about 5 km in southern Kanto, and the 10 °C level occurs at about 3 km AGL in mid-summer, according to the GPS sonde observation data in 1997 (not in press). It is considered that significant vapor advection occurs associated with the sea breeze in this area, resulting in a large rising air mass on

the slopes of the mountains near coastal areas. The two discrete peaks in thundercloud generation as pointed out by Saito and Kimura (1998) in northern Kanto were not observed for southern Kanto. In northern Kanto, convective clouds form around mountaintops area early in the afternoon due to valley winds, and the later convergence of mountain wind and “large scale sea breeze (Kurita *et al.*, 1988)” produces cloud development at the foot of the mountains in the evening. However, first echoes were generated at higher altitudes (~ 5 km) over the plain, indicating that a different mechanism is responsible for thundercloud generation over metropolitan Tokyo. Cloud formation over the plain may be caused by differential heating of the land and sea. The mechanism may in fact be the convergence of local winds rather than free convection by heating. Direct observation of vertical profiles at urban area would be needed to discuss in detail.

Fujibe *et al.* (2002) discussed the surface wind patterns preceding short heavy rainfall in Tokyo. It was found that easterly wind (sea breeze) from Kashima-nada and southerly wind (sea breeze) from Tokyo Bay or Sagami Bay converge over the metropolitan region. Moreover, the heat island effect of the metropolitan area may contribute to the thundercloud-generating effect of this convergence over the metropolitan area. Regarding cumulus generation, Yonetani (1983) indicated enhancement of a cumulus by a heat island. Kai *et al.* (1994) indicated a case study on “the Kanpachi Street Cloud” over Tokyo, which was enhanced by both thermal effect (heat island) and geographical effect (convergence of sea breeze). Sato and Takahashi (1999) showed the interdiurnal variation of summer cumulus convection over the Kanto Plain. A detailed discussion of these possibilities to thundercloud generation will be the focus of future studies. Further observations are needed in southern Kanto area using Doppler radars, Doppler sodars, GPS sondes and wind profilers to make clear updrafts over the urban region, local circulation process and stability of lower atmosphere in the thundercloud formation stage.

The characteristics of first echo generation in southern Kanto were confirmed in this study, in spite of the data limitation of only two summer seasons. Further studies are needed in order to accumulate data for clarifying the formation of thunderclouds. The present paper dealt only with the characteristics of first echo generation; a future paper will discuss the subsequent development of first echoes.

5. Conclusions

Radar observations were carried out to investigate thunderclouds formation in the southern Kanto area using a X-band radar data. It was found that first echoes are generated in both mountain and plain areas in southern Kanto. Many first echoes are generated on the Boso Peninsula and at the foot of the Tanzawa mountains early in the afternoon. First echoes are also generated in the Tokyo metropolitan area in the afternoon. The most active time of day for first echo generation was found to be 11JST to 17JST. While most first echoes are generated 2-3 km AGL in mountain areas, first echoes are generated at much higher altitudes (~5 km) above the metropolitan area.

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