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THREE-DIMENSIONAL CHARACTERISTICS OF WINTER LIGHTNING DISCHARGES IN THE SHONAI AREA, JAPAN

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1. INTRODUCTION

We have conducted a field observation, "the Shonai area railroad weather project". The Shonai area is located in the coast of the Japan Sea. The project has investigated fine-scale structure of wind gust such as tornado, downburst, and gust front, in order to develop an automatic strong gust detection system for railroad. We have observed winter tornadic storms using two X-band Doppler radars and the network of 26 surface weather stations since 2007 (Kusunoki et al., 2008; Inoue et al., 2011). In 2009, the project was expanded and started lightning observation to investigate the mechanism of winter lightning and the application to strong gust prediction (Fig. 1). Many scientists have indicated that lightning activity is associated with severe weather (e.g., Goodman et al., 1988; MacGorman et al., 1989; Williams et al., 1989, 1999; Kane, 1991). Recent studies reported that flash rate of total lightning (both intra-cloud (IC) and cloud-to-ground (CG) lightning) rapidly increases prior to onset of severe weather (Williams et al., 1999; Goodman et al., 2005; Steiger et al., 2007; Gatlin and Goodman, 2010; Schultz et al., 2011). Williams et al. (1999) termed this feature as "lightning jumps". However, for winter lightning study, there is no similar approach. Hence, we have developed three-dimensional (3D) VHF lightning mapping system for winter thunderstorm, because we consider that integration of 3D total lightning monitoring and comprehensive high-density meteorological observation can provide useful index for predicting strong gust.

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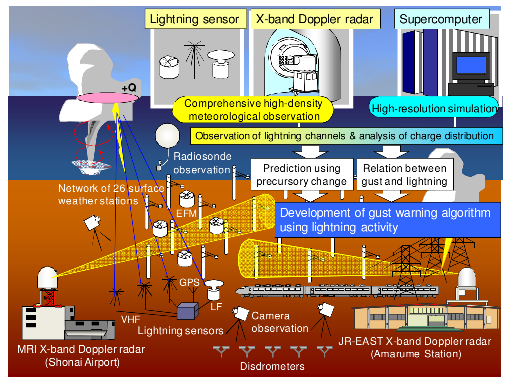

Fig. 1. Overview of the Shonai area railroad weather project.

In this paper, we introduce our lightning observation system at first. Then we show the preliminary results of 3D winter lightning mapping and some features with X-band Doppler radar observation.

2. WINTER LIGHTNING OBSERVATION AND 3D MAPPING SYSTEM

We have developed a VHF lightning observation system and a 3D mapping system. This system observes arrival time differences of VHF broadband pulses radiated by leader progression. The observation system consists of three VHF antennas (discone antennas), band-pass filters, amplifiers, GPS antenna, GPS receiver, time generator, trigger generator, high-speed digital oscilloscope, and personal computer (PC) (Figs. 2 and 3). Observed signals are digitized with the digital oscilloscope (1.25 GHz sampling; 8 bit resolution; sequential trigger mode) and stored in the PC. Precise GPS digital time data (100 ns resolution) are also recorded with the lightning waveform data,

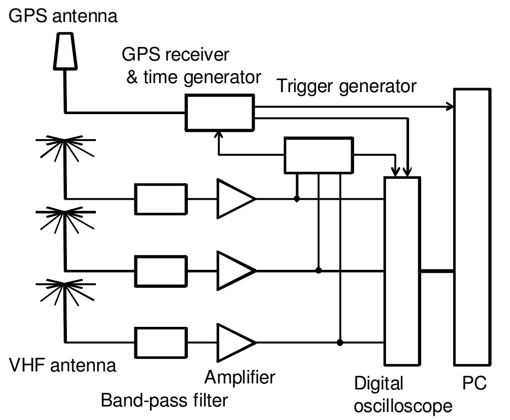

Fig. 2. Schematic diagram of the lightning observation system.

Fig. 3. Lightning observation system.

simultaneously. The azimuth and elevation of VHF radiation sources are computed from the arrival time differences of three VHF broadband pulses using cross-correlation technique. From data set of azimuth and elevation in two sites extracted within given time window, the 3D lightning mapping is conducted utilizing forward intersection method. After operation test at Meteorological Research Institute (MRI), we installed the observation system at site L1 in the north of Shonai area (Fig. 4) in October 2009. Moreover, three lightning observation sites were constructed in the Shonai area in September 2010 (Fig. 4). For instance, the layout of the sensors at the site L1 is shown in Fig. 5. We also installed three network cameras to monitor lightning activity, present weather, and antenna condition. These observation systems have been remotely controlled from MRI through fiber-optic communication network.

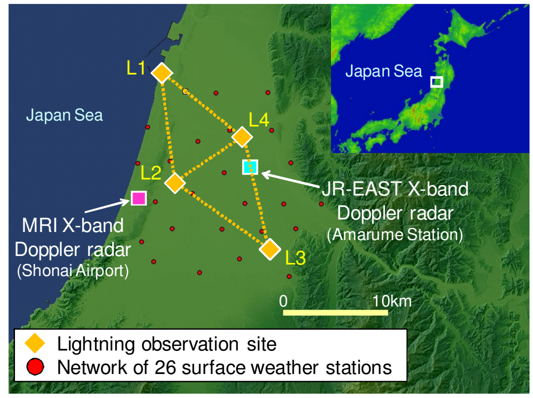

Fig. 4. Location of the observation sites in the Shonai area.

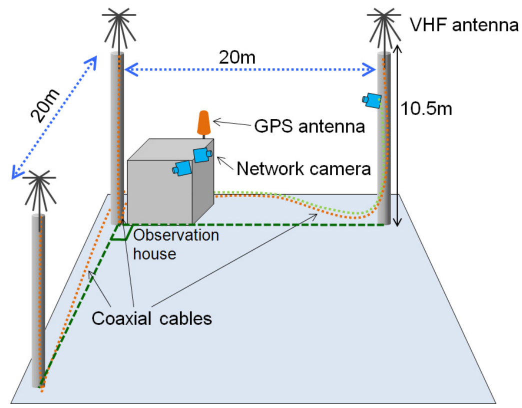

Fig. 5. Layout of the sensors at site L1.

3. RESULTS

3.1 *3D winter lightning mapping*

Figure 6 shows the result of 3D VHF lightning mapping. We observed at sites L1 and L4 at 0113:32 JST on 4 December 2010 (1613:32 UTC on 3 December). The VHF radiation sources are distributed about 7 km in E-W, 10 km in N-S, and 0-5 km in altitude. The detailed structure of the thundercloud was observed with the MRI X-band Doppler radar. The spatial distribution of VHF sources is consistent with the echo region. This lightning flash initiated at strong echo region (> 40 dBZ) at about 2.2 km altitude and progressed toward weak echo region with reflectivity 10-25 dBZ for 55 ms. The vertical distribution of the VHF sources is the range of 0-4.5 km altitude, that corresponds to the echo-top height of about 5 km. The distribution exhibits a single maximum at 2.0-2.5 km altitude, that is consistent with the -10°C level of 2.1 km at 00 JST (15 UTC) (Fig. 6).

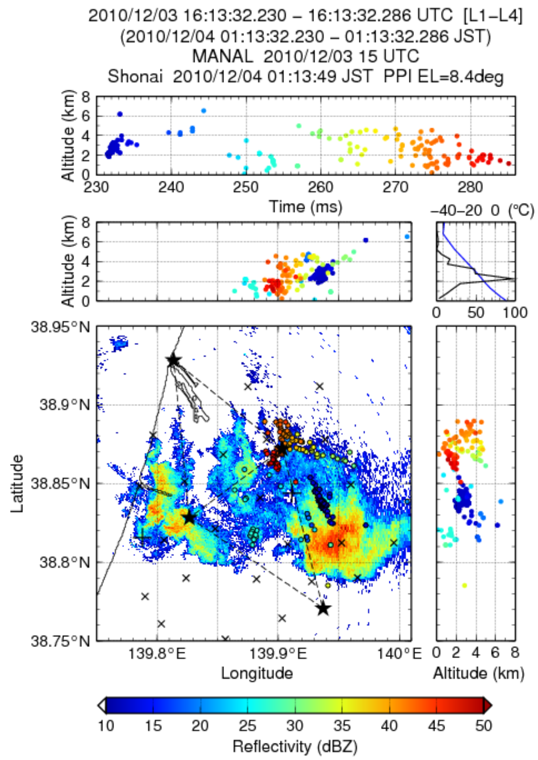

Fig. 6. 3D mapping of VHF radiation sources and radar echo observed with the MRI X-band Doppler radar (PPI scan, elevation: 8.4°). Blue line in the histogram shows atmospheric temperature profile.

The atmospheric vertical profile data are retrieved from Meso-scale Analysis (MANAL) data released by the Japan Meteorological Agency (JMA). Therefore, we estimate that electric charges accumulated around the -10°C level of 2.1 km. This result supports the numerical study on rimming electrification mechanism (Takahashi, 1984) and activity diagram for winter lightning (Michimoto, 1993; Nishihashi et al., 2011).

3.2 *Relationship between lightning activity and vortices*

We observed lightning flashes in the Shonai area during 22-23 JST (13-14 UTC) 30 November 2010. The temporal variation of 5-minute flash rate is shown in Fig. 7. The analyzed area is illustrated in Fig. 8. Numerous lightning flashes occurred at 2230-2235 JST. For instance, Fig. 8a shows the VHF lightning

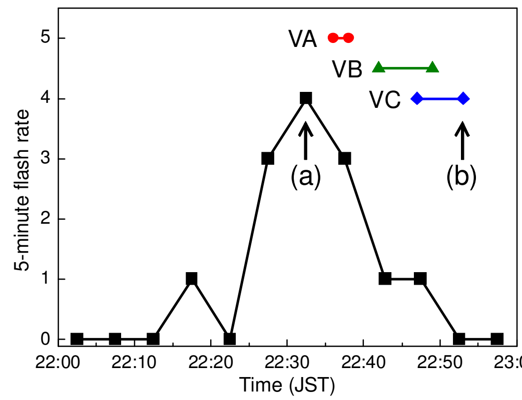

Fig. 7. Temporal variation of 5-minute flash rate and detection time of three vortices (VA, VB, and VC). (a) and (b) correspond to Fig. 8.

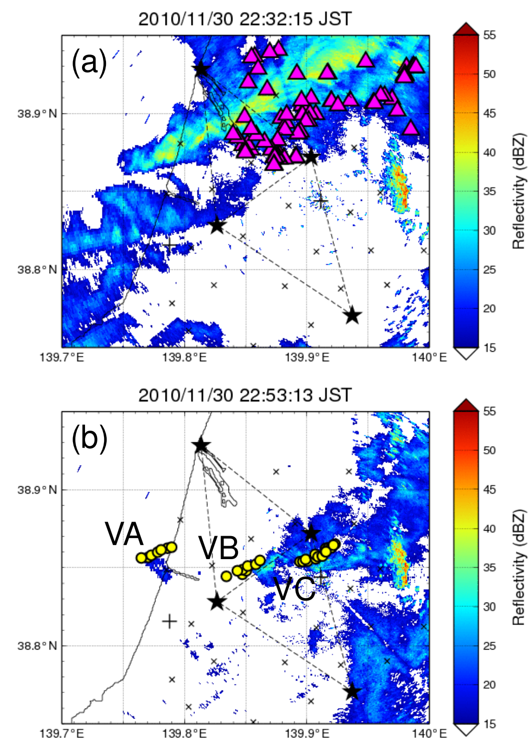

Fig. 8. VHF radiation sources, radar reflectivity, and trajectories of three vortices. (a) 2232:15 JST, (b) 2253:13 JST.

radiation sources and radar reflectivity observed with the JR-EAST Doppler radar (PPI scan, elevation: 3°) at 2232:15 JST. Most VHF radiation sources are distributed in the echo region of 15-30 dBZ that is located around the strong echo region of 40 dBZ. After the peak of lightning activity, three vortices were detected

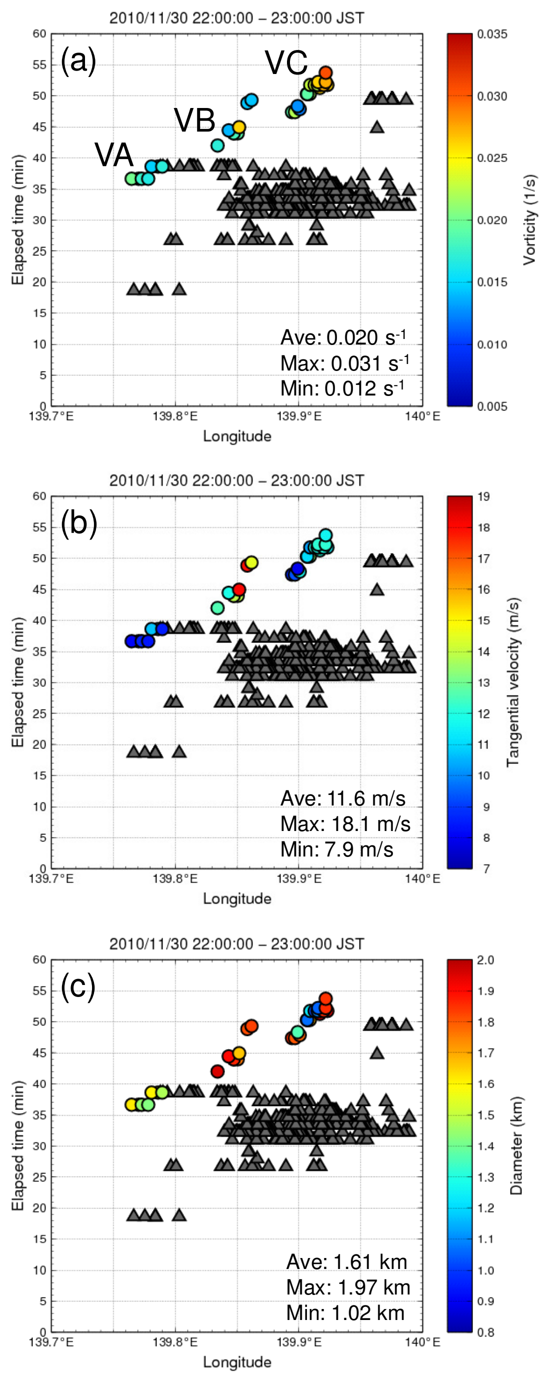

Fig. 9. Temporal-spatial variation of VHF radiation sources and parameters of three vortices. (a) Vorticity, (b) Tangential velocity, (c) Diameter.

intermittently during 2236:39-2253:42 JST (Fig. 7). Figure 8b shows the radar reflectivity at 2253:13 JST and the trajectories of three vortices. Figure 9 shows the temporal-spatial variation of VHF radiation sources and the parameters (vorticity, tangential velocity, and diameter) of three vortices. We found that the trajectories of the vortices are located behind from the concentration of the VHF sources. Although the average tangential velocity of the vortices is 11.6 m/s, it is possibility that the wind speed near the ground was about 20 m/s because the moving velocity of the vortices is around 10 m/s. The values of the vortex parameters are similar order as previous observation results in the Shonai area (Inoue et al., 2011). Therefore, the vortices in this study have typical characteristics in the Shonai area.

4. SUMMARY AND FUTURE WORKS

We developed VHF lightning observation system and 3D mapping system. Arrival time differences of VHF broadband pulses are observed at 0.8 ns intervals (1.25 GHz sampling) and provide the azimuth and elevation of VHF radiation sources by cross-correlation technique. From data set of azimuth and elevation in two sites extracted within given time window, the 3D lightning mapping is performed utilizing forward intersection method. We constructed 3D lightning observation network in the Shonai area in 2010.

This paper presents the 3D mapping result of winter lightning observed at 0113:32 JST on 4 Dec. 2010. The spatial distribution of the VHF radiation sources was compared with the radar reflectivity observed with the X-band radar. The vertical distribution of the VHF sources exhibits a single maximum at 2.0-2.5 km altitude, that is consistent with the -10°C level of 2.1 km. Hence, we estimate that electric charges accumulated around the -10°C level. This result supports the previous stidues on winter lightning.

We observed winter lightning flashes and vortices during 22-23 JST on 30 November 2010. About 5-20 minutes after the peak of lightning activity, three vortices were detected intermittently. The result indicates that there is a relationship betwen lightning activity and vortices in winter thunderstorm.

We need further analysis of 3D structure of winter lightning discharges and a relationship between winter lightning activity and severe weather utilizing not only 3D lightning mapping data but also comprehensive meteorological observation data.

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