687 Observation of winter lightning in the Shonai area railroad weather project: preliminary results

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1. INTRODUCTION

Strong wind gust often affects safety operation of the train. In order to prevent railroad accident, many propeller-vane / cup anemometers have been distributed on the railroad. However, it is difficult to detect strong gust with high accuracy and high resolution with the present system. Therefore, a new comprehensive monitoring system using the other meteorological observation data has been required.

The Shonai area railroad weather project has investigated fine-scale structure of wind gust using two X-band Doppler radars and the network of 26 surface weather stations since 2007, in order to develop an automatic strong gust detection system for railroad. 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). Lightning discharge is known to be related to microphysical and dynamical processes within storms. 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; Price, 2008). Hence, integration of continuous 3D total lightning monitoring (intracloud and cloud-to-ground lightning) and comprehensive high-density meteorological observation can provide useful index for predicting strong gust.

In this paper, we introduce our lightning observation system and the observation results. Using the observation data, we investigate the relationship between the echo-top temperature and the -10°C level, in order to understand the characteristics of winter thunderclouds.

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2. WINTER LIGHTNING OBSERVATION

2.1 *Observation System*

We developed a lightning observation system that consists of three VHF (23-200 MHz) sensors and one LF (<480 kHz) sensor (Fig. 2). Observed signals are digitized with two digital oscilloscopes (VHF: 1.25 GHz sampling, LF: 2.5 MHz sampling) and stored in a personal computer. Precise GPS time data (100 ns resolution) are also recorded simultaneously. The azimuth and elevation of VHF radiation sources originated from lightning flashes are computed using arrival time difference of three VHF pulses. After operation test at Meteorological Research Institute (MRI), we installed this system at Ohama, Sakata in the north of Shonai area (Fig. 3) in October 2009. The observation system and the layout of the sensors at the Ohama site are shown in Figs. 4 and 5, respectively. We also installed three network cameras to evaluate the observed VHF radiation sources and monitor the antennas. The system has been remotely controlled from MRI.

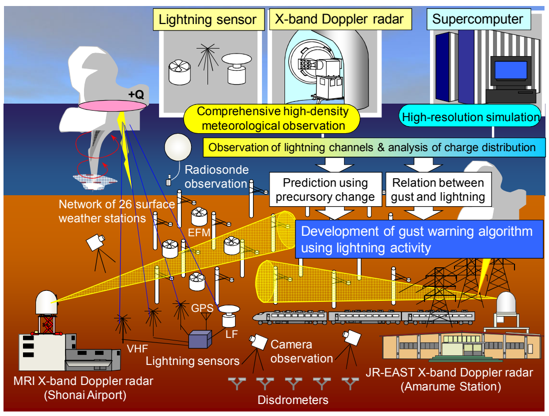

Fig. 1. Overview of the Shonai area railroad weather project.

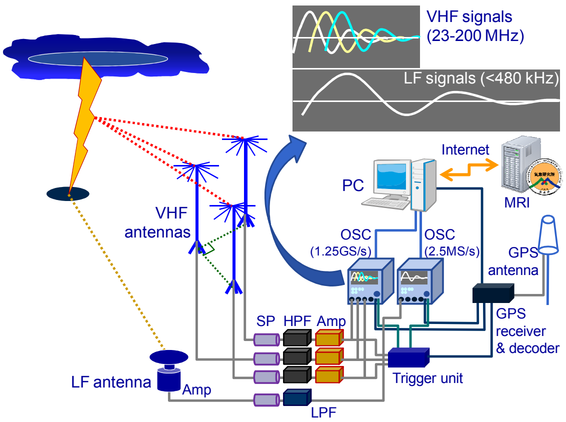

Fig. 2. Schematic diagram of the lightning observation system.

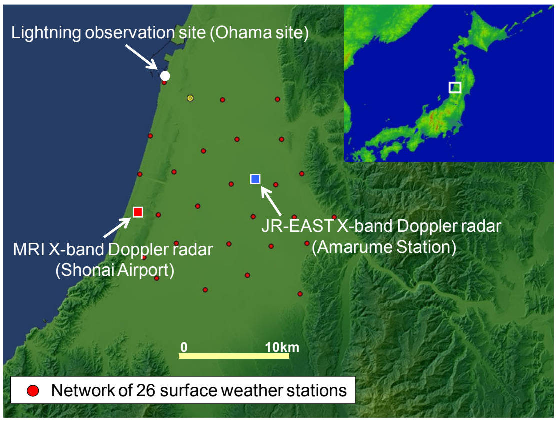

Fig. 3. Location of the observation sites in the Shonai area (the coast of the Japan Sea).

Fig. 4. Lightning observation system.

2.2 *Example of Observation Results*

Figures 6 and 7 show VHF lightning radiation sources observed at 211616 JST (121616 UTC) on 22 February 2010. The radiation sources are widely distributed from 155° to 360° in azimuth and from 0° to 80° in elevation. The cloud-to-cloud discharge occurred 116 ms after the upward leader progress. When this

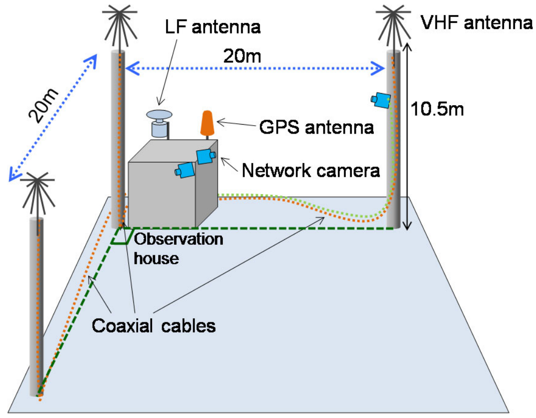

Fig. 5. Layout of the sensors at the Ohama site.

lightning was recorded at the Ohama site, the strong echo region (around 50 dBZ) was detected with MRI X-band Doppler radar at the Shonai Airport (Fig. 8). The observed lightning discharges were caused by the convective system associated with the cold front. The top altitude of the discharge estimated from the horizontal distance between the Ohama site and the strong echo (about 5 - 10 km) is consistent with the echo-top level (about 3 - 4 km) obtained by the RHI scan (Fig. 9). We consider that the lightning propagated along the edge of the echo region. This lightning was also recorded with the network camera at the Ohama site.

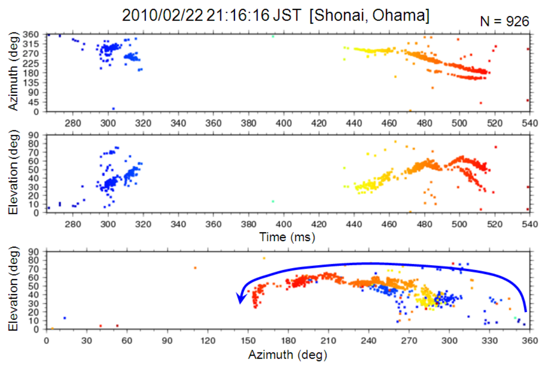

Fig. 6. Azimuth and elevation of the VHF radiation sources at 211616 JST on 22 February 2010.

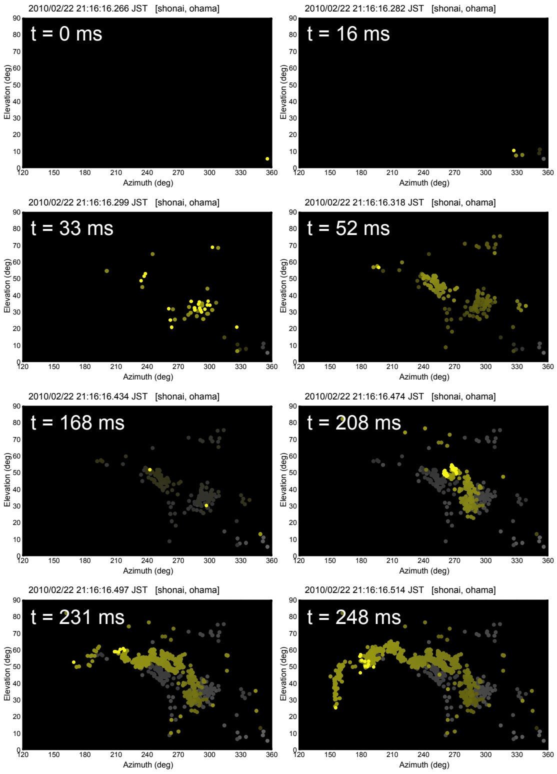

Fig. 7. Snapshots of 2D mapping at 211616 JST on 22 February 2010.

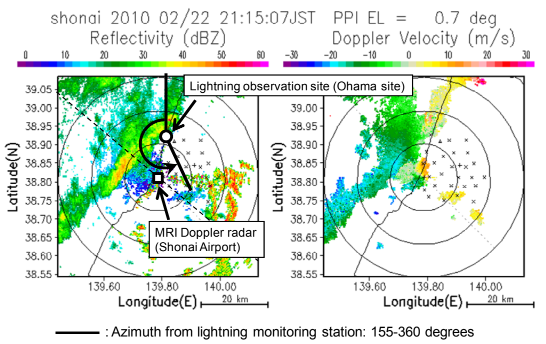

Fig. 8. Radar reflectivity and Doppler velocity observed with MRI X-band Doppler radar at 211507 JST on 22 February 2010.

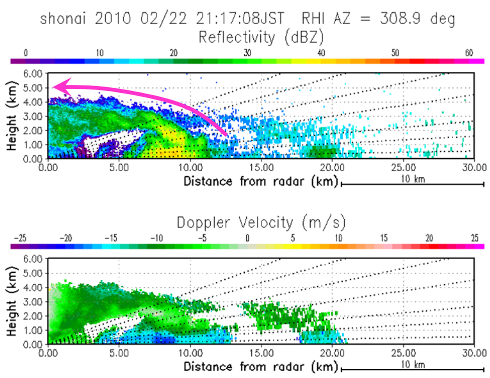

Fig. 9. RHI observation result at 211708 JST on 22 February 2010.

3. CHARACTERISTICS OF WINTER THUNDERCLOUDS

3.1 *Michimoto's Diagram*

In order to understand the characteristics of winter thunderclouds, we investigate the relationship between the echo-top (20 dBZ) temperature and the -10°C level based on Michimoto (1993). Michimoto (1993) observed the echo-top level of winter thunderclouds using meteorological radar and lightning direction finders in the Hokuriku area. He also investigated the echo-top temperature and the -10°C level using rawinsonde data obtained at Wajima observatory of the Japan Meteorological Agency (JMA). Then he proposed three criteria in the diagram (Fig. 10) to classify the lightning activity. These criteria are as follows: (A) during relatively intense lightning activity, echo-top temperature is lower than -20°C and -10°C level is higher than 1.8 km, (B) during no lightning activity or only very weak lightning activity, echo-top temperature is lower than -20°C and -10°C level is lower than 1.8 km, (C) during no lightning activity, echo-top temperature is higher than -20°C. In this paper, we plot the diagram using lightning data and radar data observed in the Shonai area and compare our result with Michimoto's diagram.

3.2 *Data and Processing*

The analyzed period is about 4 months from 30 October 2009 to 9 March 2010. During this period, 149 lightning flashes were observed at the Ohama site. We utilize the X-band radar data (PPI and RHI scan) to decide the echo-top level. If the target echo deviates from the radar beam of RHI scan, we use the echo-top level of the neighboring echo region. The atmospheric vertical profile around the Shonai area is derived from Meso-scale Analysis (MANAL) data released by the JMA. The obtained profile is average values of 9 grid points (15 km × 15 km) centered at 139.7°E, 39.0°N. The time resolution is 3 hours. We compute the echo-top temperature and -10°C level using the profile data.

3.3 *Results*

The result shows that the echo-top temperature is lower than -20°C and the -10°C level is higher than 1.7 km during relatively frequent lightning flashes (area A in Fig. 11). Meanwhile during low lightning activity, the

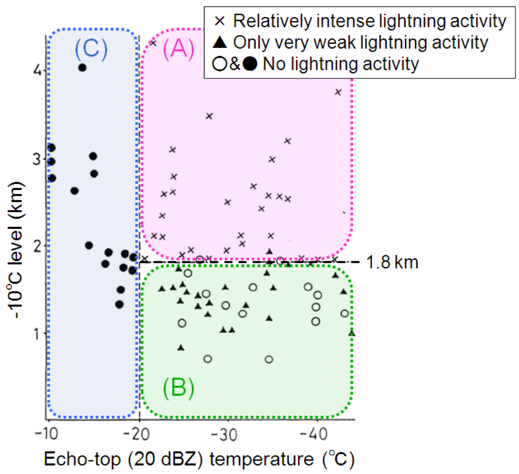

Fig. 10. The relationship between echo-top temperature and -10°C level shown by Michimoto (1993). (A) Relatively intense lightning activity (echo-top temperature ≤ -20°C and -10°C level ≥ 1.8 km). (B) No lightning activity or only very weak lightning activity (echo-top temperature ≤ -20°C and -10°C level < 1.8 km). (C) No lightning activity (echo-top temperature > -20°C).

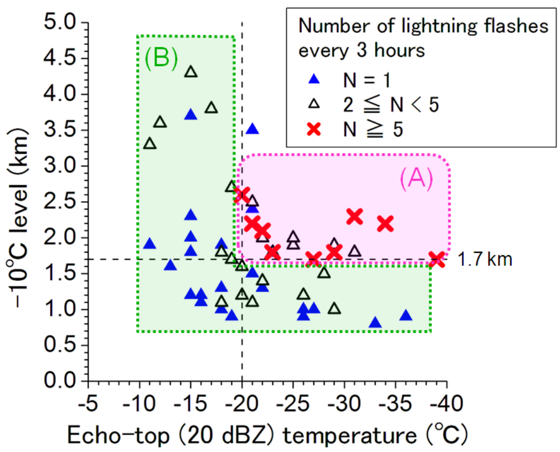

Fig. 11. The relationship between echo-top (20 dBZ) temperature and -10°C level. (A) Relatively frequent lightning flashes (echo-top temperature ≤ -20°C and -10°C level ≥ 1.7 km). (B) Low lightning activity (echo-top temperature > -20°C and/or -10°C level < 1.7 km).

different environmental conditions are shown, which are the echo-top temperature is higher than -20°C and/or the -10°C level is lower than 1.7 km (area B in Fig. 11). This result is consistent with Michimoto (1993), except during the echo-top temperature is higher than -20°C. The difference indicates that our sensor is more sensitive to weak discharges. The average echo-top level during lightning activity is 2.1 times higher than -10°C level. Hence, the atmospheric environment that echo-top level is greatly higher than -10°C level is necessary for lightning discharge. As pointed out by the rimming electrification mechanism proposed by Takahashi (1978, 1984), the process of charge separation and accumulation attributed to collisions between graupel and ice crystals around the -10°C level is important to electrical characteristics of winter thunderclouds.

4. CONCLUSIONS

This paper shows the relationship between the echo-top (20 dBZ) temperature and the -10°C level of winter thunderclouds. The lightning data and radar data observed in the Shonai area are investigated. The analyzed period is about 4 months from 30 October 2009 to 9 March 2010. The atmospheric vertical profile was derived from MANAL data. The result indicates two atmospheric conditions as follows, (A) during relatively intense lightning activity, the echo-top temperature is lower than -20°C and the -10°C level is higher than 1.7 km, (B) during low lightning activity, the echo-top temperature is higher than -20°C and/or the -10°C level is lower than 1.7 km. This result is consistent with Michimoto (1993), except during the echo-top temperature is higher than -20°C. The difference indicates that our sensor is more sensitive to weak discharges. The process of charge separation and accumulation around -10°C level is important to winter thundercloud electrification.

5. FUTURE WORK

We constructed three lightning observation sites in the Shonai area in September 2010, in order to visualize lightning discharges in three dimensions. Using the 3D lightning data, we need further analysis of winter thundercloud characteristics and relationship between winter lightning discharge and wind gust.

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