Three-dimensional characteristics of winter lightning observed in the Shonai area railroad weather project

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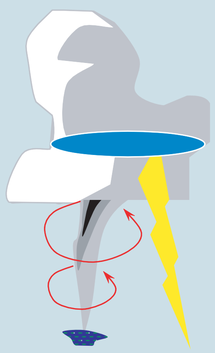
Introduction

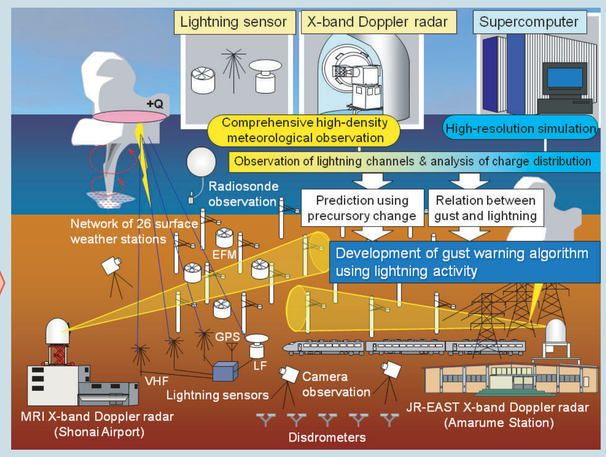


Lightning and Wind gust

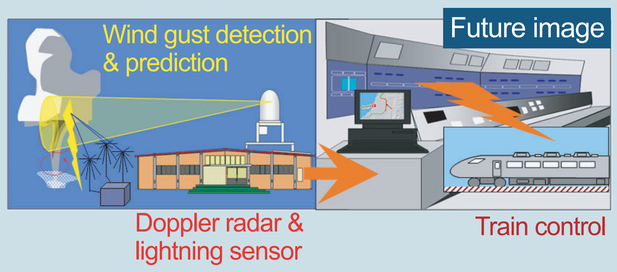
Many scientists have indicated that lightning activity is associated with severe weather (e.g., tornado, downburst, excessive precipitation, hailstorm). Therefore, integration of continuous three-dimensional (3D) total lightning monitoring (intracloud and cloud-to-ground lightning) and comprehensive high-density meteorological observation can provide useful index for predicting strong gust.

"Development of monitoring & warning system of severe weather for railroad system using high-precision sensing technology"

The Shonai area railroad weather project has investigated fine-scale structure of wind gust (vortex) using two X-band Doppler radars and the network of 26 surface weather stations since 2007, in order to develop an automatic 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 wind gust prediction.



Shonai area railroad weather project



Main subject

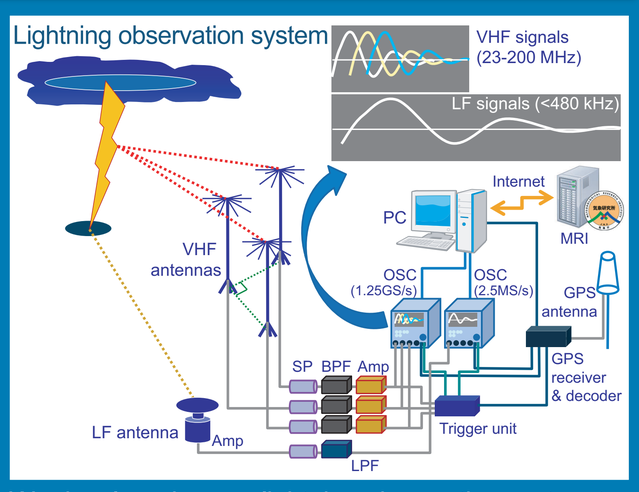
1. Development of wind gust detection system using X-band Doppler radar
2. Development of wind gust & lightning warning system using lightning sensor & X-band Doppler radar

Summary & Future plan

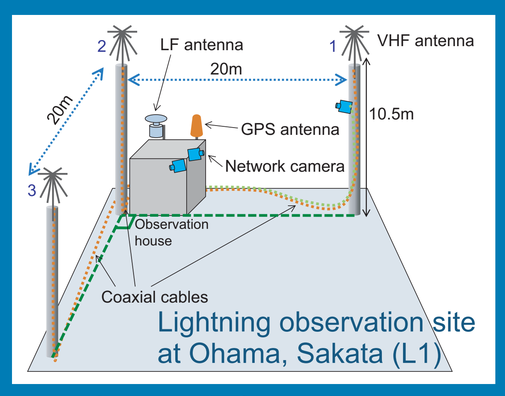
- New lightning observation system was developed in 2009 & installed in the Shonai area (coastal area of the Japan Sea) in 2009 - 2010.
- We developed a 3D mapping algorithm of VHF lightning radiation sources using forward intersection method.
- Lightning flash observed at 01:13:32 JST on December 4, 2010 (16:13:32 UTC on Dec. 3, 2010) has been visualized in 3D.
- The horizontal distribution of VHF radiation sources is consistent with the rim of the strong echo region.
- The lightning discharge started at about 2 km level (= -10 ℃ level) that electric charges accumulated.
- We investigates the relationship between the echo-top temperature & the -10℃ level of winter thunderclouds.
  The result indicates two atmospheric conditions exist as follows,
  (A) during relatively intense lightning activity, the echo-top temp. ≦ -20℃ and -10℃ level ≧ 1.7 km,
  (B) during low lightning activity, the echo-top temp. > -20℃ and/or -10℃ level < 1.7 km.
  This result is consistent with Michimoto (1993), except during the echo-top temp. > -20℃. The difference indicates our sensor is more sensitive to weak discharges. The process of charge separation & accumulation around -10℃ level is important to winter thundercloud electrification.

We need accuracy improvement of the 3D mapping algorithm & further analysis of relationship between winter lightning & wind gust.

Lightning observation system



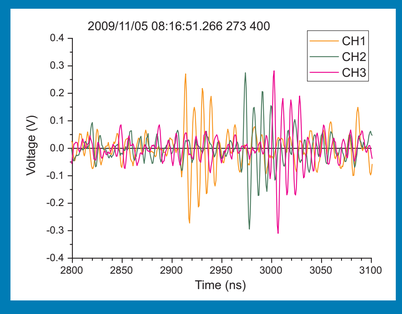
We developed a new lightning observation system to visualize VHF radiation sources. Azimuth and elevation of VHF radiation sources are computed using arrival-time differences of three VHF pulses received at three antennas in one site.



Lightning observation site at Ohama, Sakata (L1)

Observation system

Map of the Shonai area (coastal area of the Japan Sea)



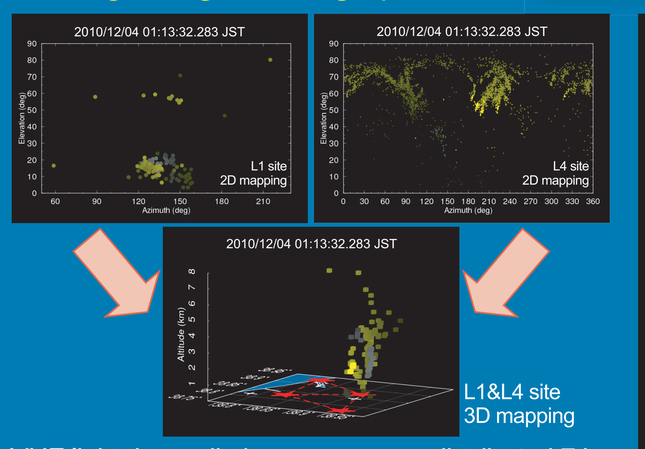
Waveform of VHF lightning pulses observed at L1

After operation test at Meteorological Research Institute (MRI), we installed this system in the north of Shonai area (L1) in October 2009. Moreover, we constructed three lightning observation sites (L2, L3 & L4) in the Shonai area in September 2010, in order to visualize lightning discharges in 3D.

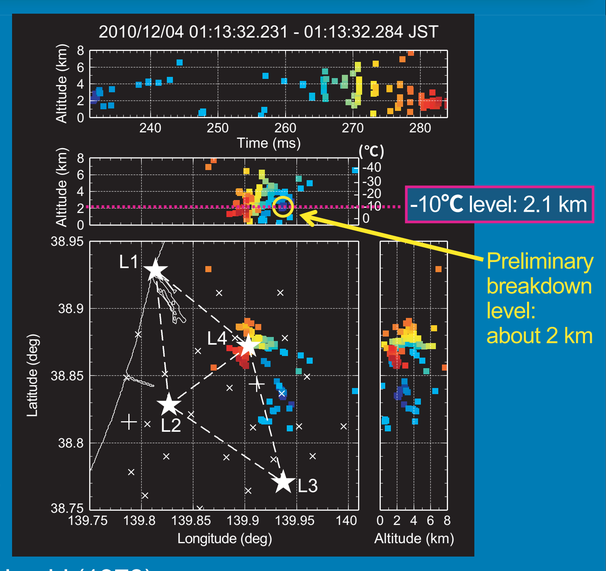
3D lightning mapping

We developed a 3D mapping algorithm of VHF lightning radiation sources using forward intersection method. This study conducts 3D mapping using 2D mapping data observed at two sites, 01:13:32 JST Dec. 4, 2010 (16:13:32 UTC Dec. 3, 2010).

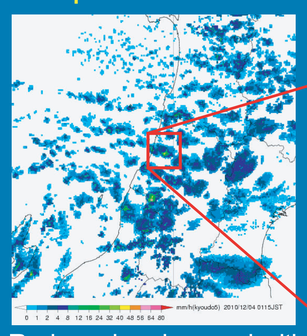
VHF lightning discharge process



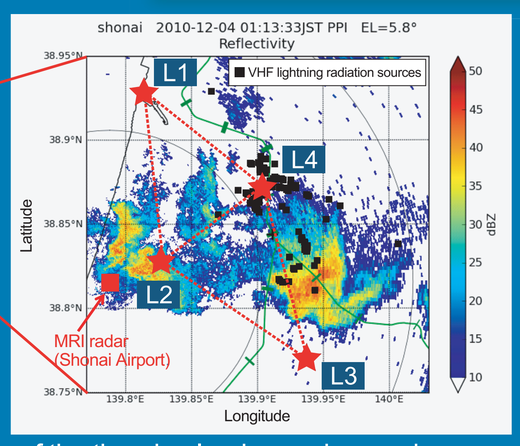
VHF lightning radiation sources are distributed 7 km in E-W, 10 km in N-S, 0-5 km in height. We consider that electric charges accumulated around 2 km level (= -10 ℃ level). This result is consistent with the rimming electrification mechanism proposed by Takahashi (1978).

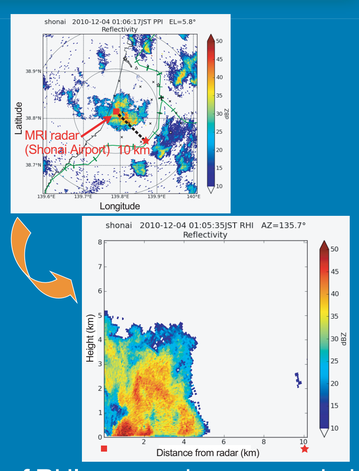


Comparison with radar echo



Radar echo observed with JMA C-band radar (2010/12/04 01:15 JST)





The detailed structure of the thundercloud was observed with MRI X-band radar. Black square shows the VHF sources observed at 01:13:32 JST on Dec. 4, 2010. The horizontal distribution of VHF sources is consistent with the rim of the strong echo region.

Result of RHI scan and corresponded PPI scan 7-8 min before the lightning. Deep convective cloud was observed. The echo-top height is 4-5 km.

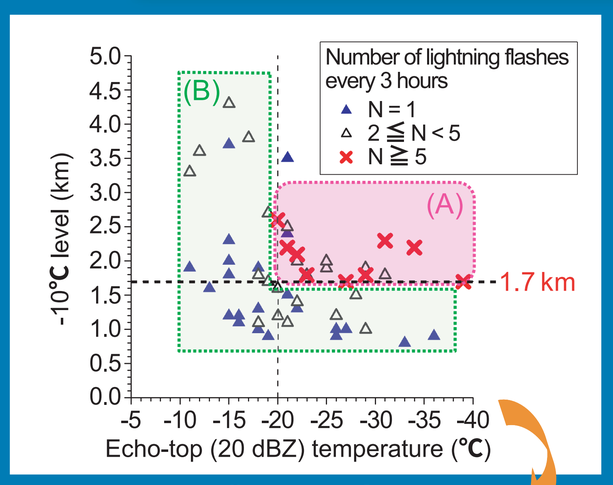
Characteristics of winter thunderclouds

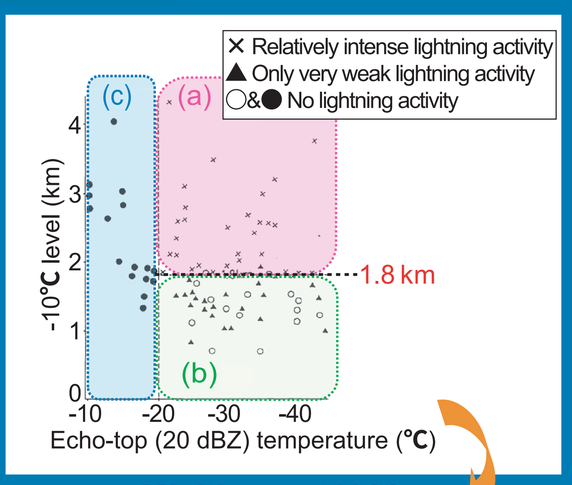
In order to understand the characteristics of winter thunderclouds, we investigate the relationship between the echo-top (20 dBZ) temperature and the -10℃ level based on Michimoto (1993).

Data

Period: 2009/10/30 ～ 2010/03/09 (about 4 months)
Data: 149 lightning flashes observed at L1 site & radar data (PPI and RHI) observed at Shonai Airport
Atmospheric vertical profile: Meso-scale Analysis (MANAL) data released by the JMA
(average values of 9 grid points (15 km×15 km), time resolution is 3 hours)

Result





Our result

(A) echo-top temp. ≦ -20℃ and -10℃ level ≧1.7 km
⇒ relatively intense lightning activity

(B) echo-top temp. > -20℃ and/or -10℃ level < 1.7 km
⇒ low lightning activity

Michimoto (1993)

(a) echo-top temp. ≦ -20℃ and -10℃ level ≧1.8 km
⇒ relatively intense lightning activity

(b) echo-top temp. ≦ -20℃ and -10℃ level < 1.8 km
⇒ No lightning activity or low lightning activity

(c) echo-top temp. > -20℃
⇒ No lightning activity

Our result is consistent with Michimoto (1993), except during the echo-top temperature is higher than -20℃. 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℃ level. The atmospheric environment that echo-top level is greatly higher than -10℃ 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℃ level is important to winter thundercloud electrification.