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Review of recent progress in lightning and thunderstorm detection techniques in Asia

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ABSTRACT

In recent years, lightning and thunderstorm detection techniques have been rapidly developed in many regions of Asia. As the most populous continent, hazards caused by lightning and related phenomena are being paid more and more attentions and lightning observations and detections are booming in many countries. In this paper, we will give a brief review on recent progress of lightning and thunderstorm detection techniques in Asia. First, we will introduce several widely used lightning location systems including VHF interferometers, VHF time-of-arrival systems and LF time-of-arrival systems. As an example, a newly-developed system called BOLT is described and recent observation results are introduced. Second, we will review studies of a special type of intracloud discharge called "narrow bipolar event" (NBE). NBE studies in Asia are flourishing in recent years and are making great contributions to the understanding of various properties of NBE. Finally, we will introduce a fast-scanning phased array radar (PAR) system installed in Osaka University. This radar system has a temporal resolution of 10–30 s, which is much faster than the traditional weather radar and is ideal for observations of fast-evolving storm structures and the analysis of their relationship with lightning activities. Preliminary observation results with PAR are described.
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Contents

1. Introduction

It is well known that thunderstorms are often accompanied by various severe weather phenomena such as tornadoes, hails, floods, lightning flashes and so on. These phenomena pose great threat to our lives particularly in densely populated area and the number of such phenomena tends to increase as a result of global warming. One of the best ways to observe

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thunderstorm and its related phenomena (e.g. lightning) is through remote sensing using electromagnetic wave technology.

As a result of the recent advances on information and communication technology, rapid scanning technologies have been developed and applied to the radar remote sensing studies. One typical example of such innovations is the development of the phased array radar (PAR) system. As is well known, lightning-producing thunderstorm and its related phenomena such as tornadoes, squall lines, flash floods etc. evolve rapidly and locally (Liu et al., 2013), and cannot be fully resolved by the conventional S or C band Doppler weather radar system with large antenna. In order to discuss the relationship between the structures of thunderstorm and lightning discharges, rapid scanning radar like PAR is required, and a new PAR system for thunderstorm observation has been developed by Toshiba Corporation and Osaka University under a grant of National Institute of Information and Communications Technology (NICT), and recently installed in Osaka University, Japan in 2012.

On the other hand, lightning emits broad range of electromagnetic waves and by analyzing the time variation of intensity at electromagnetic waves we can know the physical process of lightning (Cui et al., 2009; Xie et al., 2013). In particular, the information on the location where the lightning occurs is very important for the electrification studies inside thunderstorm (Qie et al., 2009a; Zhang et al., 2009; Li et al., 2013; Makela et al., 2014) and the consideration of the cause of damages due to lightning (Zhang et al., 2014). In such a way, lightning location systems have been installed in many countries all over the world and their data have been widely used in power electric companies, meteorological organizations, and space agencies.

Recently a special type of intracloud discharge called narrow bipolar event (NBE) has been reported and attracting wide attentions. This unique event has different characteristics from well known intracloud pulses, and has been reported to be correlated with convective activities inside thunderstorm. Furthermore, NBEs tend to be isolated with other lightning discharges and potentially useful for monitoring thunderstorms. However, statistical studies on the characteristics of the NBEs are not so many and what type of thunderstorm produces them is not clear. In order to discuss such connections, a new lightning location system, called Broadband Observation network for Lightning and Thunderstorm (BOLT) has been developed in Osaka University, Osaka, Japan.

In this paper, new remote sensing techniques for weather radar and lightning location systems are reviewed. In Section 2, recent progress of lightning observation system in Asia, including the BOLT, is introduced. In Section 3, recent studies related to NBEs in Asia are reviewed. In Section 4, the fast scanning PAR and the recent observation results are described.

2. Recent progress of radio location system for lightning discharges in Asia

Lightning is one of the most powerful and spectacle natural phenomena. It is well-known that lightning discharges produce broadband electromagnetic radiation ranging from a few Hz to several GHz. To obtain clear two-dimensional (2D) or three-dimensional (3D) images of whole structure of both cloud-to-ground (CG) and intracloud (IC) discharges, several types of lightning mappers in VHF and LF bands have been designed and developed in Asia. In this section, recent development of lightning mappers in VHF and LF bands is reviewed and, lastly, our newly-developed 3D LF lightning locating system, called BOLT, is introduced.

2.1. Major progress of VHF lightning mappers in Asia

A research group in Osaka University in Japan has played an important role in designing and developing VHF broadband digital interferometers (DITF) (Ushio et al., 1997; Kawasaki et al., 2000; Mardiana and Kawasaki, 2000). The VHF DITF requires at least two pairs of antennas spaced about 10 m apart. The basic idea of the VHF broadband interferometry is to calculate phase difference of the pairs of antennas that lead to incident angles against the antenna pairs. Arrival angles in azimuth-elevation format are estimated by two or more incident angles estimated in the pairs. Simultaneous observation of two or more VHF DITF produces 3D VHF images using triangulation (Morimoto et al., 2005). The VHF DITF described by Ushio et al. (1997) consisted of flat plane antennas having a pass-band of 10 MHz to 200 MHz and the signals were recorded at a digital oscilloscope with a sampling rate of 500 MS/s. Ushio et al. (1997), observing rocket-triggered lightning that began as an upward negative leader, confirmed that the first radiation source located by the VHF DITF was near the rocket launcher. Morimoto et al. (2004) and Morimoto et al. (2005) designed an analog-to-digital converter (ADC) and an amplifier specialized for the VHF DITF to improve the performance of the system.

The research group of Osaka University conducted observation campaign in many places, including Darwin, Australia, and the coastal area of the Sea of Japan (Kawasaki et al., 2002; Kawasaki et al., 2000). These observations revealed characteristics of K-process (Akita et al., 2010), relationship between lightning leaders and charge structure within thunderstorms (Akita et al., 2011), and characteristics of descending negative leaders close to the ground (Yoshida et al., 2012a). They also conducted rocket-triggered lightning observation campaign in Florida, USA, with a use of the VHF DITFs, succeeded in locating 3D upward positive leaders of the rocket-triggered lighting (Yoshida et al., 2010). Further, they showed that IC discharges or negative recoil leaders could initiate initial continuing current pulses in an initial stage in triggered lightning (Yoshida et al., 2012b).

An international collaborative research between Osaka University and New Mexico Institute of Mining and Technology improved greatly the VHF DITF developed by the research group of Osaka University (Morimoto et al., 2005) and observed lightning discharges with an “upgraded VHF digital interferometer” system (Akita et al., 2014). The basic configuration of the upgraded VHF DITF was the same as conventional VHF DITFs described in Morimoto et al. (2005) except for a digitizer with extremely large memory allowing to store continuous VHF radiations associated with lightning for 2 s or longer. The upgraded VHF DITF consisted of identical three VHF antennas having frequency respond ranging from 20 MHz to 80 MHz that were deployed at apexes of a right triangle. The signals from the antennas were digitized with a sampling rate of 180 MS/s and vertical resolution of 16 bit. They estimated VHF sources in 2D for every 128 sample points (711 ns) with

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