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The Jianghuai Area Sferic Array: Some Applications

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***Abstract*—In this presentation we introduce a newly developed local network capable of continuous detection of lightning activities at Jianghuai Area in central China, which was called the Jinghuai Area Sferic Array. The network consists of six stations separated at a baseline of 150-300km and was featured by real-time, continuous recording of lightning-produced electromagnetic pulse waveforms in VLF/LF band with no dead-time. We use the time of arrival (TOA) technique to give the 2-D locations of those lightning events which were recorded synchronously by more than 3 stations. The network was originally deployed to study the distinct compact intra-cloud discharge(CID), and we will give in brief our observations of temporal contexts of CIDs to normal lightning discharges. With the detailed waveforms of lightning discharges recorded by the network, it is of potential to give properties of cloud to ground discharges by accurate-stroke-count studies. By analyzing the ionosphere reflected waveforms of located lightning return strokes, the network can serve as a potential research tool for studying the lower ionosphere.**

Keywords—lightning detection network, return strokes, compact intracloud discharges, the lower ionosphere, time of arrival technique

I. INTRODUCTION

Since 2011 we have established a 6-station lightning detection network in Jianghuai Area in the central China, which was called the Jianghuai area sferics array (JASA) in this presentation. JASA was originally deployed to survey the meteorology activities of a distinct type of lightning discharges called compact intra-cloud discharges(CID) some authors or Narrow bipolar events(NBEs) by some other authors[e.g., Smith et al.,1999;Nag et al.,2010;Wu et al.,2012]. In order to achieve this goal, the system must meet the following requirement in three areas.

First, JASA has the ability to continuously record signals from lightning discharges with no-dead time, in an attempt to technically reduce the risk of missing CIDs occurring in thunderstorms interested. A software-based solution in conjunction with a high performance digitizer with FIFO enables us to automatically and continuously record up to three signals each at a sampling rate of 5MHz. Electric radiation field of lightning discharges in VLF/LF band (800 Hz-400 kHz) along with magnetic radiation field components, whose amplitude exceeds the software-adjustable preset threshold, will be registered as a triggered event and saved in data fragment of 1.6 ms in length.

Secondly, JASA has the ability to locate the triggered lightning events, which will help group CIDs and normal lightning discharges from different individual thunderstorms. We set up as many as 6 spaced stations (with a baseline of about 200 km) and each station was equipped to time-stamp the triggered event via a GPS receiver at an accuracy of better than 0.1 us. For those triggered events which were synchronously recorded by three stations or more, their 2-D locations were achieved by using the time-of-arrival technique.

Thirdly, LASA has the advantage of post-processing data. Waveforms of electric and magnetic fields of lightning discharges during the whole life cycle of thunderstorms were recorded and saved locally at multiple stations. One can base on time-varying waveforms measured at one station or multiple stations to develop and testify certain algorithms for some specific scientific purposes, for example, algorithms to discriminate CIDs with normal lightning discharges.

In short, JASA has the ability to continuously record electric and magnetic fields of lightning discharges and has the capacity in locating lightning events, similar to those systems for specific scientific purpose [e.g., Smith et al., 2002]. It is of potential to use JASA as a research tool by analyzing record time-varying waveforms of lightning discharges. In this presentation we will demonstrate in brief three applications of JASA.

II. OPERATION AND DATA

In 2011 we set up six stations at Huangshan (HS), Hefei (HF),Jinzhai (JZ), Shouxian (SX), Mengcheng (MC) and Nanjing (NJ). Each station was equipped with a VLF/LF receiver which consists of a vertical electric field antenna and two orthogonal magnetic field loop antennas, all having the frequency bandwidth from 800 Hz to 400 kHz. At SX station, an additional VHF receiver (from 112.5 MHz to 117.5 MHz) was employed for better identification of CIDs associated with powerful VHF emissions. At the central HF station the gain of the VLF/LF receiver was purposely set higher than other five stations, in an attempt to recognize as weak lightning signals as possible from distant thunderstorms and ensure a high detection efficiency of lightning discharges for JASA. Please refer to Qin et al. [2015] for configuration of JASA.

During the field campaign in 2012, more than eight mass thunderstorms occurring in Jianghuai area of Anhui province, where JASA was located. We have developed an algorithm to precisely recognize CIDs (and also return strokes) based on electric field waveforms observed at the central HF station. The algorithm was carefully testified and validated by cases associated with VHF emissions recorded at SX station. Fig.1 illustrated examples of VLF/LF bipolar waveforms produced by a typical positive CID.

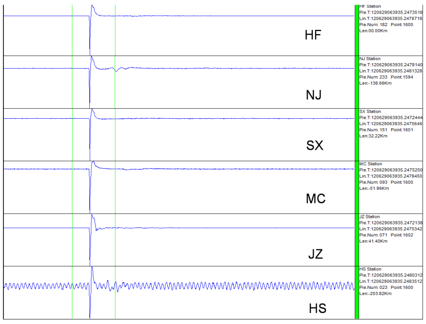

Fig. 1. Examples of VLF/LF electric fields observed at different stations for a positive CID,which occurred about 115 km away from HF station.

III. APPLICATIONS

A. *The temporal context of CIDs to normal lightnig discharges*

By applying our CID identification algorithm to raw data observed at central HF station during eight thunderstorm days, overall 21257 CIDs were identified and geo-located at a distance to HF station from several tens of kilometers to as far as 500 km. Among these CIDs about 9.6%(2039/21257) were negative CIDs, while the portion of negative CIDs with respect to all CIDs in the individual thunderstorm ranged from 5.9% to 16.1% respectively. It implied that both positive CIDs and negative CIDs can occur frequently in the relatively lower latitude regions (~30° N).

Meanwhile, normal lightning events were also discriminated and located in 2-D (if possible). It provided us an opportunity to study the temporal context of CIDs to normal lightning discharges on a statistical basis. For located CIDs, normal lightning events within 500 ms before and 500 ms after that CID were located and grouped into flash(es) with respect to their occurrence locations. Normal lightning events within 200 km from HF station were grouped into a flash only when they were within 5 km from each other, and normal lightning events within 300km from HF station were grouped into a flash only when they were within 10 km from each other, and 15 km for events within 400 km from HF station and so on, in view of different location errors for registered events with respect to distance from HF station. It is worth noting that the 'flash' in this article was not the same as 'cloud to ground flash' or 'intra-cloud flash' reported by some commercial lightning location systems, rather it was possible to be an intra-cloud flash, or a cloud-to-ground flash, or a combination of cloud-to-ground flash and intra-cloud flash in nature.

As to the temporal context of CIDs to normal lightning discharges, CIDs were classified into four groups according to the relative position of 'flash' occurring within 500 ms before or after a CID: (1) solitary CIDs(S-CIDs)，which were not followed or proceed by any 'flash' within a range of 50 km from the CID, (2) precursor CIDs, which were followed by a 'flash' within a range of 50 km, as if they initiated the following flash, (3) accompanying CIDs(A-CIDs), which occurred after the spatial correlated flash had initiated, (4) two or more CIDs were spatially and temporally clustered close to each other (e.g.,Nag et al.,2010), which were termed clustering CIDs(C-CIDs). Fig. 2 illustrated a precursor CID which occurred at the beginning of an intra-cloud discharge and was within 2 km from the succeeding incloud events (labeled IC in the Figure).

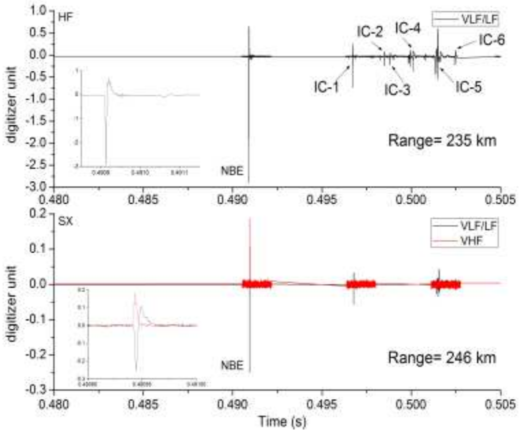

Fig. 2. Examples of a precursor CID, which was followed by an intracloud discharge.This CID was associated with obviously VHF emission(red in the figure) observed at SX station. The first incloud event(IC-1) was about 2 km away from the preceeding CID (labeled NBE in the figure).

To study the temporal context of CIDs to normal lightning discharges, we chose only those CIDs which were within 300 km from HF station to ensure a better detection of normal lightning flashes by JASA. A summary of different types of CIDs in five such thunderstorms was illustrated in Table 1. As can be seen in the table, each type of CIDs can occur in all of five thunderstorms and their proportions with respect to all CIDs in the parental storm varied from storms to storms. In case of precursor CIDs, the space interval between CIDs and the succeeding first Intra-cloud event averaged 3.1 km (median value of 1.5 km) and the time interval averaged 185 ms (median value of 65 ms). Since CIDs and successive intra-cloud events were close related in time and space, we inferred that precursor CIDs were likely to associate with the initiation of the lightning flash, which was in agreement with Rison et al.[1999].

It is interesting to note that, solitary CIDs and precursor CIDs altogether comprised the majority of CIDs in each thunderstorm, with the percentages ranging from 74% to 85% for a single thunderstorm and 84% for all five thunderstorms. If solitary CIDs were taken as failed precursor CIDs, that is to say, solitary CIDs failed to initiate the normal lightning flash as precursor CIDs were supposed to do, we inferred that CIDs were likely to favor conditions before lightning flashes were initiated, hence CIDs were less likely to occur after the lightning flash had initiated, as for the small percentage for A-CIDS in Table 1.

Table1. A summary of different types of CIDs in five thunderstorms.

Storm	Total CIDs	S-CIDs	P-CIDs	A-CIDs	C-CIDs
0629	1637	538	817	183	99
0701	1566	583	745	182	56
0703	1255	542	391	274	48
0706	3556	1321	1762	335	138
0708	641	380	153	90	18
Total	8655	3364	3868	1064	359

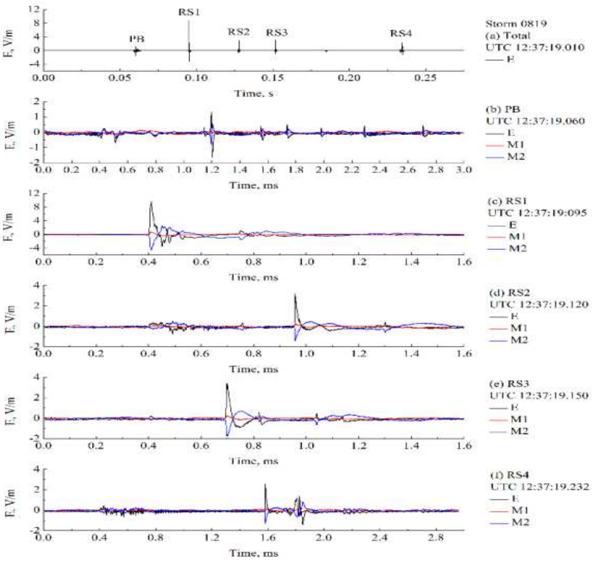

Fig. 3. Consecutive records of preliminary breakdown (PB) and four return strokes(RS) for a cloud-to-ground flash which occurred 112 km from HF station of JASA. Time expansion waveforms of electric field(E) and magnetic fiend compenent(M1,M2) were also shown.

B. *Accurate-stroke-count study on characteristics of cloud-to-ground flashes*

It is generally believed that accurate-stroke-count studies have the low probability to miss return strokes and enable better statistics for lightning properties [Rakov and huffiness, 2003]. JASA has the ability to continuously record electric field waveforms of lightning discharges with no-dead time, which provides an opportunity to study characteristics of cloud-to-ground flashes based on accurate-stroke-count studies, in that one can precisely identify return strokes by careful examination of their electric field waveforms in consecutive records and group them into individual CG flashes manually. Figure 3 gave an example of a four-stroke cloud-to-ground flash recorded at HF station of JASA. In practice, we took full account of the characteristic waveform of preliminary breakdown, stepped leader/initial return stroke,dart leader/subsequent return stroke and their temporal contexts to enhance flash data. Since JASA can uninterruptedly record entire lightning discharges during thunderstorms, it is promising to report properties of CG flashes on a thunderstorm basis, achieving a high reliability on data representation. JASA observations of all negative CG flashes from a local thunderstorm were presented in Zhu et al.[2015]

C. *Detecting the lower ionospheric layer*

There exist great difficulties in remote sensing of the lower ionosphere since VHF/HF operating signals used in conventional ionosphere sounding apparatus suffer weak reflection due to the relatively low electron density in this ionosphere layer. However this layer is a good reflector for VLF/LF radiations, and a new sounding technique basing on the powerful very low frequency (VLF) radiation emitted by lightning discharges is under developing[e.g.,Lay and Shao, 2013]. A promising usage of JASA is to monitor the fluctuation of the lower ionosphere to use the lightning electromagnetic field waveforms and their ionospheric reflecting waveforms recorded during the whole life cycle of thunderstorms. Both return strokes and CIDs can be used, and elevated CIDs will produce a pair of ionosphere reflects comparing with only one reflection for return strokes ,as can be seen in Fig.1 and Fig.3. The delay time(s) for ionospheric reflects varied with changing source location and the reflecting height of ionosphere. Once the source location as well as the delay time of ionospheric reflects were obtained from JASA data, variations of the reflecting height of ionosphere with can be obtained [Qin et al.,2015].

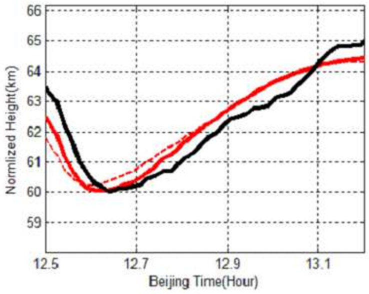

Fig. 4. Variations of reflection heights of ionosphere (black) derived from electric field waveforms of return strokes observed by JASA and associating solar x-rays density (red,log scale in arbitary units,downward for larger value) during the period of a solar flare on July 4,2012.

Fig.4 illustrated our observations of the fluctuation of lower ionosphere during the period of a solar flare. The low ionosphere layer was sensed in terms of the reflecting height for VLF/LF waveforms of return strokes. The solar X-ray flux (solid red for frequency range of 0.1-0.8 nm and dash red for 0.05-0.4 nm), was recorded by GEOS-15satellite (http://www.ngdc.noaa.gov/stp/satellite/goes/). The X-ray flux was in logarithmic scale and was linearly scaled to reflecting height in Fig.4. As can be seen in the figure, the solar X-ray flux changed suddenly and rapidly during the period of flare, and the low ionosphere responded markedly as the reflection height decreased with the increasing X-ray flux and vice versa. However the lower ionosphere seemed to respond to the solar flare with about 2-3 minutes delay.

IV. CONCLUSIONS

We have developed a local observation network which is capable of recording VLF/LF electromagnetic field waveforms of lightning discharges with no-dead time at different GPS-synchronized stations. By post-processing full waveform data under different specific algorithms, it is promising to take JASA as a research tool not just monitoring of lightning activities.

We have demonstrated the potentials of JASA in studying meteorological properties of lighting discharges. By using the algorithm developed to precisely identify CIDs, a distinct type of lightning discharges which was not well discriminated by many commercial lightning location system, the temporal context of CIDs to normal lightning discharges was studied on a statistical basis. It was interesting to find that, the great majority (84%) of CIDs occurred in isolation, or occurred just as the very beginning of normal lightning discharges, showing a tendency to reject the electrical environment after a lightning discharge had initiated. By manually grouping individual return strokes into flash, it is expected to present accurate-stroke-count studies on CG flashes with a high reliability on data representation.

We have also demonstrated the potential to probe the lower ionosphere by using data collected by JASA. Lightning discharge waveforms in VLF/LF band can be reflected by the lower ionosphere, thus it provides a feasible and physical way to study the lower ionosphere variations from the time-coherent lighting data. A case study based on JASA raw data in association with solar x-ray data suggested that, the solar flare will cause significant modifications of the lower ionosphere in about 2-3 minutes. It is expected to carry out more case studies in the future to clarify how the low ionosphere responds to the solar flare.

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