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Development Progress of Dual-band Lightning Locating System

Wansheng Dong, Hengyi Liu
Laboratory of Lightning Physics and Protection Engineering, State Key Laboratory of Severe Weather
Chinese Academy of Meteorological Sciences
Beijing, China
dongwsh@camscma.cn
liuhy@camscma.cn

Abstract*—the dual-band lightning locating system (DULLS) which works in VHF and VLF/LF bands synchronously and uses TDOA method to locate lighting discharges was introduced in this paper. The system currently consists of 14 dual-band sensors deployed over an area about 100km in diameter in Chongqing China, can describe the lightning activity of a thunderstorm continuously, images the structure of lightning discharges in 3D and records the waveforms of lightning radiations at two bands. The time resolutions of the location results in VHF and VLF/LF bands are 100 µs and 1ms respectively. The location accuracy of DULLS is better than 200 m within the coverage of the sensors according to a Monte Carlo simulation running at an altitude of 7 km. The observation results of the thunderstorm occurred on 30 August 2014 were shown here. It was seen that both of the location results of the two bands could describe and track the lightning activity in the thunderstorm, although there was also some difference between them. When the dual-band location results were used to describe the structure of a flash, it could be seen that most of the VLF/LF sources overlapped with VHF sources. The combination of the observations in two band are helpful to describe a lightning more integrally.

Keywords-lightning locating system; 3D lightning locating; VHF lighning locating; VLF/LF lighting locating; total lightning locating

I. INTRODUCTION

The characteristics of lightning activity could be related to the dynamic features and microphysical processes in thunderstorm. From one aspect, the observation of lightning can give us some insight into the evolution of the electrical structure, dynamic process and cloud microphysical process in thunderstorm. In addition, lightning is an important phenomenon in severe weather, the study on lightning detection can contribute to the monitoring and warning of weather disaster. The lightning locating systems are usually divided into VLF/LF system and VHF system based on the different receiving frequency. It is generally thought that, the lightning location results in VLF/LF band are mainly related to the lightning discharges producing long scale current surges, and those in VHF band are good at describing the breakdown processes occur over short distances. Therefore, most of the exiting VLF/LF lightning locating systems were designed for locating return stroke and the IC processes have pulse-type waveforms in 2D or 3D to track thunderstorm, and could provide the information about the type and strength of lightning discharge [1-3]. The exiting VHF mapping systems could produce detailed path of lightning discharges, which could be used to infer the charge structure of a thunderstorm and its evolution [4-7]. Some of VLF/LF network also could give a 3D lightning images that were remarkably similar to those created by VHF mapping systems, but the link between the two kinds of lightning location results were still needed to determine [8-11]. Both lightning locating results of the two kinds of systems are highly complementary, the combination of which would be helpful to study lightning and related physics. But by now there was no lightning locating system could describe the lightning activity of a thunderstorm synchronously and continuously in both of VLF/LF and VHF bands.

The technology used to locate lightning discharge could be roughly divided into two main categories: time difference of arrival (TDOA) method and direction finding (DF) method. Since the location accuracy of TDOA system have been improved a lot by utilizing Global Positioning System (GPS), TDOA technology has been adopted by more and more lightning locating systems in recent years. In VLF/LF band, TDOA technology have a better location accuracy than magnetic direction finding (MDF) method and could be used to locate intra-cloud lightning discharges. In VHF band, the exciting TDOA systems can locate lightning discharges in 3D with tens of microsecond time resolution, which have a better three-dimensional location accuracy and more continuous observation than the interferometric systems.

Recently, a dual-band lightning locating system was designed and deployed in Chongqing China. DULLS was upgraded from the original VLF/LF network [12], worked in VLF/LF and VHF bands synchronously, used high stability GPS modules for timing and TDOA method for 3D locating, could identify the type of lightning and provide some physical parameters such as the polarity and strength of a discharge. This system and some preliminary observation of that would be introduced later in this article.

II. INSTRUMENTS AND DATA

As shown in Fig. 1(a), the dual-band sensor includes two parts: receiving and acquisition. The VHF receiving module is comprised of a broadband VHF antenna and a VHF receiver. The frequency range of the VHF antenna is 100~500MHz. The bandwidth of the VHF receiver is 6 MHz, the center frequency of which can change from 30 to 300 MHz with a step size of 1 MHz. The center frequency used in Chongqing is 266 MHz to decrease electromagnetic interference. The VLF/LF receiving module is a fast electric field change meter with a decay time constant of 1 ms, consist of a metal plate and a VLF/LF receiver. The acquisition module is made up of a high-speed A/D card with 14 bits resolution, a GPS receiver and a computer. The VHF and VLF/LF signals are continuously digitized by segments at a sample rate of 20 MHz and 5 MHz respectively. The segment lengths of the two channels are 25000 and 5000 samples respectively. Each sensor is GPS time synchronized with an accuracy better than 100 ns. The data provided by each site include two categories, original waveforms and detected waveform parameters. The waveform data is comprised of the waveforms and the time information of the two bands. The parameter data are extracted in real time, include peak value of pulse, time information and the waveform features of VLF/LF signal. The sizes of the windows used for extracting parameters from VHF and VLF/LF signals are 100 μs and 1 ms respectively. When the system is working, the parameter data will be saved at first then the waveform data are saved as much as possible to keep the system running properly. TDOA technology is used to locate the sources of the VHF and VLF/LF signals. The type of lighting is classified automatically by a procedure. One by one, the procedure examines the largest pulse in each of VLF/LF waveform segment. The features such as rise time, fall time, pulse width and signal-noise ratio are extracted to identify return stroke or NBEs from the other intra-cloud events.

Fig. 1(b) gives the layout of the sensor network deployed in Chongqing and the vertical estimated errors of VHF locations at the altitude of 7 km simulated by Monte Carlo method when error of timing is set to 100 ns. The simulation results of VLF/LF location errors are about double values of VHF results for using a 200 ns timing error. This dual-band sensor network was upgraded from the original VLF/LF network from January 2014, was made up of 14 dual-band sensors. The maximum of site spacing is about 128 km and the minimum of that is about 10 km. Data are sent back to data processing center via Internet. According to the simulation results, it is thought that the error of DULLS is better than 200m in the area covered by the sensor network.

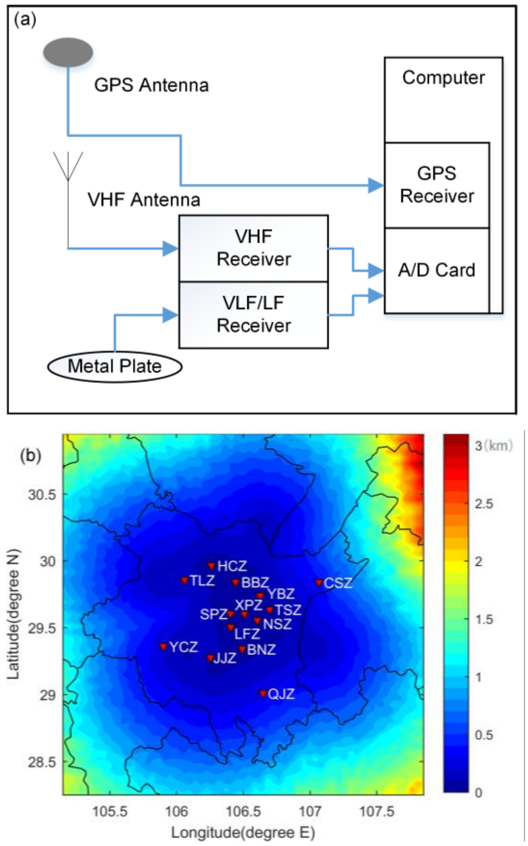

Figure 1 (a) hardware constitution of DULLS, (b) layout of the sensor network and vertical estimated errors at the altitude of 7 km given by a Monte Carlo simulations

III. OBSERVATION RESULTS AND ANALYSIS

Fig. 2 shows the densities of VHF and VLF/LF source altitudes and flash rates as a function of time in the thunderstorm occurred on August 30, 2014. The lightning observation of the thunderstorm began at August 30, 2014, 19:40, was about 40 km from the southwestern edge of the sensor network. After about 6 hours of developing, the active lightning-occurring area of the storm moved into the region covered by sensors from southwest to northeast at about August 31, 02:00, the activity of which gradually increase and leaved this area at about 05:00. Fig. 2 (a, b) give the densities of VHF and VLF/LF source altitudes versus time respectively. The spatial resolution of VHF source distribution is 100 m, that of VLF/LF source distribution is 1000 m. The temporary resolution of the two plots are 1 minute. In the two plots, the colors are used to show the number of the discharge events per minute at a given height. Fig. 2(c) gives the flash rates of negative cloud-to-ground lightning, positive cloud-to ground lightning and intra-cloud flash as a time function.

As shown in Fig. 2, the distributions of the sources of VHF and VLF/LF bands were comparable in the whole thunderstorm, but there was still some difference between them. From 19:00 to 1:00 the next day, the VHF sources mainly distributed in the

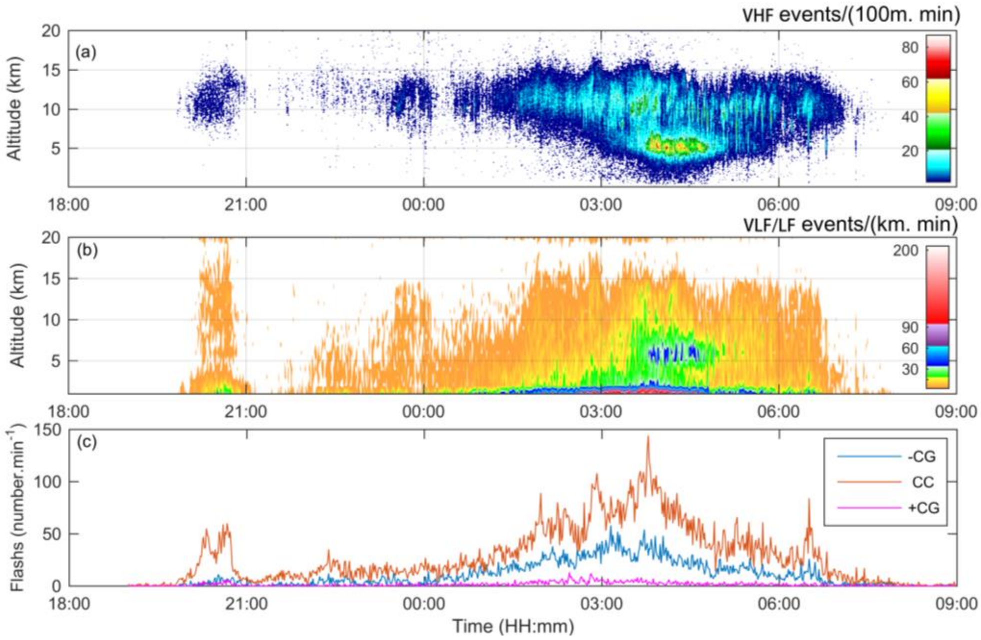

Figure 2 Densities of VHF and VLF/LF source altitudes and flash rates as a function of time in a thunderstorm occurred on August 30, 2014

altitudes of 5~15 km, centered around 10 km; the VLF/LF sources mainly occurred below 5 km, thinly occurred in the altitudes of 5~15 km, centered below 1 km. From 1:00 to 3:00, the distributions of VHF and VLF/LF sources were nearly unchanged, while the lightning activities were increasing. The lightning activities became intense from 3:00 to 6:00. During this time, the region of high VHF source density around 10 km were still existed and growing strong, while another strong lightning intensity core generated around 5 km altitude and gradually became the region of the highest lightning discharge density in this storm. Accordingly, a region of high VLF/LF source density also appeared in the meantime, but the highest VLF/LF source density was still below 1 km altitude. It is thought that the VHF radiation of negative breakdown process is more noise than that of positive breakdown process, thus the region of high VHF radiation source density can partly reflect the position of positive charge center in a thunderstorm. Hence, the distribution feature of the VHF radiation sources in this thunderstorm may indicated that the main positive charge center was at an elevation of about 10 km before 03:00, then a new positive charge center appeared at a height of about 5 km. According to this instance, the VHF location results mainly reflect intra-cloud discharges; the VLF/LF location results mainly reflect return stroke, while also describing some intra-cloud discharges.

Fig. 3 shows the composite radar reflectivity and dual-band lightning location results within a radar scanning time at August 31, 04:36, in which the radar reflectivity is moving from southwest to northeast. The black and blue points represent VHF and VLF/LF radiation sources respectively. As shown in Fig. 3 (a), both VHF and VLF/LF radiation sources occurred in the strong echo region in the front of the storm, covering almost the same region. Fig. 3 (b) shows a profile of the radar reflectivity and the lightning location results within 1 km of the profile. According to this figure, VHF location results were mainly above 3 km, clustered at the altitude of 5 km; VLF/LF location results occurred at several altitude levels, relatively concentrated below 1 km. These distribution features are consistent with the cases in fig. 2.

Besides giving the distribution of lightning activity continuously and tracking thunderstorm, DULLS also can describe the time-space evolution of a lightning by using the dual-band location results and the waveforms recorded by the sensors. Fig. 4 gives the IC flash occurred at August 31, 04:38:20 including the fast electric filed change waveform (Fig. 4a) and the dual-band 3D location results (Fig. 4b~f). Physics sign convention for electric field change polarity is used throughout this paper, that means a negative cloud-to-ground return stroke produces a negative polarity electric field change signal. The colored scatters and gray diamonds represent VHF and VLF/LF location results respectively. Fig. 4(b) gives the source altitudes as a function of time. The east-west vertical view, plan view and north-south vertical view of DULLS sources are shown in Fig 4c, e, and f respectively. The VHF source number versus height is given in Fig. 4 (d). The duration of this IC flash was about 600 ms. As shown in Fig. 4 (e), the entire development of the IC flash could be divided into 10 paths. In the first 30 ms, the discharges developed upward from 5 km altitude to 10 km altitude along path 1, then started to expand horizontally along paths 2~10. The location results in path 1 corresponded to the initial breakdown stage of the flash, in which most of the VLF/LF sources overlapped with VHF sources. In the subsequent horizontal breakdown process, most of the VHF sources distributed around 10 km altitude, a few dotted around 5 km altitude; VLF/LF sources also distributed around the two height levels and most of them occurred in or

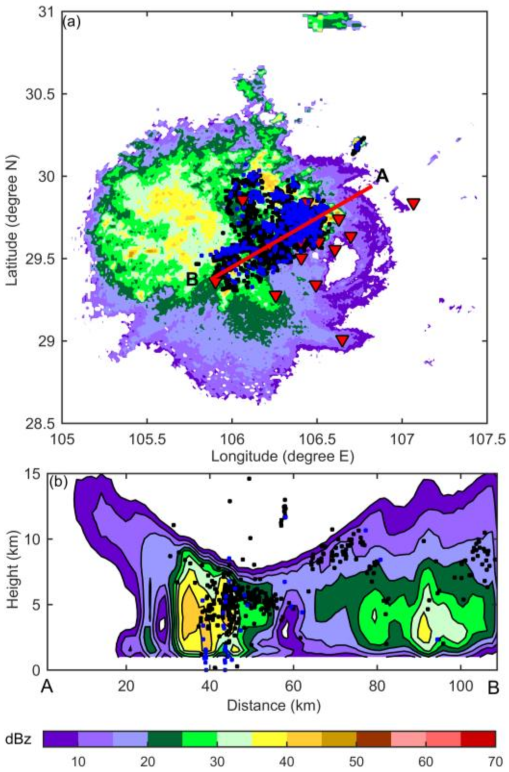

Figure 3 Composite radar reflectivity with VHF and VLF/LF location results of lightning discharges within 6min of the radar scanning time at August 31, 04:36. Black points represent VHF radiation sources; blue points represent VLF/LF radiation sources and red triangles represent the observation sites. (b) is a profile display of radar reflectivity along the segment AB in (a), and radiation sources within 1km of the profile

beside the region where the VHF sources appeared, while there was not significant difference between the numbers of the VLF/LF sources around the two height levels.

IV. CONCLUSION

This paper introduced DULLS: a lightning locating system working in VHF and VLF/LF bands synchronously, using TDOA method to locate lightning discharges, and gave some preliminary observations. This system lies in Chongqing, China, is made up of 14 dual-band sensors, can provide dual-band lightning location results continuously, uses VHF location result describe the evolution of the lightning activity in thunderstorm, images the path of lightning with 100 us time resolution, also can identify the type of lightning discharge and gives the distribution of the lightning discharges causing long current surge, especially the return stroke, by using VLF/LF observation. Compared with the exiting VHF lightning locating systems, DULLS has a broader observation frequency band and could record the waveforms of VHF and VLF/LF signals for research purpose, while the location result is similar. The VLF/LF location result is also similar to some VLF/LF location network designed for imaging the development path of lightning, but the time resolution of which is somewhat lower for using a time window of 1 ms[9-11].

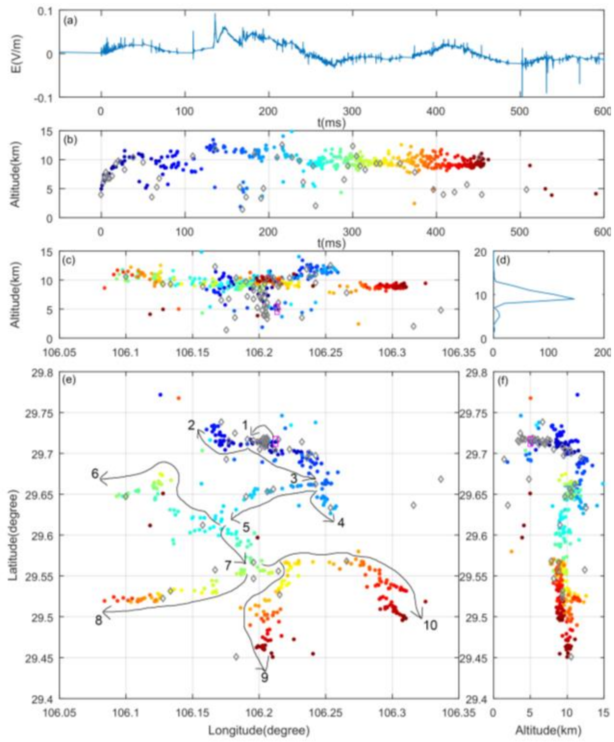

Figure 4 A IC flash occurred at August 31, 04:32:52(a) Fast electric field change waveform; (b) VHF and VLF/LF sources altitude versus time; (c) east-west vertical view of the sources; (d) VHF source number distribution along height; (e) plan view; (f) north-south vertical view

In recent years, VHF lightning locating system has been one of the most important tool to study the principle of the occurrence and development of lightning, especially for the study of intra-cloud flash. Although the VHF location result already has the ability to describe most of the lightning discharges, the advantages of VLF/LF lightning locating system such as lightning type recognition, discharge parameter calculation and detection range still cannot be replaced. The combination of the location results of the two bands should be conducive to describe the physical process of lightning more integrally. Recently, some researcher tried to use 3D VLF/LF location result to image the development path of lightning and got some result that is remarkably similar to those given by VHF mapping systems. As seen in the contrast of HAMMA and LMA [9]and the dual-band results of DULLS, the results of the two bands could overlap each other properly. But, to understand the relationship between the two kinds of radiation sources still needs more investigations, and that is why DULLS record the waveforms of the two bands signals as much as possible.

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