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A dual band 3D lightning locating system

Hengyi Liu [(1)], Wansheng Dong [(1)], and Liangfu Li [(2)]
(1) Laboratory of Lightning Physics and Protection Engineering, State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing, 100081,China
(2) Chongqing Meteorological Bureau, Chongqing, 401147, China

1. Introduction

The characteristics of lightning activity are highly related to the dynamical and microphysical processes in thunderstorm. 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 could be divided into VLF/LF and VHF system based on different focuses on frequencies. In general, the VLF/LF band is sensitive to long-scale current surges such as return stroke, and the VHF band is more capable of imaging the breakdown processes occurring over short distances. Therefore, most of the exiting VLF/LF lightning locating systems are designed to locate return strokes and Intra-Cloud (IC) processes that bear pulse-type waveforms, provide 2D or 3D location results to track thunderstorm or describe a particular lightning process. Since the VLF/LF waveforms not only contain the information of time and amplitude but also mean a physical quantity introduced by a certain lightning process, when a lightning discharge is located, the type, strength and polarity of the discharge also can be determined[1-6]. Meanwhile, the VHF systems are usually used to map detailed paths while discharges break through the air and this is helpful to understand detailed charging structures and evolutions of thunderstorm[7-11]. Some of the VLF/LF network can also give 3D lightning images that are remarkably similar to those created by VHF mapping systems, but the linkage between the two is still under debate[12-15]. Both lightning locating results of the two kinds of systems are highly complementary, the combination of which would be helpful to study lightning occurrences and its physics. But by now, there was no lightning locating system that working in VLF/LF and VHF bands simultaneously and could provide 3D dual-band lightning location results continuously.

The technologies used to locate lightning discharge are roughly categorized into Differential Time of Arrival (DTOA) method and Direction Finding (DF) method. Since the advent of Global Positioning System (GPS), the location accuracy of DTOA system had been tremendously improved and nowadays it is more common to be used for such purpose. In VLF/LF band, DTOA technology can be used to locate IC flash unlike Magnetic Direction Finding (MDF) method which are mainly designed to locate return stroke[16]. In VHF band, the existing DTOA systems can locate lightning discharges with time resolution of tens of microsecond[9,17], and are more economical and easier to give continuous 3D lightning observation throughout entire thunderstorm process than interferometric systems.

Recently, a Dual-band Lightning Locating System (DULLS) was designed and deployed in Chongqing, China. DULLS was upgraded from the original VLF/LF network[18], worked in VLF/LF and VHF bands, used high stability GPS modules for timing and DTOA method for 3D locating, can 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 will be introduced in this article.

2. Instruments and Data

As shown in Figure 1a, the dual-band sensor includes two parts: receiving and processing. The bandwidth of 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 output center frequency of the VHF receiver is 15 MHz. The VLF/LF receiver is similar to the circuit used in a fast electric field change meter with a decay time constant of 1 ms, is design to measure the electric field change caused by lightning.

The processing module is made up of a high-speed A/D card with 14 bits resolution, a GPS

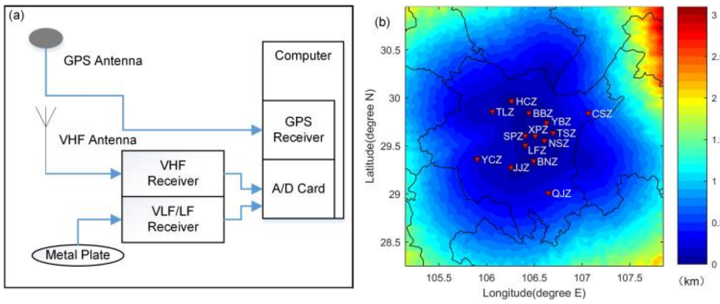

Figure 1 Device and site map of DULLS. **(a)** hardware constitution of DULLS, **(b)** layout of the sensor network and vertical estimated errors at the altitude of 7 km given by a Monte Carlo simulations

receiver and a computer, which is responsible for real time parameter extraction and data storage. The VHF and VLF/LF signals are digitized continuously and independently at a sample rate of 20 MHz and 5 MHz respectively. The record lengths of the two channels are 25000 and 5000 samples respectively. The parameter extractions of VHF and VLF/LF waveforms are also independent. The parameters extracted from VHF waveform are peak value of pulse and time information. In addition to time and amplitude, the parameters extracted from VLF/LF signal also include some pulse feature used to identify the type of lightning such as polarity, rise time, fall time and pulse width. The widths of the extracting windows applied to VHF and VLF/LF signals are 100 μs and 1 ms respectively.

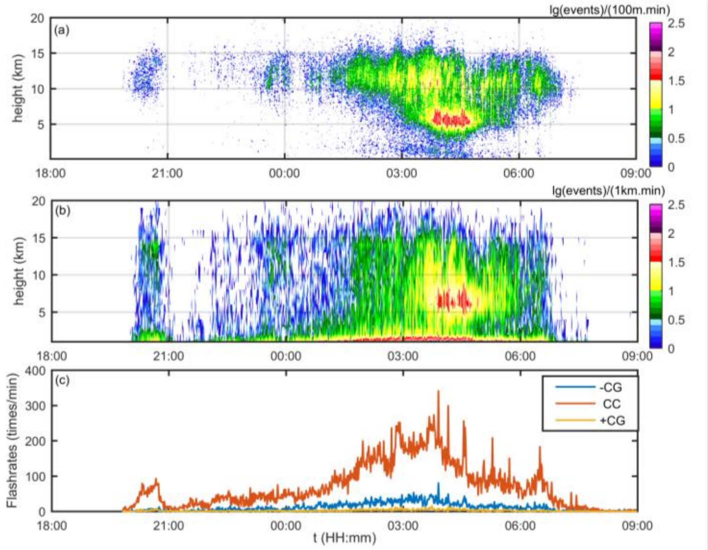

Figure 2 Densities of VHF and VLF/LF source altitudes and flash rates as a function of time in a thunderstorm occurred on August 30, 2014. **(a)** density of VHF source altitude, **(b)** density of VLF/LF source altitude, **(c)** flash rates versus time

Each sensor is synchronized by GPS device with an accuracy better than 100 ns. The data recorded in each site include two categories, original waveforms and detected waveform parameters. The waveform data are comprised of the waveforms and the time information of the two bands. When the system is working, the parameter data will be saved and transferred back to the center station via the Internet at first, then the waveform data are saved to local storage as much as possible to keep the system running properly. DTOA technology is used to locate the sources of the VHF and VLF/LF signals. The type of lighting is classified automatically by identifying the features of the VLF/LF waveform.

Figure 1b gives the layout of the sensor network deployed in Chongqing and the vertical estimated errors of the VHF results at the altitude of 7 km simulated by Monte Carlo method when error of timing is set to 100 ns. This dual-band sensor network was upgraded from the original VLF/LF network from January 2014, which is 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. According to the simulation results, the error of DULLS is better than 200m in the most area covered by the sensor network.

3. Observation results and analysis

Figure 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 activity began at 19:40 on August 30, 2014, was about 40 km from the southwestern edge of the sensor network. After about 6 hours, the lightning-occurring area of the storm moved into the region covered by sensors from southwest to northeast around 02:00 on August 31, and leaved this area at about 05:00. During this period, the lightning activity increased first and then decreased. Figure 2a and 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. Figure 2c gives the flash rates of negative Cloud-to-Ground (-CG) lightning, positive Cloud-to-Ground (+CG) lightning and IC flash as a function of time.

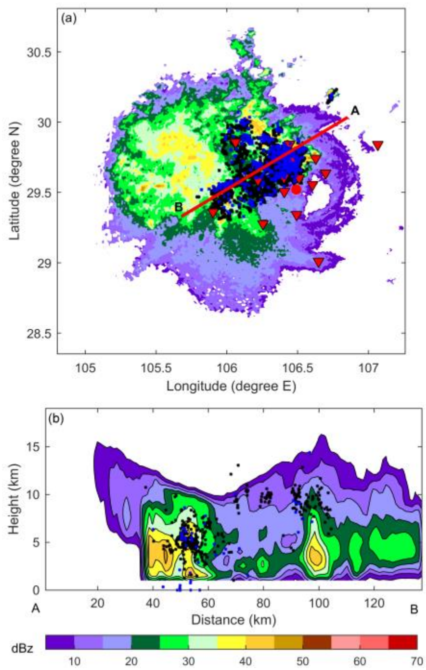

Figure 3 Composite radar reflectivity with VHF and VLF/LF location results of lightning discharges within 6min of the radar scanning time at 04:36 August 31. **(a)** plan view of radar reflectivity and lightning data. Black points represent VHF radiation sources; blue points represent VLF/LF radiation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

As shown in Figure 2, the distributions of the sources of VHF and VLF/LF bands are comparable in the whole thunderstorm, but look different. From 19:00 to 1:00 the next day, the VHF sources mainly distributed at altitudes of 5~15 km, centered around 10 km; the VLF/LF sources mainly occurred below 5 km, a small portion of them occurred at 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 remain and growing strong, while another strong lightning intensity core appeared 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 around 5 km, 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 stronger than that of positive breakdown process[9], 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 indicate 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 IC discharges; the VLF/LF location results mainly reflect return stroke, while also describing some IC discharges.

Figure 3 shows the composite radar reflectivity and dual-band lightning location results within a radar scanning time at 04:36 on August 31, 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 Figure 3a, both VHF and VLF/LF radiation sources occurred in the strong echo region in the front of the storm, covering almost the same region. Figure 3b shows a profile of the radar reflectivity and the lightning location results within 1 km of the profile. According to this figure, VHF sources were mainly above 3 km, clustered at the altitude of 5 km; VLF/LF sources occurred at several altitude levels. These distribution features are consistent with the cases in Figure 2.

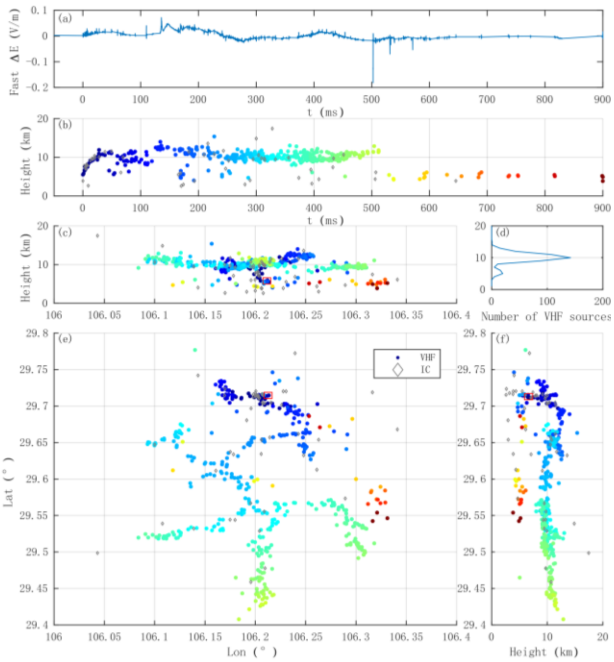

Figure 4 An IC flash occurred at 04:32:52 on August 31

(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

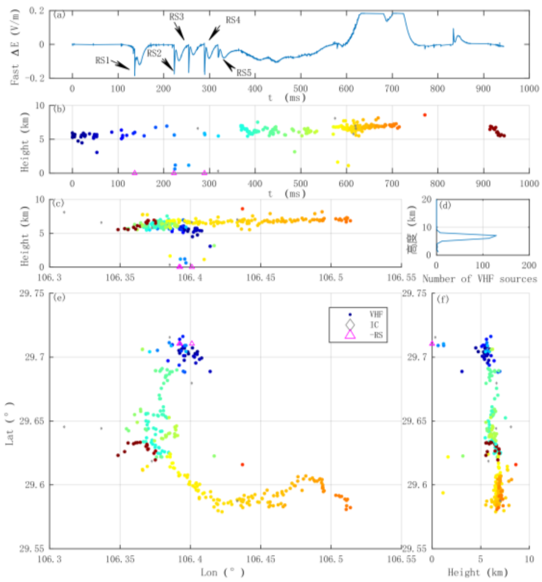

Figure 5 Similar to Figure4 but for a CG flash occurred at 04:40:22 on August 31

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. Figure 4 gives an IC flash occurred at 04:38:20 on August 31. 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 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. Figure 5 is similar to Figure 4 but gives a -CG occurred at 04:40:22 on August 31. This CG flash had 5 return strokes, lasted for about 1 s.

4. References

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