LIGHTNING OBSERVATIONS IN DARWIN AND TRMM/PR, LIS OBSERVATIONS

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1. INTRODUCTION

Lightning Research Group on Osaka University (LRGOU) has conducted field campaigns in Darwin, Australia to study lightning physics for these consecutive ten thunderstorm seasons. The period of the campaign is during building up phase of the monsoon in Darwin, when we are able to expect frequent active thunderstorm occurrences.

The objectives of this project are followings. (1) To realize the high performance of VHF broadband digital interferometer (DITF), which is a brand new technique for lightning location and monitoring developed by LRGOU, (2) To investigate the maritime continent thunderstorm activity around Darwin, and (3) To provide the ground base measurement and to confirm advantages of space borne measurement.

Darwin is located in the area of one of “the world three chimneys” from the aspect of the global climate changes, and others are Amazon and the central Africa. The contribution of lightning activity of these areas to the global electrical circuit is speculated to be the main cause of Carnegie Curve. TRMM/LIS may give us the evidence of this in terms of statistics, and combining with the ground base measurement by VHF BDITF may provide us the additional proof.

This paper presents a brief summary of the broadband DITF, and then gives some results of DITF and TRMM observations.

2. A VHF BRADBAND DIGITAL INTERFEROMETER

A broadband ITF is a system to locate a source of VHF impulse based on the digital interferometric technique [Ushio et al., 1997; Mardiana and Kawasaki, 2000a; Mardiana and Kawasaki, 2000b].

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A remarkable feature of a broadband DITF is its wide detection frequency range, and this system takes no account of a carrier frequency. The system observes the electric field change due to a lightning discharge in the ultra-wide VHF band, and Fast Fourier Transform (FFT) is applied to calculate various frequency components of the received EM pulse. Computed phase difference for each Fourier component between two antennas is a function of the incident angle of the EM pulse against the baseline. A couple of antennas as a two-element array of a broadband DITF are able to estimate the incident angle. Two pairs of antennas, and independent two baselines, enable two-dimensional (2D) mapping of sources in azimuth and elevation format.

Fig. 1 shows its antennas arrangement and the schema of the VHF impulse source location. In our system, we use three sensors, which are equipped at three apexes of a level isosceles right-angled triangle, and we define orthogonal two baselines with 10m length. Fig. 2 illustrates a block diagram of one unit of the broadband ITF for 2D mapping. We use circular flat-plate antenna witch has a diameter of 30cm, and its bandwidth is calibrated to be between 10MHz and 250MHz. The received broadband signals are amplified by amplifiers equipped beneath antennas, and are digitized at a sampling rate of 500MHz with 8-bit resolution. Two thousands EM pulses for 1μs with about 70μs mechanical interval between pulses can be recorded for one lightning flash within 1s. Notice that “two thousands” are the maximum and the total amount of observed EM pulse number depends on the event’s feature and distance from the observation site. Here after it is called “event triggering”. An additional sensor to measure the electric field change, called slow antenna, is equipped. This sensor is used to discriminate CG stroke and to know the polarity of lightning discharge in case of CG flash. Global positioning system (GPS) receiver is also set up to get the accurate time of the lightning occurrence.

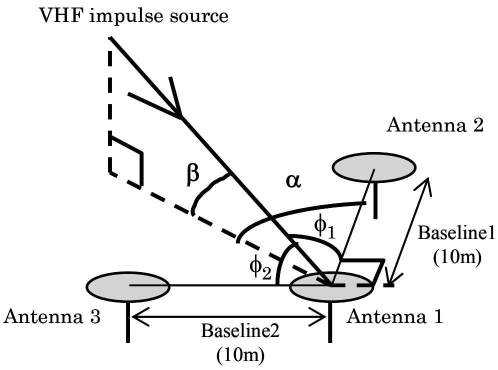

Fig. 1. Antenna arrangement of a perpendicular baseline on the broadband DITF for two-dimensional mapping. The antennas 1 and 2 form the first baseline, and the antennas 1 and 3 form the second baseline.

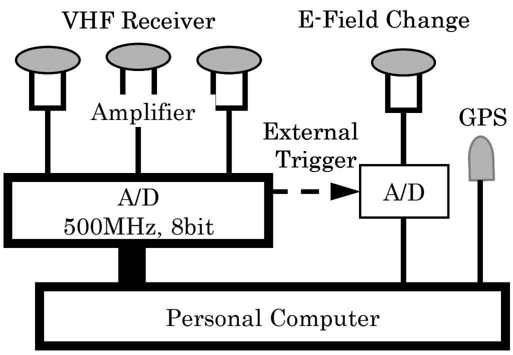

Fig. 2. A block diagram of the broadband DITF.

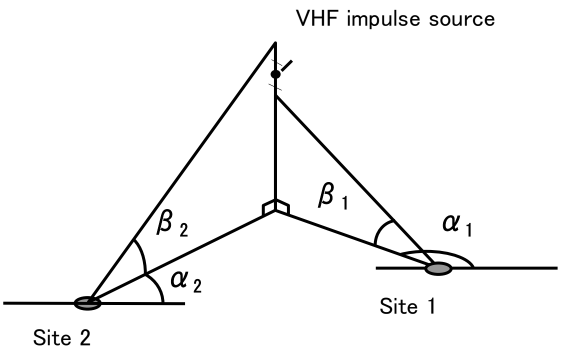

Fig. 3. Triangulation scheme. Each site provides azimuth-elevation mapping of radiation source.

Using three sensors, the direction of an impulse source can be estimated as azimuth (α) and elevation (β) by the following equations (see Fig. 1).

$$\alpha = \tan^{-1} \frac{\cos\phi_1}{\cos\phi_2} \qquad (1)$$

$$\beta = \cos^{-1} \frac{\cos\phi_1}{\cos\alpha} \qquad (2)$$

Where ϕ_1 and ϕ_2 are the angles of incidence relative to each baseline.

Three-dimensional (3D) imaging of VHF impulse sources are accomplished by a synchronized operation of two units of the DITFs with a proper distance separation. Fig. 3 gives a conventional algorithm for three-dimensional imaging by triangulation.

3. RESULTS AND DISCUSSION

3･1 Three-dimensional Localizations and Its Validation

Fig. 4 shows three-dimensional VHF impulse sources for a cloud-to-ground (CG) flash recorded on November 16, 2002 at 2156:44h (UTC) in the ’02 summer thunderstorm observation campaign in Darwin. They are superimposed on the vertical cross section of radar echo at the same time drawn by plan-position-indicator (PPI) scanning of a C–band radar at variable elevations. Impulse sources drawn in Fig. 4 are located within 1.5km from vertical plane of the cross section. In this figure, an active core with intensity of more than 50dBz is observed. The locations of VHF impulse sources are concentrated around the core. This coincidence is understandable in common sense.

To validate the function of the broadband DITF the authors have also compared its observation results with already established narrowband interferometer [Murakami et al., 1999; Kawasaki et al., 2000] and other previous studies [Morimoto et al., 2004] in terms of the locations and the progression velocities of negative leaders. Morimoto et al. [2004] described about the accuracy of the source locations determined by the broadband DITF. The consistencies of these results with previous studies and other observations are clear evidences that the broadband DITFs work well.

3·2 A Distinct Class of Negative Cloud-to-ground Flashes

In Figs. 5 and 6, altitudes of VHF radiation sources located by a broadband DITF are drawn in time domain. Both are correspond to leader propagation phases of negative CG flashes recorded during ’02 campaign in Darwin. The character “R” in these figures indicates the occurrence of RS. When we pay our attention to leader propagation channel of negative CG flashes especially their initiation, two categories as shown in Figs. 5 and 6 are identified. In the farmer, negative leader begins at an altitude of around 8km AGL and goes down to the ground for several tens milliseconds. The latter, in contrast, has some intermittent VHF radiations at 10km AGL about 1ms, which circled in Fig. 6, before continuous leader development. From the fact that narrow bipolar pulses (NBPs) are clearly noticed in the electrical field changes in synchronization with VHF radiations at high altitude (no shown), it is clear that these two categories are classified phenomenally. The results of cross-polarized radar observations show that the main precipitation particles are wet graupel at an altitude of 8km and the dry snow is dominant above 10km high. Assuming the tri-pole electric charge structure based on the riming electrification mechanism [Takahashi, 1979], it is considered that the former is triggered at lower positively charged region or between lower positive and dominant negative charge region, and the latter is triggered at higher positively charged region or between higher positive and dominant negative charge region. Additionally, the ignitions at high altitude might relate to transionospheric pulse pairs (TIPPs) [Mssey and Holden, 1995] and/or compact intracloud discharges (CIDs) [Smith, 1998].

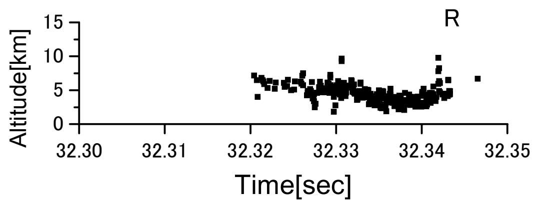

Fig. 5. Altitudes of VHF radiation sources located by the broadband ITF in time domain.

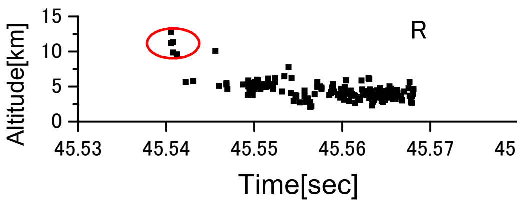

Fig. 6. Similar to fig.5.

3·3 TRMM Observations

For the duration of ’02 campaign, from 1312h to

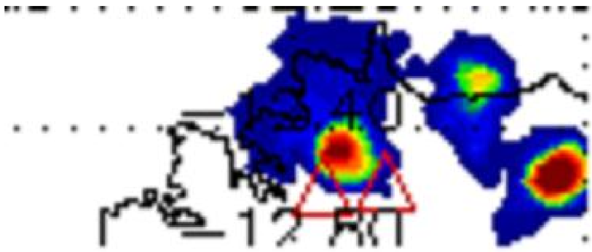

Fig. 7. The spatial distribution of lightning events observed by LIS from 1312h to 1314h on November 16, 2002(UTC). Triangles indicate the location of the DITF observation sites.

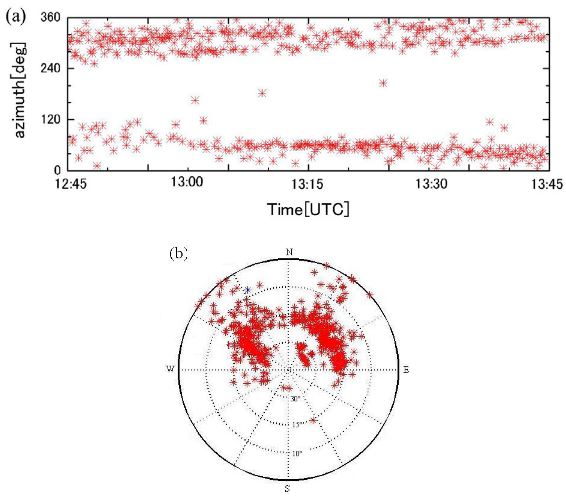

Fig. 8. Estimated locations of lightning activities recorded by the DITF at the right triangle in Fig. 7 for one hour surrounding the TRMM observation. The median values of azimuths in a lightning flash are plotted in time domain in the panel (a). The panel (b) shows the mean values of azimuth and elevation in circumferentially and radially, respectively.

1314h on November 16, 2002 (UTC) TRMM/LIS observed lightning activity around the DITF coverage area. Fig. 7 shows the spatial distribution of lightning events observed by LIS in this period. Triangles in this figure indicate the locations of the DITF observation sites. Three lightning activities are noticeable in this figure. Fig. 8 shows estimated locations of lightning activities recorded by the DITF at the right triangle in Fig. 7 for one hour surrounding the TRMM observation. The median values of azimuths in a lightning flash are plotted in time domain in the panel (a). The panel (b) shows the mean values of azimuth and elevation in circumferentially and radially, respectively. Here, azimuth is represented as 0° equal north and positive in anticlockwise direction. It should be accented that two-dimensional mapping as shown in Fig. 8 can be given in quasi real-time. Quasi real-time means the interval from data acquisition to output of the mapping for a flash is an instant (at most one second). The short baselines are responsible for the feature in the sense of that the data transfer from other sites is not needed. In Fig. 8, lightning activities are mapped in at least two directions of northwest and northeast consisting with LIS results.

4. Summary

The first result what LRGOU has achieved is the accomplishment of the quasi-real time operation of theVHF BDITF. The two-dimensional lightning channel imaging in azimuth and elevation format, and thunderstorm evolution in terms of the total lightning activity are now available. The superimposition of the VHF source location by BDITF with some microsecond order time resolution on BOM (Bureau of Meteorology, Australia) radar observations has been done after the campaign period for archived data. This enables us the discussion of the micro physics aspects, and reveals the interesting results on the initiation lightning discharge. In case we have the simultaneous observations of lightning discharge especially the initiation from space and the ground, we may have the instantaneous radar cross section for the serious discussion of the microphysics aspects. We are now looking for such kind of dataset. We had provided the height distribution of VHF sources by means BDITF, and comparison with LIS results is highly expected to have better understanding on physics of lightning.

Acknowledgements

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