SOME LIGHTNING OBSERVATION RESULTS
OBTAINED FROM BROADBAND RADIO INTERFEROMETERS

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Abstract: The VHF/UHF broadband radio interferometers operated from 10 MHz to 200 MHz have been developing for locating radiation sources emitted from lightning discharges. The observations have been conducted at two separated ground stations. Each station consisted of a broadband interferometer and an electric field sensor as well as a GPS receiver. Location of radiation sources is resolved using triangulation equations. The system was able to observe different type of lightning discharges and estimate the initial and subsequent leader progression speeds. The initial leaders had progression speeds of about $10^3$ m/s, typical for negatively charged initial leaders. The preliminary activity prior to the initial leader was also recognized and acted as a part of the initial leader. A dart leader and an attempted leader were also found to be negative-polarity discharges and they propagated upward or downward to ground with the estimated speeds of about $10^3$ m/s. Two of the flashes are presented here. These flashes contained subsequent leaders that took different channels and created new terminations on ground.

Keywords: Lightning, Broadband Interferometer.

1. INTRODUCTION

Lightning discharges produce electromagnetic radiation over a very large frequency spectrum, from a few hundred kHz to the GHz. Hence, during the past two decades a new range of investigation has been opened by the application of VHF/UHF electromagnetic localization techniques to the field of thunderstorm remote sensing. The VHF/UHF narrow band interferometers have been developed for locating two- and three-dimensionally (2D and 3D) lightning discharges [1]-[6]. Interferometer technique is based on the measurement of phase differences between signals received on different antennas of an antenna array. These phase differences are directly related to the direction of arrival of the signal and are used to calculate the angular position of the source in azimuth and elevation.

The experimental broadband interferometer has been manufactured and its capability to locate and reconstruct the lightning progression has been demonstrated. Shao et al. [2] have used the broadband interferometer in one-spatial dimension. Ushio et al. [3] demonstrated the first result of lightning mappings in a two-spatial dimension. Mardiana and Kawasaki [4] have explained the detailed principle and system of broadband interferometer for two-dimensional observations. The comparison between broadband and narrow band has been studied previously [5]. Interferometer technique is best suited for mapping the continuous signal and allow the source of nonimpulsive radiation to be located. Since interferometers have superiority to locate continuous radiation sources, which are natural of lightning discharges, with microsecond time resolution, the interferometers also were able to observe other lightning characteristics such as the speeds of initial and subsequent leaders and multi channels or multi terminations of ground flashes [6]. In this paper we introduce the 3D lightning observation system. There were two stations and each station consisted of three broadband antenna sensors to locate the direction of radiation sources. We then present the observation results of two CG lightning flashes, which show multi-stroke flashes, obtained by using broadband interferometers [6].

2. TRIANGULATION METHOD

A triangulation scheme is proposed to observe 3D lightning progressions and to locate ground stroke points. Figure 1 shows this proposed scheme. For a given source, each site provides the time of occurrence and the direction (azimuth $\alpha$ - elevation $\beta$) which are required to participate in the $(x,y,z)$ solution. The azimuth and elevation directions from the two sites will almost certainly never intersect precisely. For simplicity of the calculation, the estimated 3D location is placed directly above the intersection point of both azimuth directions. If we get a source position in the $xy$ coordinate, that is the intersection point of both azimuth directions, then there will be two possible altitudes. Consider the triangulation equations below,

$$
a_1 = \tan \alpha_1
$$

$$
a_2 = \tan \alpha_2
$$

$$
x = \frac{a_1 X_1 - a_2 X_2 - Y_1 + Y_2}{a_1 - a_2}
$$

$$
y = a_1 (x - X_1) + Y_1
$$

$$
Z_1 = \sqrt{(x - X_1)^2 + (y - Y_1)^2}.\tan \beta_1
$$

$$
Z_2 = \sqrt{(x - X_2)^2 + (y - Y_2)^2}.\tan \beta_2
$$
where \( (\alpha_0, \beta_1) \) is the direction of a source detected at station 1 and \( (\alpha_0, \beta_2) \) is that of a source detected at station 2. Positions \( (X_1, Y_1) \) and \( (X_2, Y_2) \) are Cartesian coordinates of station 1 and station 2, respectively. The \( Z_1 \) and \( Z_2 \) are the two possible altitudes of the source. We determine the \( z \) as the mean value of these possible altitudes, then the \( (x, y, z) \) will be the estimated 3D source location. The distance between \( Z_1 \) and \( Z_2 \) is a kind of error of altitude location.

Fig. 1 A triangulation scheme to obtain the 3D location of radiation sources.

3. OBSERVATION RESULTS

The observations were basically intended to observed CG flashes. Two representative negative CG flashes are presented, and these flashes occurred during a thunderstorm on November 27, 1998 in Darwin, Australia. These observations employed identical stations at two sites. The distance between these two stations was 23.1 km.

A. Two-Stroke Flash

This flash occurred at 05:03:24 (UTC). The system detected 421 radiation sources (herafter events) into 3D location. The electric field waveforms are shown in Fig. 2a and Fig. 2b. The classic atmospheric electricity convention sign was applied to the electric field, that is a positive charge corresponds to the addition of positive charge above the observation site, or, equivalently to the removal of negative charge. There were two return strokes. The return stroke could be recognized as indicated by an abrupt positive change of electric field. Figure 3 is the extended scale of Fig. 2c. This figure shows the lightning progression prior to each return stroke. The flash started with a preliminary in-cloud activity. This in-cloud activity was possibly a part of initial leader L1 as shown in Fig. 3a. The L1 propagated from approximately 7 km downward to 4 km. This L1 had a speed of about 0.8x10^5 m/s. The first stroke was followed by the second leader L2, which persisted for 60-65 ms, as shown in Fig. 3b. This leader had a progression speed of about 1.0x10^5 m/s. The flash then finished with in-cloud discharges within a hundred milliseconds interval after the final stroke.

Fig. 2 (a) and (b) are electric field waveforms. R denotes return stroke. (c) Location of the events in height-time plot.

Fig. 3 (a) Preliminary in-cloud discharges is indicated inside the circle. L1 is the initial leader. (b) L2 is the subsequent leader. The waveform is the electric field recorded at station 1.

Figure 4 shows the 3D-plan view of this flash. The flash had a channel length of approximately 8 km, but we found no event up to 4 km from ground for L1 and up to 2 km from ground for L2. It is worthwhile to mention that the first stroke on ground S1 had a different position with the second stroke S2. The distance of S1 was 13.6 km and 17.8 km from station 1 and station 2, respectively. S2 had a distance of 9.55 km from station 1 and 17.5 km from station 2. The distance between S1 and S2 was 4.2 km. In our calculation we assumed that if the distance between two stroke points on ground (in
a single lightning flash) is less than 1 km then we treated this lightning as a single stroke flash, otherwise this lightning will be treated as a multi-point stroke flash.

![Image of 3D plan view for the two-strokes flash.](image)

**Fig. 4** 3D plan view for the two-strokes flash. Circles S1 and S2 are ground stroke points of leader L1 and L2, respectively.

The fact that L1 and L2 had a different ground stroke point is supported by: (a) the S2 was initiated by a long duration (60 - 65 ms) leader L2, which is typical for initial leaders, (b) both electric field waveforms in Fig. 2a and Fig. 2b show positive field change during L1 progression and, on the other hand, both electric field waveforms show zero or slightly negative change during L2 progression. This means L2 descended closer to station 1 and station 2 than L1 [7].

### B. Four-Stroke Flash

This flash occurred at 04:54:53 (UTC). Total of 510 events could be mapped into 3D location. The electric field waveform recorded at both stations is shown in Fig. 5. There were four return strokes. Only the first-three leaders emitted strong radiation during their progression. Fig. 6 is the extended scale of Fig. 5c. The system mapped the initial leader L1, as shown Fig. 6a, from an altitude of 6.5 km downward to 2 km with a corresponding speed of about 1.9x10^6 m/s. The second leader L2 in Fig. 6b was mapped from approximately 6.5 km downward to 2.5 km, with a speed of about 1.0x10^6 m/s. In-cloud activity was detected prior to the third leader L3 in Fig. 6c. The leader L3 progressed from approximately 7 km to 3.5 km, with a speed of about 1.1x10^5 m/s. About 20-25 ms after the third stroke, another leader was detected at a short period of about 1.8 ms. This leader moved downward from approximately 6.6 km to 4.2 km with a speed of about 1.4x10^5 m/s, but no return stroke was detected as shown in Fig. 6d. The absence of a return stroke lead us to conclude that this leader was so-called an attempted leader AL [1]. The final leader L4 in Fig. 6d was likely a dart leader [1]. There were not so many observations of this dart leader, and its occurrence was very short. The approximate speed of L4 is 2x10^6 m/s.

Figure 7 displays the 3D-plan view of this flash in x-y-z format for all events. It is interesting to note that the first stroke S1 on ground following L1 had nearly or probably the same ground stroke point as the second stroke S2 (the distance between S1 and S2 was about 100 m), but the third S3 had a different position relative to previous ones. From the aspect of the leader speeds, leaders L1 and L2 had a possibility to have a different ground stroke point since their speeds agreed with initial-type leaders, but their stroke points on ground did not seem to support it. In case of leader L3, since its stroke point was different with the former strokes, the leader speed had a speed of typical initial leaders. The distance of S1 was 8.7 km and 17.4 km from station 1 and station 2, respectively. Third point S3 had a distance of 5.8 km from station 1 and 18.9 km from station 2. The distance between S1 and S3 was 2.8 km. From the electric field measurement at station 1 and station 2, it is found that both electric field waveforms show positive field change during leaders L1 and L2 progressions. On the contrary, the electric field waveform at station 1 shows negative field change during leader L3 and it shows positive change at station 2. These support the suggestion that leaders L1 and L2 had the same ground stroke point. However, leader L3 had a different ground stroke point and moved downward closer to station 1 than station 2. The fourth leader L4 had not so many events during its progression. But we speculate that leader L4 progressed through the same channel as leader L3 so that its ground stroke point S4 had the same position as S3. From x-z and y-z plots the flash had a vertical channel length of about 8 km, but from about 2 km down to ground, the same as the previous flashes presented here, we found no event.

![Image of electric field waveform.](image)

**Fig. 5** The same as Fig. 2, but for the case of four-strokes flash.
4. CONCLUSIONS

This paper has shown some results of three-dimensional lightning observations by means of broadband interferometers. The interferometers have observed several types of lightning discharges and their progressions. The results can be concluded as follows:

1. The system was able to locate multi-point strokes on ground in a single lightning flash. Up to several tens kilometers the lightning could be detected using two stations.

2. The system was able to estimate the speed of leader progressions. The lightning initial leaders had a progression speed in the range of 0.8-1.9x10^5 m/s, agree well with previous studies [1].

3. The subsequent leaders could follow the initial leader path, or they created a new channel and ground stroke point.

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REFERENCES


