LF/VLF Intracloud Waveform Classification

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LA-UR-03-2078

April 2, 2003

Abstract

The Los Alamos Sferic Array network of fast electric-field-change meters has geolocated over seven million lightning events in the United States (primarily near New Mexico and Florida) from 1998 to the present. Previous work has included the automated identification of cloud-to-ground lightning and a specific type of intracloud lightning (narrow bipolar events). We are extending this work to include the identification of general intracloud lightning activity and leader activity preceeding cloud-to-ground discharges.

1 Introduction

The Los Alamos Sferic Array (LASA) is an array of electric field change meters operated as an experimental system for ground support of satellite observations of lightning. We now have a five year data set of over seven million multi-station, differential time-of-arrival located events. LASA was originally used primarily for ground-truthing the FORTE satellite observations of specific type of intracloud lightning activity called Narrow Bipolar Events (NBEs) or Compact Intracloud Discharges (CIDs) [Smith *et al.*(1999)]. The signature of CIDs observed in the VHF by FORTE were termed Trans-Ionospheric Pulse Pairs (TIPPs) [Massey *et al.*(1998)]. In support of GPS satellite observations of both CID and cloud-to-ground (CG) lightning, LASA's classification routines were expanded to identify both CIDs and CGs. Approximately half of all LASA events are identified as either CIDs or CGs. In order to improve event classification, we are beginning to algorithmically identify general intracloud lightning activity and improve our identification of CG lightning. This paper presents examples of intracloud lightning LF/VLF radiation observations in comparison to NBE, CG, and leader LF/VLF signatures.

1.1 Lightning LF/VLF Radio Emissions

The transient electrical activity of thunderstorms generates electromagnetic radiation events known as atmosferics, or sferics. A typical return stroke produces radiation with peak energy at $\sim$10 kHz. Radiation at these frequencies propagates through the earth-ionosphere waveguide and can be observed at large distances ($>$ 2000 km) from the source. The large current return stroke usually produces the strongest electric field transient and other lower-amplitude pulses in electric field change waveform can be attributed to other aspects of the discharge process (*e.g.* channel tortuosity and branching [Willett *et al.*(2000)], leader activity [Heavner *et al.*(2002)], or general intra-cloud activity).

In terms of LF/VLF electromagnetic radiation, intracloud lightning is generally not as well characterized as cloud-to-ground (CG) lightning. This is primarily because CG lightning is a much stronger radiator at these frequencies. Intracloud lightning can not, in general, be observed at distances as great as CG lightning. For example, one study of intracloud lightning rates used sensors with a range of detection of approximately 14 km [Mackerras *et al.*(1998)]. VHF systems (such as the New Mexico Tech Lightning Mapping Array or the Kennedy Space Center Lightning Detection and Ranging System) are sensitive to intracloud lightning within a range of approximately 150 km.

Intracloud lightning activity is of interest for several reasons. First, optical satellite observations may be more sensitive to intracloud lightning than to CG lightning [Light *et al.*(2001), Boccippio *et al.*(2000)]. LASA is a system which provides ground truth for satellite observations of intracloud lightning activity (specifically CIDs) over a large spatial region (1000 km in radius or more). Second, the possibility of determining thunderstorm convective state based on the ratio of intracloud and CG lightning activity [Williams *et al.*(1989), Boccippio *et al.*(2001)]. Finally, monitoring total lightning activity on a large scale until continuous satellite observations are available. The difficulty in large-scale, ground-based observations of intracloud lightning, and the fairly long range observation capabilities of LF/VLF systems has motivated the routine identification of intracloud lightning by LASA.

1.2 Los Alamos Sferic Array

The Los Alamos Sferic Array (LASA) was originally built for ground verification of lightning observations by the FORTE satellite. LASA has evolved into a tool for studying both FORTE and GPS lightning observations, as well as a stand alone tool for studying lightning. LASA is an array of LF/VLF electric field change meters which is digitized at 1 MHz with 12 bit resoltuion. Each LASA station utilizes GPS receivers to provide absolute event time tagging with an accuracy of better than 2 μs. Using differential time of arrival methods for the event times at multiple stations, lightning events are geo-located. Most commonly, LASA records are 8 ms in duration and have been collected by a threshold triggering mechanism that includes 2 ms of pre-trigger data. Based on initial investigation into intracloud and leader LF/VLF radiation, 80 ms and 1 s records were collected by LASA stations to provide stroke context.

During operations of the sferic array from 1998 through the present, stations have been located in the United States, in the states of New Mexico, Texas, Nebraska, Colorado, and Florida. [Smith *et al.*(2002)] describe the operation and instrumentation of LASA and characterize the accuracy of LASA geolocation. The classification of NBEs is also describe in detail. Briefly, the NBEs are distinct based on the relative lack of neighboring radiation (or the isolation) and the narrow nature of the signature (the rise time and the fall time of the waveform). The classification of CG events is based solely on the relatively slow (greater than 30 μs) fall time.

2 Data

Figure 1 shows six events recorded by LASA stations. Figure 1 A is a typical -CG LF/VLF waveform. There is some low amplitude leader activity preceding the large negative excursion which is the return stroke. The fall-time, or return from the minimum to zero, is nearly 100 μs. Figure 1 B is a typical -CID event recorded by a LASA station. The two pulses at approximately 0.1 ms are the ionospheric and ground-ionospheric reflections of the signal (see [Smith *et al.*(2003)]). Figure 1 C is a typical +CID waveform with two reflections appearing at almost 0.2 ms after the initial burst of radiation. The middle and right columns of Figure 1 are the same events. The middle column is a 600 μs view of the waveform at the trigger point and the right column shows the full 8 ms record of the event. Figure 1 D is an intracloud lightning event observed by a LASA station. Note the positive polarity of the pulses in this case. Figure 1 E is a second example of an intracloud lightning waveform. Note that the event in E has less high frequency content than the event in D. Event E was 420 km from the sensor, compared to 180 km for event D. The earth-ionosphere waveguide does act as a low-pass filter, but the distance of 420 km is not enough to explain the lack of high frequency content (*i.e.*other leader events at a distance of 420 km or greater show high frequency content similar to event D). Figure 1 F is an example of a fast/intense stepped leader preceding an initial negative cloud-to-ground return stroke as discussed in [Heavner *et al.*(2002)]. Figure 1 F1 and D1 are similar waveforms with opposite polarity. Because of the fast/intense nature of the leader, the return stroke is part of the long record presented in Figure 1 F2 at approximately 5 ms. Without the return stroke in the full waveform, it is difficult to distinguish IC and CGs with fast/intense leader activity. Because negative leaders radiate more effectively than leaders associated with positive CGs, the polarity of the pulses provide an indication of the nature of the radiation (IC vs CG).

While typical strong leader pulses occur approximately 20 ms before the -CG return stroke, the literature does provide some examples of the fast/intense leader activity illustreated in Figure 1 F. [Uman *et al.*(1978)] report an ‘unusual lightning flash’ which included a return strokes with “a stepped leader of relatively short duration.” [Brook(1992)] and [Ogawa(1995)] present electric field records of intense lightning leader features within several milliseconds of the return stroke, similar to Figure 1 F2. [Heavner *et al.*(2002)] reports on fast/intense leader activity within 4 ms of the initial return stroke.

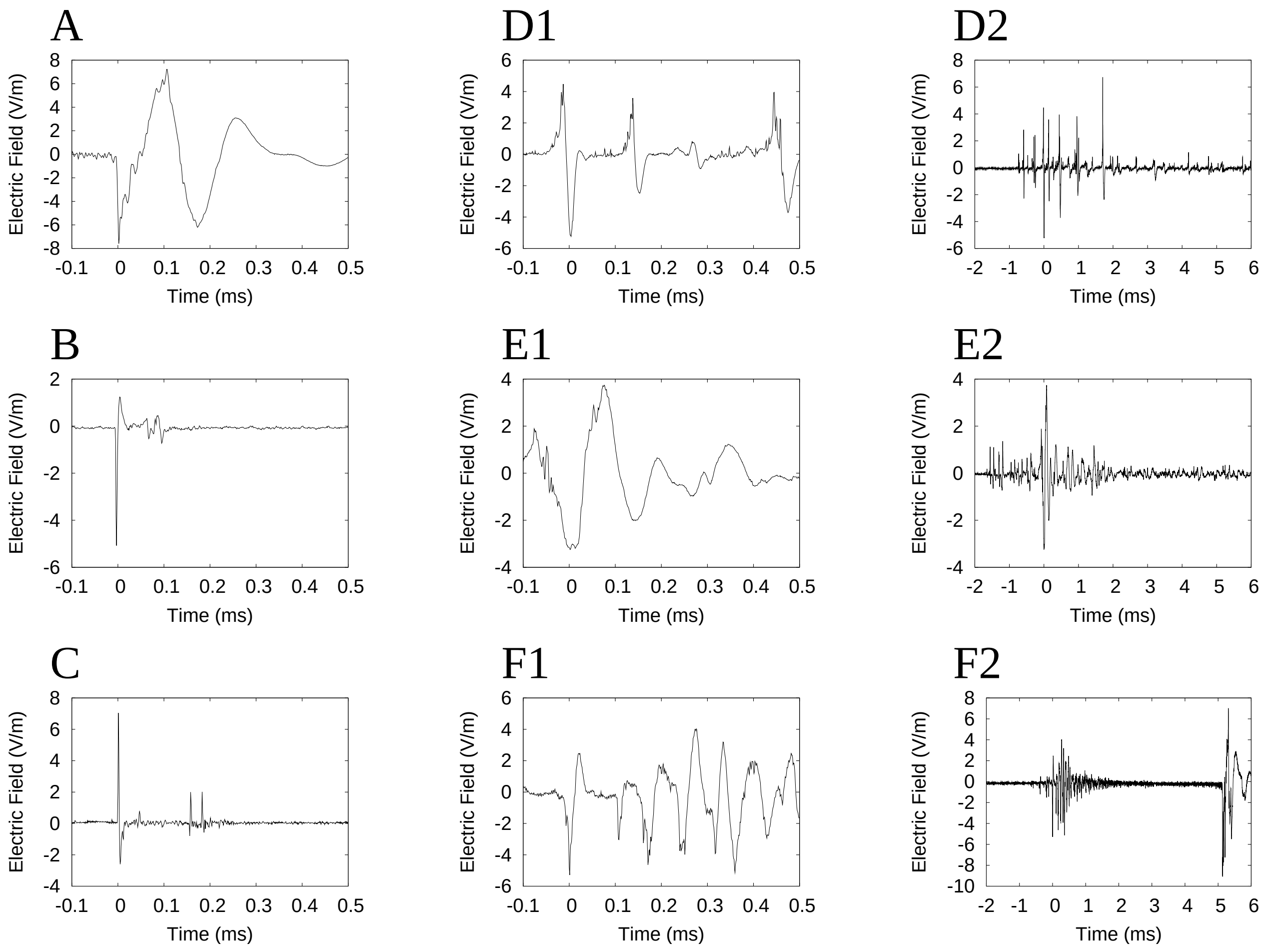

Figure 1: Representative LASA waveforms of A) cloud-to-ground, B) negative CID, C) postive CID, D) and E) intracloud, and F) CG with fast/intense leader. See description in text.

3 Current Research

We have included a criteria for algorithmically identifying LASA waveforms which include both fast/intense stepped leader radiation and return stroke radiation. The algorithm first requires the identification of a negative CG, next requires a large negative excursion more than 200 μs before the return stroke, and finally requires a power ratio of greater than 100 of the 10 μs around the return stroke and the beginning of the record up to 6 μs before the return stroke. This crude criteria does find CGs with intense leader activity in the record. We are currently improving the leader recognition algorithm and implementing an algorithm to recognize non-NBE intracloud events. We will present the results in the accompanying poster.

4 Future Directions

The current event classification algorithms are robust for identifying NBE waveforms, which, as seen in Figure 1 are the most distinctive. The currently CG identification is good, but somewhat conservative. As indicated in the introduction, only half of all LASA event waveforms are identified as either NBEs or CGs. A random selection of 1000 non-NBE/CG identified events found the following overall breakdown of events: 78% -CG, 13.5% +CG, 3.5% +NBE, 0.8% -NBE, and approximately 5% IC and/or leader events. Initially, based on the possibilty of 50% IC events, LASA could potentially provide IC event location over a large geogrpahic region. However, despite the now apparently low IC detection efficiency, the identification of IC events is of continuing interesting to gain insight into the differences between CID and other IC discharges. After we have implemented the new classification algorithms, we plan to explore the general LASA IC detection by comparing the observations with the New Mexico Tech LMA and the Kennedy LDAR systems.

5 Acknowledgements

This work was performed under the auspices of the United States Department of Energy. LANL personnel who also made significant contributions include A Jacobson, M Pongratz, X M Shao, M Carter, D Roussel-Dupré, and R Sheldon. We thank the many hosts of LANL sferic array stations, without whom this research would not be possible. M Heavner acknowledges many fruitful discussions with C Talus.

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