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Title: OPERATION OF AN ARRAY OF FIELD-CHANGE DETECTORS TO PROVIDE GROUND TRUTH FOR FORTE DATA

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OPERATION OF AN ARRAY OF FIELD-CHANGE DETECTORS TO PROVIDE GROUND TRUTH FOR FORTE DATA

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ABSTRACT: We have deployed an array of fast electric-field-change sensors around the state of New Mexico to help identify the lightning processes responsible for the VHF RF signals detected by the FORTE satellite's wide-band transient radio emission receivers. The array provides us with locations and electric-field waveforms for events within New Mexico and into surrounding states, and operates continuously. We are particularly interested in events for which there are coincident FORTE observations. For these events, we can correct both the array and FORTE waveforms for time of flight, and can plot the two waveforms on a common time axis. Most of the coincident events are from cloud-to-ground discharges, but the most powerful are from a little-studied class of events variously called "narrow bipolar events" and "compact intra-cloud discharges". We have therefore focussed our attention on these events whether or not FORTE was in position to observe them.

INTRODUCTION

Los Alamos National Laboratory has built and flown two satellites that have wide-band VHF radio receivers on board. The first of these satellites (named ALEXIS) had a receiver dubbed "Blackbeard" that recorded a 75 MHz analog bandwidth, and was usually tuned to 25-100 MHz or 100-175 MHz. This receiver had a video trigger circuit whose trigger level had to be set quite high to avoid triggering on communications and other non-geophysical signals, and as a result, only the most powerful transient radio signals were recorded. The surprising (at the time) result was that the events detected were very brief (a few microseconds duration), and occurred in pairs separated by 10-100 μs. We dubbed these events "TIPPs", for "trans-ionospheric pulse pairs" [Holden *et al* 1995, Massey and Holden 1995]. Radiation like that expected from ordinary lightning (intracloud or cloud-ground) was only rarely seen. The FORTE satellite, also built by Los Alamos for the Department of Energy, has several instruments capable of detecting lightning emissions. Two instruments detect optical emissions, while a package of VHF receivers detects radio emissions from 30-300 MHz. A multi-band trigger circuit allows FORTE to trigger on much weaker transients than Blackbeard, and as a result, FORTE most commonly triggers on intracloud and cloud-ground (CG) lightning events, though Blackbeard-style short-duration TIPPs are also recorded.

Using an array of electric-field-change sensors, Smith *et al* [1999] were able to show that TIPP events were the same narrow-bipolar events first described by Le Vine [1980]. By geolocating the events using differences in the measured times of arrival, Smith *et al* [1999] were able to show that these events occurred within thunderstorm regions with radar reflectivities exceeding 50 Dbz, and that they occurred within the cloud, in the region just above the negative charge layer.

With the utility of a field-change array proven, we deployed four field-change sensors in New Mexico, at Los Alamos, Socorro, Tucumcari, and Roswell, which form a rough square with sides of 200 km.

Array design

Each station consisted of a flat-plate antenna under a rain-shielding dome, an integrating amplifier, a bipolar trigger circuit, and a PC with a 1 mega-sample/s digitizer and a GPS timing card. The trigger thresholds are controlled by a D/A card in the PC. The digitizer runs constantly, so that pre-trigger samples can be obtained. When an event triggers the system, 4-12 milliseconds of post-trigger data are taken, and the post-trigger and 4 milliseconds of pre-trigger data are recorded by the PC. The trigger pulse is time-tagged by the GPS card. The PCs use the Linux operating system, and have internet connections over which data are transferred to a central PC at Los Alamos. Each night, header files containing the time-stamps are downloaded, coincident events are identified, and the corresponding waveform files are downloaded. The waveform data for an event are cross-correlated to provide fine-scale timing, and the locations are determined by minimizing the chi-squared timing error. Locations thus determined were compared to NLDN-provided locations [Cummins, 1998], and for events within our array's nominal coverage, most locations agreed within 10 km.

The stations operated continuously, with very few outages, from May 15 through October 1998. As many as 4000 events were located per day, with a total of more than 100,000 events during the season.

FORTE description

The FORTE satellite contains optical and radio instruments capable of detecting lightning emissions. In this paper we use data from the two "TATR" receivers, which have an analog bandwidth of 22 MHz, and are tuned (for these data) to center frequencies of 38 and 130 MHz. The output from each receiver is digitized at 50 mega-samples/second with 12-bit precision. A multi-band triggering circuit identifies transient events to be recorded in memory and transferred to the ground station. The primary antenna system is a crossed pair of 10-meter long log-periodic antennas. The antenna is nadir-pointing. The pattern has a null at the limb of the earth, though we still detect signals from near the limb. Timing and location information are provided by an on-board GPS receiver.

Coincidences with FORTE

Coincidences between the array data and FORTE events were identified by the requirement that the difference in trigger times be less than 10 milliseconds. These candidate events were analyzed to remove the propagation time (including ionospheric delays in the FORTE data) from the event to FORTE and to an array station. For most events, the resulting waveforms were coincident to within a few tens of microseconds. The largest uncertainty in these calculations was the event location (which could contribute as much as 33 μs error). The locations of the array stations and FORTE were determined by GPS receivers to a few hundred meters.

From May 15 through September, there were 15 coincidences where FORTE observed a negative CG, 77 coincidences with positive CGs, and 8 coincidences with positive narrow bipolar events. Jacobson [1999] has shown that FORTE is a more efficient collector of positive CGs than negative CGs, but the number of events in the present study is too small to conclude that we are seeing that effect.

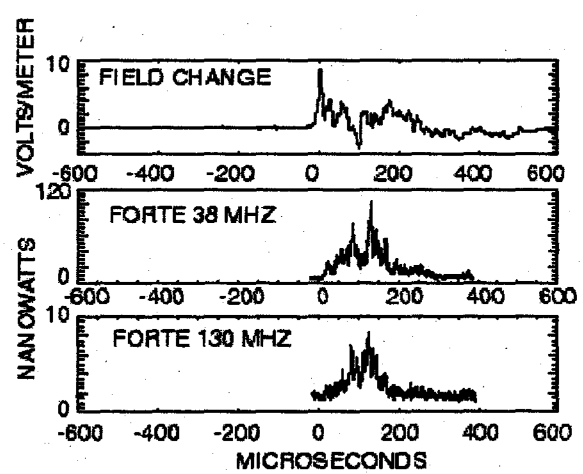

Figure 1. Waveforms from a positive CG event. The top waveform is the electric field recorded at the Los Alamos station. The middle and bottom waveforms are the dispersion-corrected RF power fluxes observed at FORTE. The time axes are corrected back to the event time.

Examples of FORTE coincidences with these three lightning types are shown in figures 1-3. Figure 1 shows a positive CG, figure 2 shows a negative CG, and figure 3 shows a positive narrow bipolar discharge.

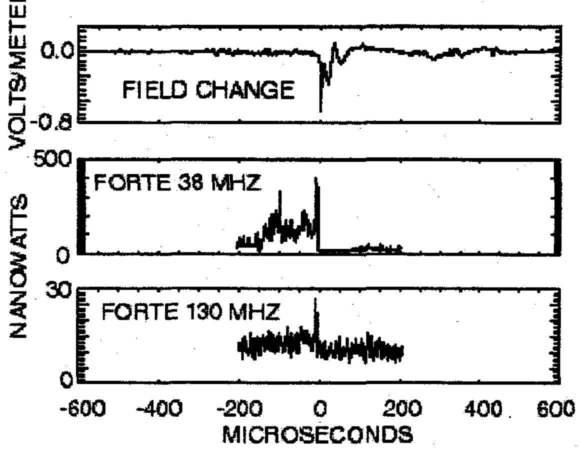

Figure 2. Waveforms from a negative CG event on August 7, 1998.

The positive CG of figure 1 occurred during a series of storm systems over the Texas panhandle and western Oklahoma on May 15, 25, and 27. Lyons *et al* [1998] have noted that these storms produced an unusually high fraction of positive CG strokes, and in fact our array detected only positive CGs. At the time of these storms, the Tucumcari station was not yet operating, so we had only three stations, and these storms occurred at an azimuth for which we had poor range resolution. Fortunately, almost all events recorded by both FORTE and the array were also observed and located by the NLDN, so for these events we used the NLDN-derived locations rather than the array solutions. The storm on May 15 produced 40 out of our total of 100 array-FORTE coincidences. The timing relationship between the field change signature and the RF waveform for all events was similar to that shown in figure 1; that is, the RF emissions occurred throughout the field change waveform, with little RF power either before or after the field change signature.

Negative CG events like that shown in figure 2 frequently had a sharper cutoff of the RF emissions than seen for positive CG events. This particular event appears to be a subsequent return stroke, with a very prominent spike and cutoff at the time of the return stroke. Examples of first return strokes, with prominent leader features, were also found.

Waveforms for narrow bipolar discharges were very distinctive in both the field change signature and the RF emissions. The two signatures were simultaneous within our timing error. For this event, both TATR receivers (A and B) were tuned to a center frequency of 38 MHz, but were connected to different linear polarizations of the antenna. The RF power was far higher than normally observed for CG events (note that the power scale is microwatts in this plot). The very brief duration of the sources suggest that they are small (< 1 km). The waveforms frequently contained reflections, which have been used by Smith *et al* [1999] to deduce the heights of the sources, which typically occur at about 8 km, though there is a wide range of heights. In figure 3, the signals in the electric-field waveform at just over 200 μs are the reflection from the ionosphere (called the "skywave") of the main signal. The reflection from the ground of the radio signal can be seen just a few microseconds after the main pulse in the lower two traces. The height determined by the skywave analysis is 7.5 km, while the height obtained from the RF reflection is 8.0 km. The elevation angle of FORTE as seen from the event location was 15°, which explains the small delay between the direct and reflected radio signals. The pulse at about 150 μs in the FORTE traces is apparently unrelated to the narrow bipolar event.

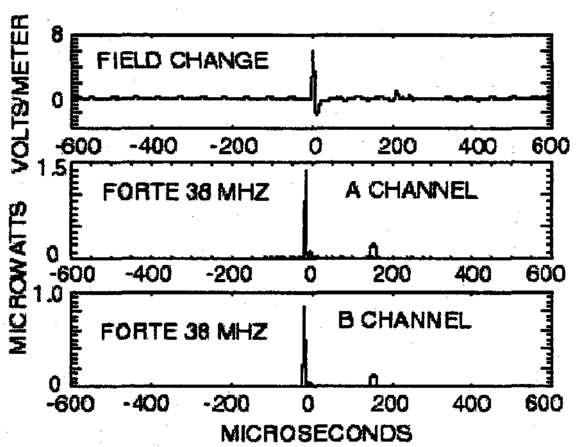

Figure 3. Waveforms from a narrow positive bipolar event on July 1, 1998.