FORTE Compact Intra-cloud Discharge Detection Parameterized by Peak Current

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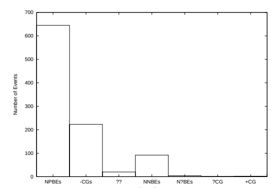
Abstract

The ground-based Los Alamos Sferic Array (LASA) has recorded over 7 million lightning-related fast electric field change records since May 1998. The waveforms are characterized with estimated peak currents and event type. During April 1 - Aug. 31, 2001 and 2002, LASA was operated in support of GPS VHF observations of lightning. The majority of GPS/LASA coincident events were compact intracloud discharges, with a threshold in LASA estimated peak current required for GPS VHF detection. In order to understand the physical properties of these LASA events, we have compared FORTE VHF observations with LASA VLF observations of NBEs.

Motivation



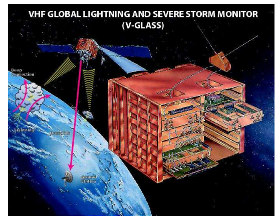
A VHF receiver onboard a GPS satellite is observing lightning emissions. The present observations are being used to develop a GPS-constellation based global-lightning monitoring program called V-GLASS. The Los Alamos Sferic Array is providing ground-truth to the GPS observations. The routine event identification by LASA processing software identifies the dominance ($\sim$60%) of positive narrow bipolar events (+NB) in the GPS/LASA coincident data set, as shown in the event type histogram at right. In order to understand the +NB observations from GPS, we focus on understanding VHF FORTE observations of positive narrow bipolar events.

Energetic intracloud events have previously been referred to as compact intracloud discharges (CIDs), energetic bipolars, and bipolar events. Their emissions have also been referred to with multiple terms, generally based on the specific signature in the data set, rather than any physical process or mechanism. The field change waveforms have been described as narrow positive and narrow negative bipolar pulses (+/- NB). Energetic intracloud VHF emissions, when recorded from space along with a ground reflection, were dubbed transionospheric pulse pairs (TIPPs).

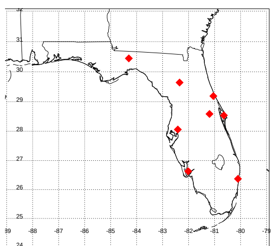
Terminology notwithstanding, energetic ICs are distinguished from other lightning events by several noteworthy characteristics, including the following: 1. The discharges are among the most powerful source of lightning radiation in the HF/VHF radio bands 2. Energetic ICs are typically isolated in time from other detectable discharges on a time scale of at least a few milliseconds, but often represent the initial event in an otherwise ‘normal’ intracloud lightning flash 3. Energetic ICs occur in both positive and negative polarities.

GPS Lightning Sensor

A VHF receiver on a GPS satellite has been used to collect lightning signatures. For this study, only the event times have been compared to LASA event times to geolocate the events and study the physical characteristics as indicated by the LASA waveform.



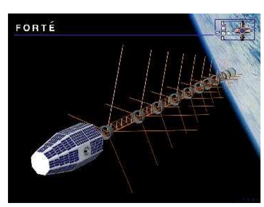
Los Alamos Sferic Array



The Los Alamos Sferic Array (LASA) has been described in detail by [5]. LASA is a collection of field change meters that has been operated since May 1998 and has consisted of as many as eight electric field change meters located in Florida (additional stations have been in NM, CO, NE, and Brazil). The array stations record and time tag (with better than 2 μs absolute accuracy) triggered field change waveforms, 24 hours per day. Differential time of arrival methods are used to geolocate the sources, and then lightning events are classified and characterized. Over seven million lightning discharges have been processed by the array over more than four years of operation.

FORTE

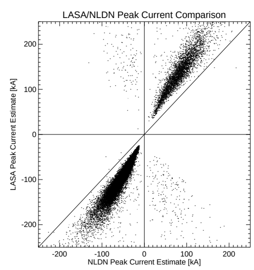
The FORTE satellite, launched Aug. 1997, has instrumentation capable of making both radio frequency and optical observations of lightning. The orbit altitude is approximately 820 km at an inclination of 70°, providing at most $\sim$ 15 minutes coverage of any ground spot. The FORTE RF payload consists of two tunable 22 MHz receivers and one tunable 85 MHz bandwidth receiver. The FORTE radio systems and typical observations are described by [3]. The FORTE optical package consists of a fast, non-imaging photometer and a slower CCD array. The FORTE satellite has collected over 4 million VHF waveforms since its launch in August 1997.



Peak Current Determination

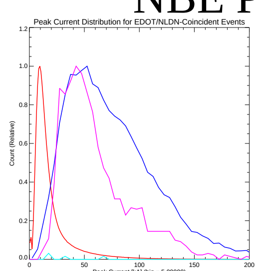
The Los Alamos Sferic array processing routine determines the peak current for all geolocated events using the Uman-McLain transmission line model (TLM) [6]. The TLM uses a channel geometry of a circular arc above the earth's surface connected to the surface. Additionally, the return stroke velocity, V_{rs}, is assumed to be constant. In proposing the TLM, [6] suggest that two models should be used for peak current calculations (the TLM and the 'Bruce-Golde' model, which uses a uniform current throughout the channel), and assume that the physical peak current value is between the value given by the models.

LASA/NLDN Peak Current



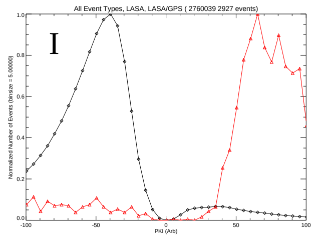
The Uman-McLain transmission line model is used by the National Lightning Detection Network (NLDN) to calculate the peak current assuming $V_{rs} = 1.2 \times 10^8$ m/s [1]. The plot shows a comparison between the LASA determined peak current and NLDN reported peak current for coincident CG events. The LASA values are systematically higher than NLDN values. [2] suggests that a higher V_{rs} (1.8×10^8) should be used. The use of a greater V_{rs} would improve the peak current agreement for earlier NLDN comparisons [2] as well as the comparison presented here.

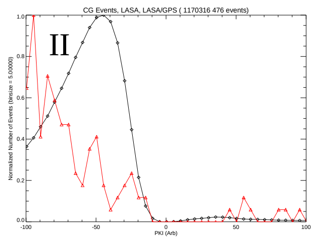
NBE Peak Currents

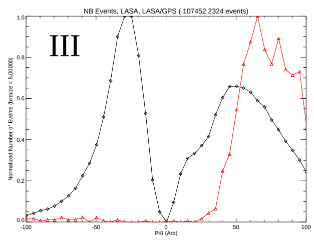


The transmission line model is probably not directly applicable to NBs, for two reasons. The intra-cloud nature of CID/NBs invalidates the geometrical assumptions, and the 'V_{rs}' is probably not correct (5×10^7 m/s may be a more appropriate propagation speed [4]. Despite the above issues, return stroke peak current calculation ($I_{pk} = -(2\pi\epsilon_0 c^2 D/V_{rs})E_{pk}$, where D is the distance to the source, and V_{rs} is the return stroke velocity) does provide a linear comparison of the relative amplitude of NBs.

The plot at right shows the NLDN peak current in red, the LASA peak current in blue, and the LASA CID/NBE peak current in magenta.





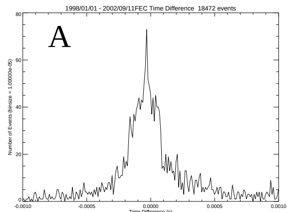


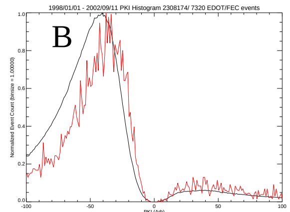
GPS Lightning Observations

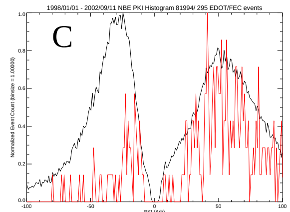
The GPS observations of lightning were the motivation for the FORTE/LASA study presented below. The GPS/LASA time tags for events were compared, and a tight temporal correlation window provided a strong separation from background (chance coincident) events. The window used was a GPS time stamp 300 μs before to 100 μs after the LASA time stamp. For events within this window, the LASA estimated peak current histograms for all events, independent of LASA classification, just CG events, and just CID/NBE events are shown at left. All LASA events and just GPS/LASA events are plotted. For all events, -CGs dominate the LASA data set, while the +NBs dominate the GPS/LASA coincident events. For just CG events, both LASA and GPS/LASA coincident events are dominated by -CGs. GPS/LASA events may have an improved detection efficiency with greater LASA estimated peak current dependent, but the GPS/LASA CGs have relatively poor statistics. For the CID/NB events, LASA has an almost equal number of both +NB and -NB events, while the GPS/LASA NBs are dominated by +NBs. The GPS/LASA +NBs also show a distinct esimated peak current threshold of $\sim$45.

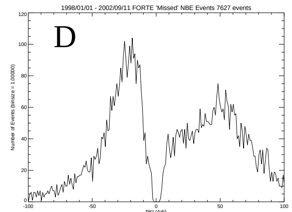
FORTE Lightning Observations

The FORTE/LASA coincident events are similar to the GPS/LASA coincident data set. As illustrated in A below, the coincident event time window (including the corrections for time of flight delays), determined independently for the two coincident sets, have the same -300μs to $+100\mu$s size. Plot B below, shows the estimated peak current for all LASA events and all FORTE/LASA events, similar to I above. For FORTE/LASA coincidents, the results are similar to the general LASA population, but much more strongly dominated by CGs. The negative events are slightly skewed towards weaker peak currents. This is most likely due to the fact that the LASA population is dominated by -CGs, while the FORTE/LASA population is dominated by -NBs, for which the peak currents are probably under-estimated. As shown in C, and similar to the GPS/LASA results in III above, the LASA NBs are nearly equivalent in total number, while the FORTE/LASA coincident events are more dominated by +NBs. The +NBs in the FORTE/LASA coincident events do not show any strong evidence of the estimated peak current threshold affect seen in III above. Plot D, below, shows the histogram for all LASA NBEs that occurred when FORTE was overhead and armed, but for which no coincident FORTE event was recorded. *A priori*, a tendency towards lower peak currents for non-FORTE detected NBEs was expected, as evidence of some threshold effect. However, no such tendency is apparent in the data.









Conclusions/Summary

This study was motivated by the VLF NBE amplitude thresholding in the GPS/LASA lightning observations. We have examined FORTE/VHF lightning observations and do not find a similar threshold effect. Any minor threshold effect is probably masked by other physical effects–possibly non-isotropic CID/NBE radiation, or a lack of any strong VLF/VHF power relationship. The large number of VLF NBE events which FORTE/VHF 'missed' have many large amptidue VLF NBE events, indicating that additional physical insight into the CID process is needed to understand the discrepency between VLF and VHF observations.

Future Directions

The data set presented here is biased towards Florida thunderstorms. Efforts towards studying more storm types are underway, including the recent participation in a Brazilian lightning campaign. This study began with LASA/VLF NBE observations and looked for matching and missed FORTE/VHF events. A complimentary study of FORTE/VHF TIPPs while in view of LASA is currently underway.

References

[1] K. L. Cummins, *et al.* NLDN peak current estimates - 1996 update. Technical Report 40700, Global Atmospherics, Inc., Tucson, AZ., July 15 1996.

[2] V. P. Idone, *et al.* Performance evaluation of the U.S. National Lightning Detection Network in eastern New York 1. Detection effi ciency. *JGR*, 103(D8):9045, 1998.

[3] A. R. Jacobson, *et al.* FORTE observations of lightning radio-frequency signatures: Capabilities and basic results. *Radio Sci.*, 34(2):337–354, 1999.

[4] D. A. Smith. *Compact intracloud discharges*. PhD thesis, Univ. of Colorado, Boulder, 1998.

[5] D. A. Smith, *et al.* The Los Alamos Sferic Array: A research tool for lightning investigations. *JGR*, 107(D13):10.1029/2001JD000502, 2002.

[6] M.A. Uman and D.K. McLain. Radiation fi eld and current of the lightning stepped leader. *JGR*, 75(6):1058–66, Feb. 1970.

Acknowledgements

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