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OBSERVATIONS AND INFERRED PHYSICAL CHARACTERISTICS OF COMPACT INTRACLOUD DISCHARGES

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ABSTRACT: Compact intracloud discharges (CIDs) represent a distinct class of electrical discharges that occur within intense regions of thunderstorms. They are singular discharges that produce brief (typically 3 μs in duration) broadband RF emissions that are 20 to 30 dB more powerful than radiation from all other recorded lightning processes in the HF and VHF radio spectrum. Far field electric field change recordings of CIDs consist of a single, large-amplitude bipolar pulse that begins to rise during the RF-producing phase of the CID and typically lasts for 20 μs. During the summer of 1998 we operated a 4-station array of electric field change meters in New Mexico to support FORTÉ satellite observations of transient RF and optical sources and to learn more about the phenomenology and physical characteristics of CIDs. Over 800 CIDs were detected and located during the campaign. The events were identified on the basis of their unique field change waveforms. CID source heights determined using the relative delays of ionospherically reflected source emissions were typically between 4 and 11 km above ground level. Events of both positive and negative polarity were observed with events of initially-negative polarity (indicative of discharges occurring between underlying positive and overlying negative charge) occurring at slightly higher altitudes. Within CID field change waveforms the CID pulse was often followed within a few ms by one or more smaller-amplitude pulses. We associate these subsequent pulses with the initial activity of a "normal" intracloud flash, the inference being that some fraction of the time, a CID initiates an intracloud lightning flash.

INTRODUCTION

During the summer of 1996, two ground-based receiver arrays in NM were used to record the electric field change signals and broadband HF emissions from lightning discharges. The arrays were fielded in support of the satellite-borne Blackbeard broadband radio receiver to try to identify the sources of powerful VHF pulse pairs called TIPP (transionospheric pulse pair) events [*Holden et al.*, 1995; *Massey and Holden*, 1995]. A distinct class of thunderstorm events was identified as the most likely source of the powerful TIPP emissions; these events were dubbed compact intracloud discharges (CIDs) [*Smith*, 1998; *Smith et al.*, 1999]. CIDs produced broadband HF radiation bursts that lasted a few microseconds and were at least 20 dB more powerful than the radiation from other recorded lightning processes. The electric field change emissions from CIDs were distinct, large-amplitude bipolar pulses that closely resembled waveforms previously identified by *Le Vine* [1980], and *Willett et al.* [1989].

During the 1996 campaign, differential time of arrival techniques were used to determine the 3-D locations of CIDs, with accurate altitude determinations made possible by considering the relative delays of ionospheric reflections from the source. Twenty-four CIDs, which were recorded from three thunderstorms in New Mexico and West Texas, were studied in detail. The events occurred at altitudes between 8 and 11 km above mean sea level. Event altitudes, in conjunction with the initially-positive polarities of their field change waveforms, suggested that the events occurred between the main negative and upper positive charge regions in their parent thunderstorms. Radar reflectivity data from two of the storms showed that CIDs occurred in close spatial proximity to thunderstorm cores with peak radar reflectivities of 47 to 58 dBZ.

Among the conclusions reached by *Smith* [1998] and *Smith et al.* [1999] were that the discharges were vertically oriented, had spatial extents of several hundred meters, and consisted of average currents on the order of 100 kA that lasted for approximately 15 μs. Based on the results of a charge distribution model, it was concluded that the events occurred in thunderstorm regions with charge densities as high as several tens of nC/m^3 and peak electric fields strengths on the order of 1 MV/m. Both of these values are an order of magnitude greater than values previously measured or inferred from *in situ* thunderstorm measurements. The unique radio emissions from CIDs, in combination with their unprecedented physical characteristics, were concluded to clearly distinguish the events from other types of previously observed thunderstorm electrical processes.

1998 OBSERVATIONS

In May of 1998 the Space and Atmospheric Sciences Group at Los Alamos National Laboratory began continuous operation of a four-station array of electric field change meters in New Mexico to provide ground-based measurements in support of RF and optical observations by the FORTÉ satellite. The array and FORTÉ observations are discussed in other papers in these Proceedings (see *Massey et al.*, *Jacobson et al.*, *Suszcynsky et al.*, and *Argo et al.*). During 1998, nearly 128,000 events were detected, recorded, and located by the array. Of these events, over 800 (0.7%) were classified as narrow bipolar pulses (NBPs), the distinct field change waveforms associated with compact intracloud discharges. Two representative NPB waveforms are shown in Figure 1.

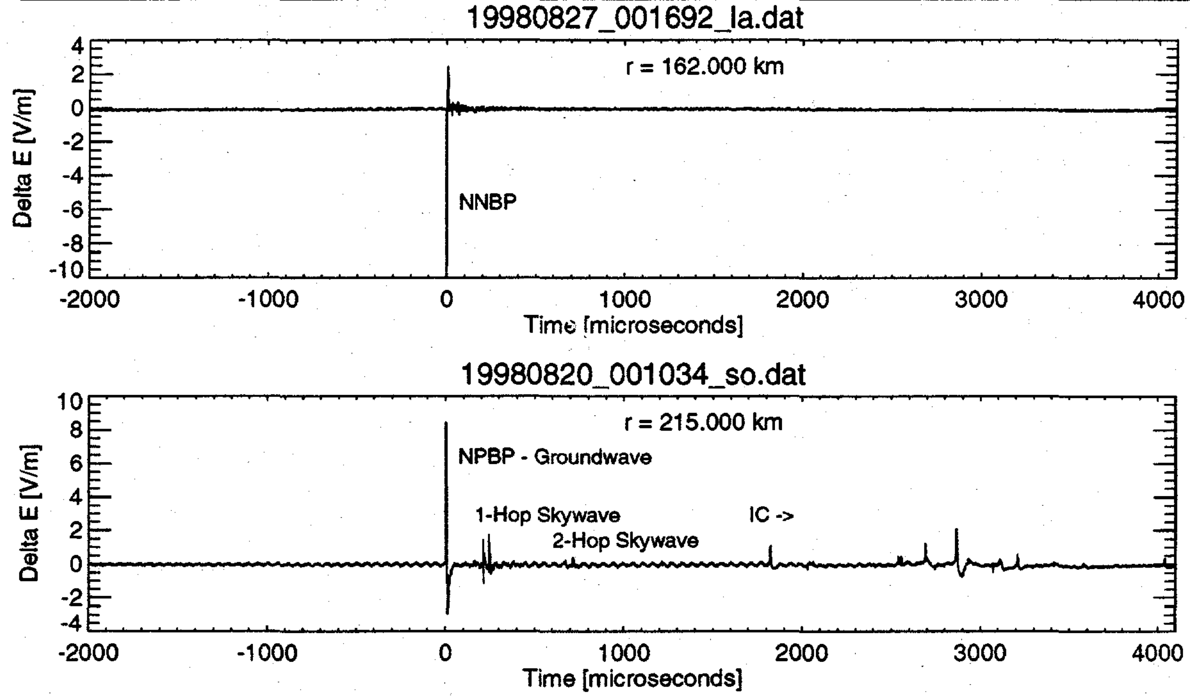

Figure 1. Electric field change recordings of narrow bipolar pulses. The upper waveform features an isolated narrow negative bipolar pulse. The lower waveform features a narrow positive bipolar pulse followed by two sets of ionospherically reflected pulse pairs and pulses corresponding to the initial activity of an intracloud stroke.

NPBs were identified on the basis of their fast rise and fall times and their isolation in contrast to other classes of events. We have shown that, in combination, these two traits serve as a good discriminant for NBPs. Rise plus fall times of NBPs were typically less than 10 μs. Isolation was parameterized by computing the ratio of the average power within a 10 μs window centered on the peak absolute amplitude in field change records to the average power occurring after the window in the record. The value of this isolation parameter (or SNR) was typically greater than 500 for CIDs and less for other types of events.

During the 1998 campaign, NPBs of both initially-positive and initially-negative polarities were observed; we refer to these events as narrow positive and narrow negative bipolar pulses respectively (NPBPs and NNBPs). Under our polarity convention, NPBPs occur between regions of underlying negative and overlying positive charge. The reverse is true for NNBPs. NPBPs were recorded three times as often as NNBPs. The upper waveform of Figure 1 features a NNBP and illustrates the fast rise and fall times characteristic of the events, in addition to their isolation. The lower waveform of the figure features a NPBP followed by a coda of additional waveform features, described below.

Although quantitatively more isolated than other classes of recorded waveforms (e.g. waveforms from positive and negative cloud-to-ground return strokes), two notable classes of post-trigger features were often discernable in NBP waveforms (post-trigger times ranged from 4 to 12 ms). The lower waveform of Figure 1 illustrates both of these classes. The first features to note are the two pulse pairs (the second is quite weak) that occur at delays of 210 and 660 μs from the groundwave signal. These pairs are 1-hop and 2-hop reflections of the CID emissions from the ionosphere and ground. Within each pair, the first pulse is the direct ionospheric reflection, and the second is the ionospheric reflection of a ground reflection. The second feature to note in the lower waveform are the weak, initially-positive pulses that begin after 1800 μs. These pulses resemble normal intracloud (IC) pulses and suggest that some fraction of the time NBPs initiate, or at least serve as a precursor to, an IC flash. Our attention was drawn to the subsequent, smaller amplitude pulses as a result of collaboration with the New Mexico Tech (NMT) research group. Their Lightning Mapping System imaged IC strokes that occurred immediately following NBPs recorded by the array and made clear an association between NBPs and "normal" intracloud lightning strokes. The data indicate that not all IC flashes begin with a NBP. It has yet to be determined whether all, or even most, NBPs are followed by an IC flash.

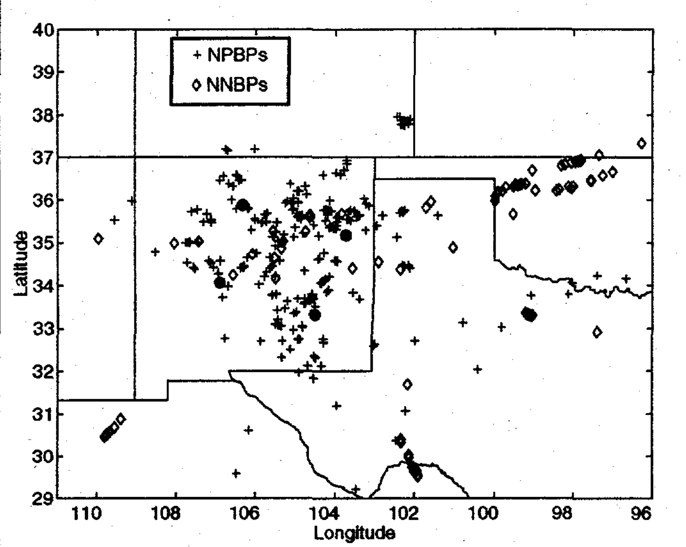

Figure 2. Locations of positive and negative narrow bipolar pulses recorded during 1998.

The locations of CIDs recorded during 1998 are shown in Figure 2. *Massey et al.* (these Proceedings) describe the method used to determine 2-D source locations. In the figure, NPBPs and NNBPs are represented by plus symbols and diamonds respectively (array stations are shaded circles). It is interesting to note that the negative events exhibited clustering to a larger degree than the positive events. That is, the negative events were produced during a relatively small number of storms, most of which produced many negative events.

Over half of the NBPs recorded featured ionospheric reflections that we were able to identify and time tag. Source heights and ionosphere virtual heights were computed for these events using the differential times of arrival between the groundwave signal and the reflected skwave signals. Histograms of source heights above ground level for both NPBPs and NNBPs are shown in Figure 3. As of this writing, we have not yet converted the heights to altitudes above mean sea level. Note that in general, the negative-polarity events occurred at higher altitudes. This observation was also true for individual storms that produced NBPs of both polarities. Because events of opposite polarity indicate a reversed charge structure, it is thought that that NNBEs occur between the upper positive thunderstorm charge region and an overlying region of negative charge, or that the events occur in thunderstorms with inverted charge structures. The fact that negative events appear to occur higher than positive events provides some support for the former hypothesis, as does the fact that events of both polarities were observed in some storms.

CID PHYSICAL CHARACTERISTICS

The mean peak range-normalized (to 100 km) amplitudes for NPBPs and NNBPs recorded during 1998 were 10 V/m and 10 V/m respectively. Mean dipole moment changes were 1 C-km and 1 C-km. Using methods described in Smith [1998] and Smith et al. [1999], estimated average currents during NPBs were on the order of 100 kA. Peak currents are estimated to be a few hundred kA.

As stated earlier, we found that computation of the rise plus fall time for all events provided a reliable means of identifying the narrow bipolar field change pulses emitted by CIDs. For measurements made from the far field (almost all of our observations), the rise plus fall time corresponds to the time to reach peak current, since the radiated field is proportional to the time rate of change of the current. We estimate average di/dt values from

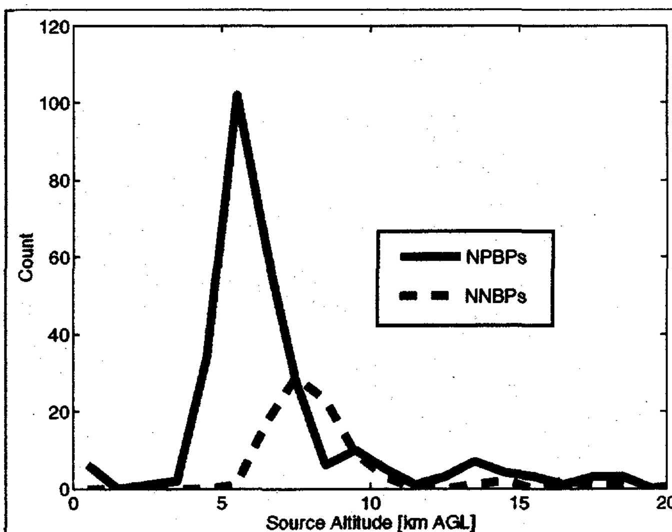

Figure 3. Altitudes (above ground level) of positive and negative bipolar pulses recorded during 1998.

event onset to peak current to be ~ 40 kA/μs for NBPs and ~ 1kA/μs for typical return strokes. Typical peak di/dt values for NBPs and return strokes were ~ 100 kA/μs and 10-20 kA/μs respectively.

SUMMARY AND DISCUSSION

During 1998, we recorded and located over 800 narrow bipolar pulses that occurred in and around New Mexico. Most NBPs occurred at altitudes between 4 and 12 km above ground level. Events of both positive and negative polarities were observed with the negatives occurring less often and in temporal clusters. Negatives also occurred at higher altitudes than positives, both in general and within individual storms. We also found that NBPs often initiate or serve as a precursor to regular intracloud discharges. It is not yet known whether this is always the case.

The remarkable physical characteristics of NBPs continue stand out from those of other lightning processes. Their breakdown RF radiation is 20+ dB more powerful than that from other lightning. Their discharge current moments are an order of magnitude greater . Among our planned activities for 1999 are the implementation of a second array in Florida to increase the likelihood of coincident detections with FORTÉ and utilize lightning research assets located there; the addition of at least one broadband RF channel (50 MHz to 1 GHz bandwidth) at a station in New Mexico to attempt to discern intra-CID structure; and further collaboration with NMT and their Lightning Mapping System to further study CIDs and their relationship to intracloud strokes.

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REFERENCES

Holden, D. N., C. P. Munson, and J. C. Devenport, Satellite observations of transionospheric pulse pairs, *Geophys. Res. Lett., 22*, 889-892, 1995.

Le Vine, D. M., Sources of the strongest RF radiation from lightning, *J. Geophys. Res., 85*, 4091-4095, 1980.

Massey, R. S., and D. N. Holden, Phenomenology of transionospheric pulse pairs, *Radio Sci., 30*, 1645-1659, 1995.

Smith, D. A., Compact intracloud discharges, Ph.D. Dissertation, Dept. of Electrical Engineering, University of Colorado, Boulder, 1998.

Smith, D. A., X. M. Shao, D. N. Holden, C. T. Rhodes, P. R. Krehbiel, M. Stanley, M. Brook, R. Thomas, Observations and analysis of distinct thunderstorm radio emissions, *J. Geophys. Res., 104*, 4189-4212, 1999.

Willett, J. C., J. C. Bailey, and E. P. Krider, A class of unusual lightning electric field waveforms with very strong high-frequency radiation, *J. Geophys. Res., 94*, 16,255-16,267, 1989.