Is Narrow Bipolar Event a Type of Isolated Lightning Discharge?

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ABSTRACT: Narrow bipolar event (NBE) has long been thought as a type of isolated lightning discharge, but there are also some observations showing contradictory results. During the summer of 2013, a LF lightning location system called BOLT was set up and recorded 827 NBEs including 638 positive NBEs and 189 negative NBEs. A type of NBE that is the initial event of a lightning flash is identified and is called initiator-type NBE (INBE). There are 103 INBEs, all of which are positive polarity. INBEs are always followed by positive pulse trains whose locations show upward propagations probably from the main negative charge region to the upper positive charge region. A major difference between INBEs and normal NBEs is that discharge heights of INBEs are generally lower. Most of INBEs are lower than 10 km while normal NBEs are mainly higher than 10 km. Other than INBEs, normal NBEs are usually temporally isolated, but it is not difficult to find NBEs accompanied by other discharge processes within tens of milliseconds and located within several kilometers. It appears that occurrences of NBEs may influence the development of other lightning flashes.

INTRODUCTION

Narrow bipolar events (NBEs) have long been thought to be temporally isolated with other lightning discharges [e.g., *Smith et al.,* 1999]. More recent studies, however, found that at least some of NBEs occur as the initial processes of lightning flashes. *Rison et al.* [1999] reported LMA (Lightning Mapping Array) observations of 13 positive NBEs that were all followed by intracloud discharges within 10 ms. *Smith et al.* [2002], based on thousands of NBEs recorded by LASA (Los Alamos Sferic Array), stated that it was neither unusual nor common to see intracloud activities following NBEs. *Nag et al.* [2010] reported 24% positive NBEs occurred prior to, during, or following cloud-to-ground (CG) or normal cloud lightning. *Wu et al.* [2011] made a statistical analysis on the temporal characteristics of NBE and found that 11.7% of positive NBEs preceded while only 1.6% followed other discharge processes within 10 ms. These studies indicate that NBEs, especially positive ones, have a considerable chance to initiate lightning flashes. It also appears that some NBEs can occur during or after lightning flashes.

In this paper, we report observations of 827 NBEs including 103 initiator-type NBEs (INBEs) with a three-dimensional (3-D) low-frequency (LF) lightning locating system during the summer of 2013. This paper will focus on these INBEs that are surely not isolated and share some distinguishing characteristics.

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Some normal NBEs also appear to be accompanied by other lightning discharge processes. Characteristics of such NBEs will be briefly analyzed.

NBEs are also known as compact intracloud discharges (CIDs) [e.g., *Nag et al.*, 2010] because of short channel lengths. In this paper, we will use the name of NBE because only electric field change data, on which NBEs are characterized by narrow and bipolar pulses, are used for this study.

EXPERIMENT AND DATA

Lightning discharges are detected and located with a LF lightning location system called BOLT (Broadband Observation network for Lightning and Thunderstorms). This system comprises 11 stations in Osaka region of Japan since June of 2013. Each station of BOLT is equipped with a fast antenna with a time constant of 200 μs and frequency range of 500 Hz to 500 kHz. Electric field change signals produced by lightning discharges are digitized with 4-MS/s sampling rate. Recorded signals have 16-bit resolution. Triggering time of each record is provided by a GPS receiver with timing accuracy of 50 ns.

In this study, NBEs recorded from July 4 to September 2 of 2013 are analyzed. There are 638 positive NBEs and 189 negative NBEs. 103 NBEs are initial processes of lightning flashes, and all of them are positive NBEs. These initiator-type NBEs will be referred to as INBEs in the rest of this paper. Physics sign convention is used in this paper, thus positive NBE corresponds to the discharge between lower negative charge and upper positive change.

RESULTS

Propagation characteristics of INBEs and subsequent processes

First we will analyze propagation characteristics of INBEs and their subsequent processes. Figure 1 shows temporal development of discharge processes following INBEs. Figure 1a shows 6-ms discharge activities after an INBE on September 1. From the electric field change waveform, we can see that multiple positive pulses follow the INBE. Such positive pulse trains are always found following INBEs within at least several milliseconds. This flash started with an INBE at an altitude of 6.2 km and propagated upward for 5.3 ms to the highest altitude of 8.9 km. The average speed of upward propagation was 5.1×10^5 m/s. In the plan view, the discharges seemed to progress in two opposite directions, and each direction of progression later branched into two directions. However, the scale of horizontal propagation is quite small, with the farthest location point only about 1 km from the INBE. All lightning flashes initiated by NBEs observed in this study have such an initial stage in which an INBE is the very first pulse and multiple positive pulses follow up with upward propagation. This initial stage is very similar with preliminary breakdown pulses of positive polarity such as those reported by *Bitzer et al.* [2013].

After this initial stage, pulses start to change polarity and their source heights usually decrease. It seems that the discharges can develop into any type of lightning flashes and no common characteristics can be identified. Most of INBEs ended in intracloud discharge processes. Only two INBEs developed into positive CGs and five INBEs developed into negative CGs. As an example, Figure 1b shows a negative CG initiated by an INBE on 1 September 2013. This flash first showed relatively rapid upward propagation within about 16 ms with an average speed of 3.0×10^5 m/s. Before 100 ms, the flash kept propagating upward to an altitude of 12.9 km. At about 110 ms, a new upward propagation process was initiated at a location close to the INBE (horizontal distance was 1.6 km). It propagated upward for about 25 ms and was followed by gradual downward propagation. Before about 400 ms, source heights stayed within about 6 to 9 km. After 400 ms, source heights were generally lower than 5 km. The negative return stroke occurred at 619.4 ms. However, no stepped leader signals could be identified before the return stroke. From the plan view, it can be seen that processes before about 250 ms (blue points) showed several clear branches. These processes corresponded to the initial two upward-propagation stages and subsequent downward-propagation stage. Processes after them did not show clear channels in the plan view.

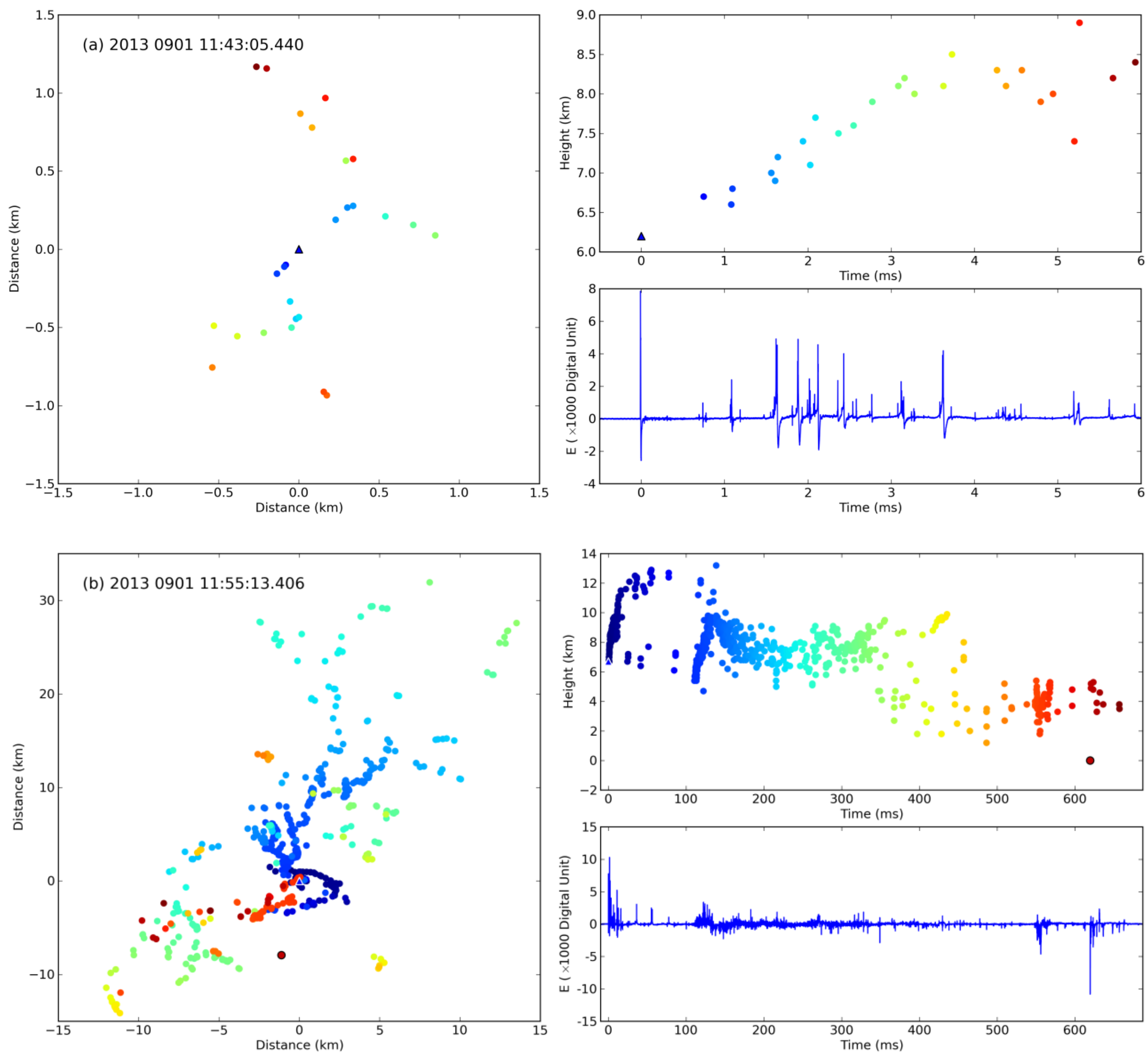

Figure 1. Two examples of temporal development of discharge processes following INBEs within (a) 6 ms and (b) 700 ms. INBEs are indicated as triangles. In Figure (b), the return stroke is indicated as a black circle.

Comparison of INBEs and normal NBEs

Pulse waveforms of INBEs have no apparent differences with those of normal NBEs. A major difference lies in their discharge heights. Height of lightning discharge is an essential property because it determines the location of the discharge in a thundercloud and thus the meteorological context in which the discharge is produced. It is now well known that positive NBEs are generally lower than negative NBEs. Positive and negative NBEs, respectively, are inferred to be produced below and above the upper positive change region [*Smith et al.,* 2004; *Wu et al.,* 2012]. In this section, we will compare discharge heights of INBEs with those of normal positive NBEs (PNBEs) and negative NBEs (NNBEs).

Height distributions of INBEs, PNBEs and NNBEs are shown in Figure 2. NNBEs are generally higher than PNBEs with some overlaps around 16 km. This result is similar to previous studies. On the other hand, although INBEs and PNBEs are both positive polarity NBEs, most INBEs are lower than PNBEs. It seems that 10-km altitude is an appropriate dividing altitude between INBEs and PNBEs. For INBEs, 97 of 103 (94.2%) are lower than 10 km while for PNBEs, 523 of 535 (97.8%) are higher than 10 km. The average heights for NNBEs, PNBEs and INBEs are 15.9 km, 13.4 km and 7.9 km, respectively. Therefore, positive NBEs higher than 10 km are probably PNBEs while those lower than 10 km are probably INBEs. In other words, NBEs lower than 10 km are probably followed by positive pulse trains. This result is consistent with LMA observation by *Rison et al.* [1999] in which an INBE was observed between 8 and 9 km altitude.

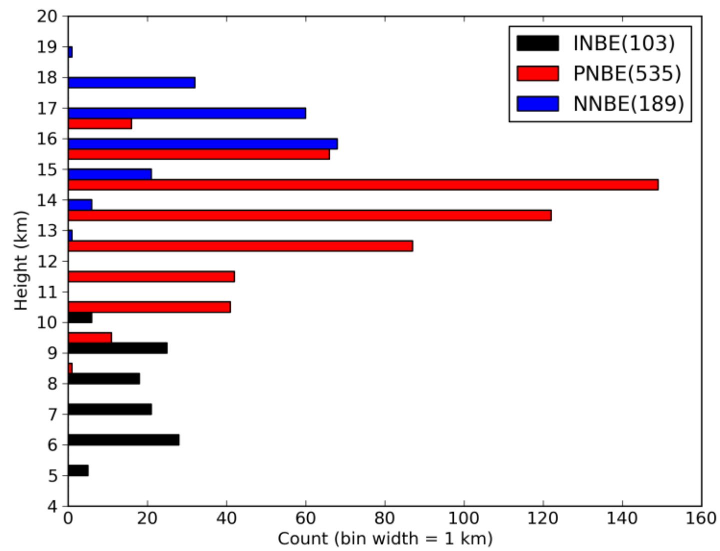

Figure 2. Discharge height distributions of different types of NBEs. Numbers in the parentheses are sample sizes.

Normal NBEs that are not isolated

Normal NBEs (NBEs except of INBEs) are usually temporally isolated with any other discharge process on the order of one second. However, it is not difficult to find NBEs associated with other lightning discharges such as return strokes. Unlike INBEs, which are always followed by characteristic positive pulse trains, we cannot find any common characteristics for normal NBEs. Here we analyze an example of a negative NBE which occurred between negative return strokes.

Figure 3 shows the E-change waveform and 3-D location results of this example. These return strokes seem to belong to two cloud-to-ground flashes. The first flash includes four return strokes, preceded by preliminary breakdown pulses. Then a negative NBE with a height of 15.2 km occurred, after which the second flash including six flashes occurred. Figure 4 shows an expanded view of all return strokes and the negative NBE. Locations of these two flashes were about 5 km apart. The negative NBE was quite close to the second flash.

Like other negative NBEs, discharge height of this negative NBE is very high, at least 7 km higher than other discharges. From this respect, it seems that although this negative NBE is temporally not isolated, its occurrence is independent of other discharge processes. In other words, it seems that this

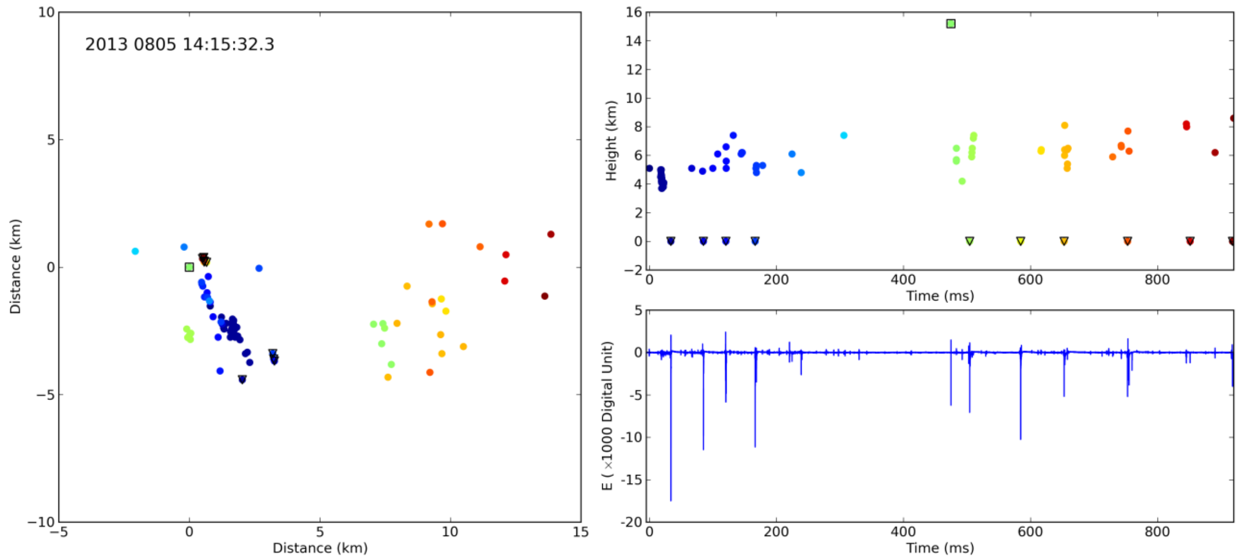

Figure 3. Temporal development of a negative NBE occurred between two negative cloud-to-ground flashes. Triangles represent return strokes. The square represents the negative NBE.

negative NBE can occur without any other discharge process.

However, this negative NBE seems to have certain influence on discharge processes following it. From the plan view (left panel of Figure 3), we can see discharges before the negative NBE are all located at the left side. For the second flash, however, sources of the return strokes are at the left side, very close to the negative NBE, but intracloud sources are mostly at the right side, about 10 km from the negative NBE. It possibly indicates that at the region of the occurrence of NBE, intracloud discharges are very difficult to occur. This again shows a tendency of NBEs to occur as isolated discharge events.

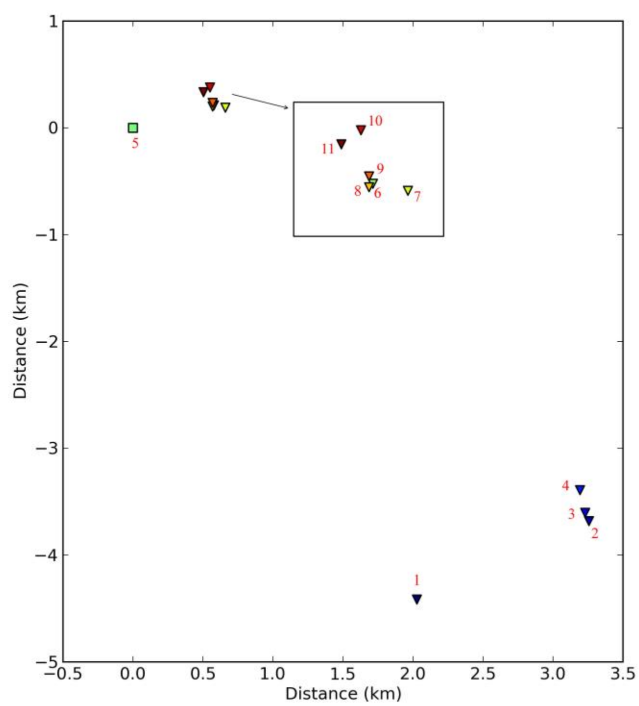

Figure 4. Expanded view of locations of return strokes and the negative NBE in Figure 3.

CONCLUSIONS

During the summer of 2013, 827 NBEs were observed with a LF lightning location system. A type of NBE that is not isolated is identified. The so-called INBE is always the very first process in a lightning flash and is followed by positive pulse trains within at least several milliseconds. Locations of the positive pulse trains show clear upward propagations, probably produced by negative leaders propagating upward from the main negative charge region to the upper positive charge region. All of INBEs are positive polarity. A major difference between INBEs and normal NBEs is that discharge heights of INBEs are generally lower than those of normal NBEs. Most of INBEs and normal NBEs are respectively lower and higher than 10 km. Therefore, NBEs lower than 10 km are mostly INBEs and are not isolated.

Other than INBEs, normal NBEs are usually isolated on the order of one second. But it is also not difficult to find NBEs associated with other discharge processes. One negative NBE occurring between two lightning flashes is analyzed. It seems that the occurrence of this negative NBE has certain influence on the flash following it. More examples are needed to analyze what kind of normal NBEs are associated with other discharge processes.

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