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Short Communication

Latitude dependence of narrow bipolar pulse emissions

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ABSTRACT

In this paper, we present a comparative study on the occurrence of narrow bipolar pulses (NBPs) and other forms of lightning flashes across various geographical areas ranging from northern regions to the tropics. As the latitude decreased from Uppsala, Sweden (59.8°N) to South Malaysia (1.5°N), the percentage of NBP emissions relative to the total number of lightning flashes increased significantly from 0.13% to 12%. Occurrences of positive NBPs were more common than negative NBPs at all observed latitudes. However, as latitudes decreased, the negative NBP emissions increased significantly from 20% (Uppsala, Sweden) to 45% (South Malaysia). Factors involving mixed-phase region elevations and vertical extents of thundercloud tops are invoked to explain the observed results. These factors are fundamentally latitude dependent. Our results suggest that the NBP emission rate is not a useful measure to monitor thunderstorm severity because regular tropical thunderstorms, where relatively high NBP emissions occur, lack suitable conditions to become severe (i.e., there is modest convective available potential energy and a lack of baroclinity in such regions). Observations of significantly high negative NBP occurrences together with very rare occurrences of positive cloud-to-ground flashes and isolated breakdown pulses in tropical thunderstorms are indicative of a stronger negative screening layer magnitude and weaker lower positive charge region magnitude than those in northern regions.

1. Introduction

Narrow bipolar pulses (NBPs) are the electric fields produced by a distinct category of intra-cloud (IC) flashes. They were first reported by Le Vine (1980) and later described in more detail by Cooray and Lundquist (1985), Willett et al. (1989), Medelius et al. (1991), and Smith et al. (1999). Narrow bipolar pulses have been observed to occur within or near the convective cores of thunderstorms (Jacobson and Heavner, 2005; Suszcynsky et al., 2005). It has been inferred that NBP flash rates and emission altitudes are generally driven by the strength of the convective updraft in mid-latitude thunderstorms (Suszcynsky and Heavner, 2003; Wiens et al., 2008; Wu et al., 2013). In other words, as the altitude of NBP emissions increase, the NBP flash rates also increase. Consequently, the NBP flash rate has been proposed as a measure to monitor thunderstorm severity (Wu et al., 2013).

Several researchers (Watson and Marshall, 2007; Nag and Rakov, 2009; Nag et al., 2010) have proposed that in the source of NBPs a hot conductive channel exists through which currents of many kiloamperes in amplitude flow. The estimated speed of propagation of the current pulse is from 0.3×10^8 m/s to 1×10^8 m/s with an estimated channel length of about 1000 m or less. Considering such very fast propagation speeds in virgin air, it is not likely that the initial breakdown will be due to the electron drift speed in the ambient electric field. That in turn suggests that the initial breakdown propagation is either photon- or fast (runaway) electron-modulated. The fact that close NBP electric field signatures appear without any detectable initial breakdown processes (pre-leader activity) preceding the event, and that high frequency (HF)/very high frequency (VHF) radiations can be detected almost simultaneously with the NBP onset, suggest that the initial breakdown processes and the formation of the hot conductive channel must occur instantaneously, i.e., at the propagation speed of light. Furthermore, frequent observations of gamma-ray glows (Dwyer and Uman, 2014) from thunderstorms suggest that the electric fields that are needed to produce runaway electron avalanches are common inside thunderstorms. As relativistic runaway electron avalanches (RREAs) come into the picture, the NBP electric field signature is believed to be generated from the propagation of RREAs alone rather than from current pulse propagation along a hot conductive channel (Cooray and Cooray, 2012; Cooray et al., 2014). The proposed simulation models fit very

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well with the electric field changes and HF/VHF radiation signatures. The estimated propagation speed is between 2–3 $\times 10^8$ m/s with estimated lengths between 400 and 600 m.

In this paper, we examine the occurrences of NBPs at various latitudes across different geographical regions ranging from northern regions to the tropics. Specifically, we analyze the percentage of NBP occurrences relative to the number of total lightning flashes and the percentage of occurrences for positive and negative NBPs as the latitude decreases from Uppsala, Sweden (59.8°N) to South Malaysia (1.5°N). Then, we provide some insights into the charge structure of thunderstorms, the relationship between NBPs and severe storms, particularly tropical thunderstorms, and the NBP discharge mechanism.

2. Data and measurements

All observations presented here were from three stations located in Uppsala, Sweden (latitude 59.8°N) and South Malaysia (latitude 1.5°N). One station uses a broad-band antenna with 500 μs and 15 ms decay-time constants. The other two stations use a broad-band antenna connected to a tuning circuit tuned to 3 MHz (HF) and 30 MHz (VHF). The output of the antennas is digitized at rates between 5 MHz and 100 MHz with a resolution of 12 bits or 8 bits (South Malaysia in 2012). Data records were between 200 ms and 5 s long and event triggered. The timing for each event was provided by a global positioning system (GPS). Additional details of the instrumentation and location techniques in Sweden are given by Baharudin et al. (2012) and Esa et al. (2014), and additional details for South Malaysia are given by Azlinda Ahmad et al. (2010) and Ahmad et al. (2014).

Measurements in Sweden were conducted for a period of 13 months between June and August 2009, 2010, 2011, and 2012 and between June and July 2014. Measurements in South Malaysia were conducted for a period of 4 months between April and May 2009 and between November and December 2012. Data for the mid-latitude sites in Asia and North America were collected from previously published studies.

Table 1
Timing information of 44 examined thunderstorms recorded in South Malaysia between April and May 2009 and between November and December 2012. The first flash event detected by the measurement system is listed in the second column, the first narrow bipolar pulse (NBP) event detected is listed in the third column, the last NBP event detected is listed in the fourth column, the last flash event detected is listed in the fifth column, the polarity of detected NBPs throughout the thunderstorm duration is listed in sixth column, and the total duration of the thunderstorm is listed in seventh column. The thunderstorm duration is defined as the duration between the first flash event detected by the measurement system and the last flash event detected. −CG, negative cloud-to-ground; IC, intra-cloud.

Thunderstorm label: Date	First flash event detected (flash type)	First NBP event detected (polarity)	Last NBP event detected (polarity)	Last flash event detected (flash type)	Polarity of detected NBPs	Thunderstorm duration (min)
1: 11 APR 2009	10:15:22 (−CG)	10:23:18 (−NBP)	12:31:49 (−NBP)	13:01:06 (−CG)	Both	166
2: 12 APR 2009	14:19:11 (−CG)	16:05:17 (−NBP)	16:32:21 (−NBP)	17:29:47 (−CG)	Only −NBPs	189
3: 13 APR 2009	07:52:56 (−CG)	–	–	09:10:22 (−CG)	No NBPs	78
4: 14 APR 2009	09:37:20 (−CG)	10:24:11 (+NBP)	10:47:33 (+NBP)	11:31:50 (−CG)	Only +NBPs	109
5: 15 APR 2009	01:50:05 (−CG)	–	–	03:23:41 (−CG)	No NBPs	93
6: 16 APR 2009	07:43:35 (−CG)	–	–	08:53:06 (−CG)	No NBPs	70
7: 17 APR 2009	07:59:45 (−CG)	–	–	09:41:42 (−CG)	No NBPs	100
8: 18 APR 2009	05:59:26 (−CG)	06:02:52 (+NBP)	09:32:43 (−NBP)	10:53:51 (−CG)	Both	293
9: 19 APR 2009	05:17:24 (−CG)	05:41:39 (−NBP)	11:21:53 (+NBP)	12:02:54 (−CG)	Both	404
10: 20 APR 2009	04:01:00 (−NBP)	04:01:00 (−NBP)	04:20:00 (−NBP)	07:33:26 (−CG)	Both	212
11: 21 APR 2009	06:38:07 (−NBP)	06:38:07 (−NBP)	06:39:25 (−NBP)	07:47:53 (−CG)	Only −NBPs	79
12: 23 APR 2009	05:52:58 (−CG)	–	–	10:39:37 (−CG)	No NBPs	287
13: 24 APR 2009	06:15:51 (−NBP)	06:15:51 (−NBP)	06:15:51 (−NBP)	08:53:04 (−CG)	Only −NBP	158
14: 26 APR 2009	03:34:27 (−CG)	04:14:44 (+NBP)	07:39:59 (+NBP)	08:37:45 (−CG)	Only +NBPs	303
15: 27 APR 2009	08:23:36 (−CG)	09:10:03 (−NBP)	10:23:15 (+NBP)	10:49:39 (−CG)	Both	146
16: 28 APR 2009	02:41:50 (−CG)	03:28:23 (+NBP)	05:39:51 (+NBP)	05:39:51 (+NBP)	Both	180
17: 30 APR 2009	02:09:20 (−CG)	03:36:00 (−NBP)	03:36:00 (−NBP)	04:32:03 (−CG)	Only −NBP	140
18: 03 MAY 2009	07:38:17 (−CG)	08:15:54 (+NBP)	08:15:54 (+NBP)	09:56:40 (−CG)	Only +NBP	138
19: 04 MAY 2009	22:40:12 (−CG)	22:42:33 (+NBP)	22:42:33 (+NBP)	02:01:11 (−CG)	Only +NBP	200
20: 05 MAY 2009	22:22:55 (−CG)	22:53:35 (+NBP)	22:53:35 (+NBP)	22:53:35 (+NBP)	Only +NBP	30
21: 08 MAY 2009	00:36:46 (−CG)	00:48:22 (+NBP)	09:59:08 (−NBP)	09:59:08 (−NBP)	Both	563
22: 08 MAY 2009	21:17:07 (−CG)	22:11:38 (+NBP)	23:52:07 (+NBP)	23:53:44 (−CG)	Only +NBPs	155
23: 09 MAY 2009	13:49:46 (−CG)	15:14:08 (+NBP)	22:32:56 (+NBP)	23:03:01 (−CG)	Only +NBPs	552
24: 15 MAY 2009	07:49:58 (−CG)	07:52:07 (−NBP)	11:15:16 (+NBP)	11:15:16 (+NBP)	Both	205
25: 16 MAY 2009	07:23:26 (−CG)	07:25:36 (−NBP)	07:25:36 (−NBP)	08:49:20 (IC)	Only −NBP	86
26: 21 MAY 2009	03:38:44 (−CG)	03:51:43 (+NBP)	05:41:22 (+NBP)	11:51:29 (−CG)	Both	493
27: 23 MAY 2009	04:32:31 (−CG)	05:37:26 (+NBP)	07:16:02 (+NBP)	07:20:03 (−CG)	Both	169
28: 25 MAY 2009	06:24:20 (−CG)	08:38:08 (+NBP)	10:19:07 (+NBP)	10:28:56 (−CG)	Only +NBPs	244
29: 26 MAY 2009	03:13:04 (−CG)	03:42:55 (+NBP)	05:52:26 (+NBP)	06:49:13 (−CG)	Both	218
30: 28 MAY 2009	07:20:20 (−CG)	07:43:46 (+NBP)	07:46:52 (+NBP)	08:56:39 (−CG)	Only +NBPs	96
31: 29 MAY 2009	06:30:58 (−NBP)	06:30:58 (−NBP)	07:33:32 (+NBP)	08:46:01 (−CG)	Both	136
32: 30 MAY 2009	02:08:38 (−CG)	02:23:19 (+NBP)	02:23:19 (+NBP)	02:45:33 (IC)	Only +NBP	37
33: 23 NOV 2012	15:55:20 (−CG)	15:57:28 (+NBP)	17:34:40 (+NBP)	18:01:36 (−CG)	Both	125
34: 27 NOV 2012	14:40:38 (−CG)	14:59:38 (−NBP)	17:49:07 (−NBP)	18:16:03 (−CG)	Both	216
35: 28 NOV 2012	15:31:30 (−CG)	16:20:56 (+NBP)	19:09:10 (+NBP)	19:12:18 (−CG)	Both	220
36: 29 NOV 2012	13:38:36 (−CG)	15:29:50 (−NBP)	15:31:00 (−NBP)	16:14:06 (−CG)	Both	156
37: 30 NOV 2012	14:05:24 (−CG)	15:23:46 (−NBP)	16:58:00 (−NBP)	17:04:14 (−CG)	Both	180
38: 05 DEC 2012	13:16:54 (−CG)	14:11:52 (−NBP)	14:47:58 (+NBP)	16:58:16 (−CG)	Both	222
39: 06 DEC 2012	12:50:54 (−CG)	15:26:38 (−NBP)	15:54:28 (−NBP)	17:22:22 (−CG)	Both	272
40: 10 DEC 2012	13:06:12 (−CG)	16:08:10 (+NBP)	16:08:10 (+NBP)	16:58:58 (−CG)	Only +NBP	232
41: 11 DEC 2012	12:22:32 (−CG)	–	–	16:10:54 (−CG)	No NBP	228
42: 12 DEC 2012	14:25:46 (−CG)	14:51:34 (+NBP)	17:37:40 (−NBP)	17:37:40 (−NBP)	Both	192
43: 13 DEC 2012	13:36:14 (−CG)	14:10:08 (+NBP)	14:10:08 (+NBP)	16:56:36 (−CG)	Only +NBP	200
44: 19 DEC 2012	12:20:48 (−CG)	13:06:56 (−NBP)	14:10:22 (+NBP)	16:27:22 (−CG)	Both	247