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Characteristics of narrow bipolar Events

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***Abstract*—From analysis of data collected by a 6-station local network, we report observations of 1395 positive narrow bipolar events (NBEs) and 144 negative NBEs occurring in the mid-low latitude Jianghuai area in China. The source height of each NBE was derived from the ionospheric reflections followed the narrow bipolar waveform. Positive NBEs occurred at a mean altitude of 9.7 km, much lower than 16.0 km for negative NBEs. However we also found that about 4% of positive NBEs occurred at the same altitudes as negative NBEs. On a statistical basis, negative NBEs, which tended to occur at higher heights than positive NBEs, were different from positive NBEs in time waveform features as well as electric field strength. However, negative NBEs showed the similar time waveform features to those positive NBEs which originated at same altitudes as negative NBEs. Characteristics of current which was thought to produce narrow bipolar pulses, in terms of peak current moment and peak charge moment, were also derived from observed narrow bipolar electric field waveforms. A NBE discharge involved in the peak current moment as much as 30 kA-km, while the charge transferred can be of the order of 0.4-0.5 C.**

Keywords-narrow bipolar events, narrow bipolar pulses,compact intracloud discharges,waveform characteristics,peak current moment,

I. INTRODUCTION

Narrow bipolar events(NBEs) refer to a distinct class of lightning discharges which are characterized by the strongest natural radio frequency emission and characteristic narrow bipolar radiation fields at far distance [1,2,3]. These events are sometimes called narrow bipolar events/pulses or compact intracloud discharges [4,5]. As a ubiquitous lightning discharge phenomenon, ground-based observations of NBEs have been reported by many researchers from different regions of the world[6,7,8,9,10].However, the physical mechanism for producing a narrow bipolar pulse remains unsolved so far [11,12,13].More phenomenological observations are still needed to better our understanding of this mysterious phenomenon. In this presentation, we report waveform characteristics of positive NBEs and negative NBEs originating at different altitudes and reveal their possible dependence on source heights.

II. INSTRUMENTATION AND DATA

The data used here were recorded by a 6-station local network which was originally developed to collect NBE data in the lower latitude regions for comparisons with those occurring in the relatively higher latitude regions[13]. Each station was equipped to record radiation fields of lightning events received by a VLF/LF receiver (800 Hz to 400 kHz), except that in Shouxian(SX) station, additional very high frequency emissions from a linear VHF receiver (112.5MHz-117.5MHz) were also recorded for better identification of NBEs. In each station observations were conducted automatically and uninterruptedly, and lightning events were recorded in a series of data segments of 1.6 ms in length. A GPS receiver was used to time-stamp each data segment in an accuracy of better than 0.1 us. For those lightning events which were recorded by at least three stations, their 2-D locations were processed by using the time-of-arrival(TOA) technique. Please refer to reference [15] for details of our recording system.

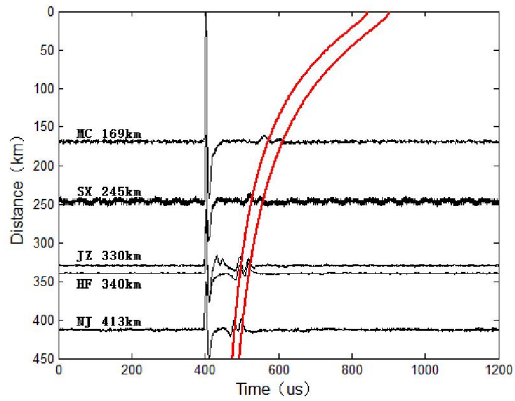

Fig.1 A example of NBE Waveform and its ionospheric reflections observed at different sites.

We have developed a PC-base software program to identify NBEs based on electric field data observed in central Hefei(HF) station. The NBE-identification algorithm was carefully testified by inspecting the bipolar electric pulse and the corresponding VHF emissions observed at SX station. As was illustrated in Fig.1, each NBE produced a typical bipolar electric field pulse in the VLF/LF band which was followed by a pair of ground and ionosphere reflections when observed at 150km away. The differences in the arrival times of narrow bipolar pulse and ground-ionospheric reflections were used to derive the source height of NBE[6,7,8] as its source location was obtained by TOA technique.

During the field campaign in 2012, more than eight mass thunderstorms occurred in Jianghuai area of Anhui province where our network was located. Here we report observations of NBEs in two thunderstorm days (July 4 and 6, 2012). Overall 1395 positive NBEs and 144 negative NBEs were identified and located and their source heights were derived following above process. In the following we will report the waveform characteristics and electrical characteristics for NBEs at different heights.

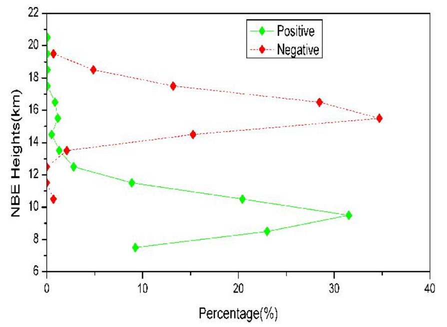

Fig.2 Histogram of NBE heights

III. Results

A. *Source Heights of NBEs*

Showed in Fig.2 was the histogram of NBE heights for 1395 +NBEs and 144 －NBEs. Average height of 9.8km for +NBEs was significantly smaller than that of 16 km for－NBEs, which agreed quite well with findings of other authors[6,7,8]. It was interesting to note that, about 4% (57) of +NBEs occurred at heights equivalent to those of －NBEs (>13km). Since +NBEs were thought to associate with the discharge between the upper positive charge region and lower-altitude negative charge region in thunderstorm, and these +NBEs at heights equivalent to –NBEs possibly indicated raised upper positive charge region for local convective cores in air mass thunderstorms. Unfortunately no information about the electrical structure of parental thunderstorms was available. In the future we plan to examine convective cores associated with +NBEs with higher heights and their possible correlation with –NBEs.

B. *Characteristcs of NBP waveshape*

A summary of characteristics of NBE waveforms was illustrated in Table 1. In general －NBEs were narrower in time than +NBEs, in that the initial rise, the initial peak full width(FW in Table 1), the initial peak width at half maximum(FWHM in Table 1), and event duration of－NBEs were smaller than the corresponding average values of +NBEs. Fig.3 gave the scatter-plot of electric field peak (normalized to 100km) and initial peak width at half maximum as a function of NBE heights. We noted that other time features of NBE show the same trend vs source heights as the initial peak width at half did and were not shown here. As can be seen in Fig.3, +NBEs occurring at altitudes where –NBEs were common were similar to -NBEs in time features of waveforms, except that they behaved different in the electric field strength, as some of －NBEs tended to have extremely strong electric field(>20V/m), which resulted in a significant larger average electric field (and standard deviation) for －NBEs than for +NBEs.

TABLE 1. A summary of characteristics of narrow bipolar events. Please refer to contexts for detail.

	Negative Size=144 Mean(SD)/Min/Max	**Positive Size=1395 Mean(SD)/Min/Max**
Source Heights	16.0(1.2)/10.0/19.7	9.7(1.6)/7.0/20.2
Initial Rise, us	2.7(0.7)/1.8/5.0	3.6(0.9)/2.0/5.8
FWHM, us	3.8(0.8)/2.0/6.6	4.9(1.2)/2.4/10.2
FW, us	6.7(1.2)/3.6/10.6	8.3(1.4)/4.6/14.0
Duration, us	21.9(3.1)/13.6/28.8	30.3(5.1)/13.8/47.2
E-peak, v/m	12.3(7.6)/2.0/35.9	8.7(3.6)/2.1/24.8
Δt, us	3.2(0.9)/1.8/6.4	4.4(1.4)/1.8/11.2
PCM, kA-km	36.0(22.6)/9.5/95.0	29.6(11.9)/5.7/80.0
PQM, C-km	0.25(0.16)/0.05/0.79	0.27(0.12)/0.04/0.83

C. *Characteristics of peak current moment and charge moment for NBE*

According to the viewpoint of electromagnetism, observed narrow bipolar radiation fields in VLF/LF band must be produced by the large current flow along the conductive channel, although what indeed occurred during NBE needed to be further experimentally revealed[13]. One can derive peak current moment (PCM in Table 1) and Charge moment (PQM in Table 1) from observed narrow bipolar waveforms of NBEs[7]. Results of peak current moment and charge moment were also summarized in Table 1. For +NBEs the derived peak current moment ranged from 5.7 kA-km(minimum) to about 80 kA-km (maximum), with a mean of 29.6 kA-km, while for －NBEs the corresponding values were 9.5, 95.0 and 36.2 respectively. The charge moment averaged 0.25 C-km with a minimum 0.05 and a maximum 0.79 for 144 －NBEs and the corresponding values for +NBEs were 0.27, 0.04 and 0.85. Our results were consistent with results for NBEs observed in Shanghai, where －NBEs gave larger values for peak current moment than +NBEs, but both were similar to each other in charge moment[7]. Fig.4 illustrated the scatter-plots of peak current moment and charge moment as a function of NBE

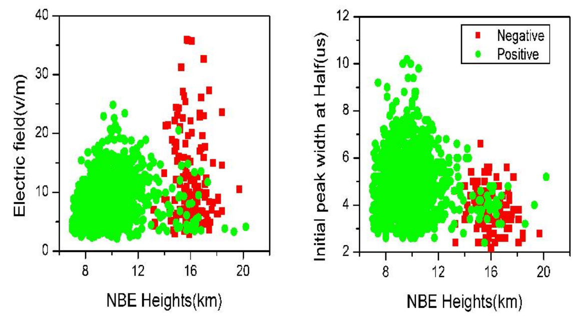

Fig.3 Scatter-plots of electric field and initial peak width at half for narrow bipolar pulses

heights. As for +NBEs occurring at heights where –NBEs are common, they did not show extremely large values of current moment than –NBEs, but showed similar charge moment distribution to the latter.

The discharge channel length of NBE can be approximated as the product of the assumed current propagation speed and the current propagation time along the channel (Δt in Table 1) and the latter can be derived from observed narrow bipolar waveforms[7]. As can be seen in Table 1, the mean value of current propagation time was 3.2 us and 4.4 us for –NBEs and +NBEs respectively. Fig.5 illustrated the scatter-plot of derived current propagation time vs NBE source heights. Again, +NBEs occurring at equivalent heights to –NBEs showed the similar small value of current propagation time to that of –NBEs, while those +NBEs occurring at lower heights tended to have values as large as 5 us or larger. If we assume the current propagation speed as half the speed of light, the average channel length would be about 500m for –NBEs and about 700m for +NBEs, which were consistent with results by other authors[3,4,16]. Taking into account the peak current moment and charge moment above, then the peak current would be 60kA for both –NBEs and +NBEs, and the charge transferred would be as much as 0.5C and 0.4C for –NBEs and +NBEs respectively.

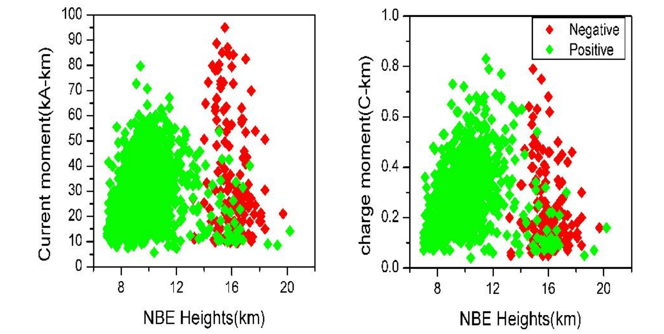

Fig.4 Scatter-plot of peak current moment and charge moment of NBE vs source heights.

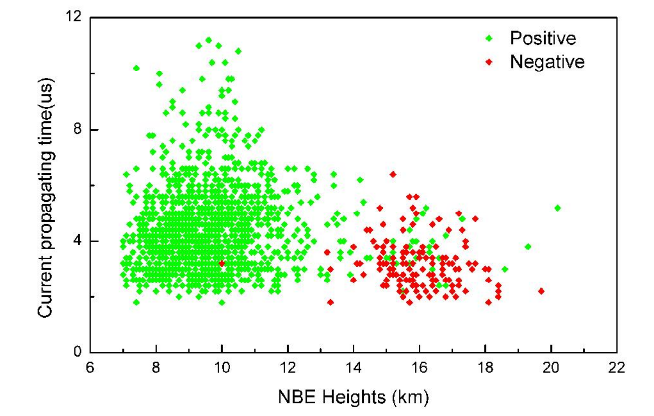

Fig.5 A scatter-plot of current propagating time of NBE

IV. SUMMARY

We summarize our observations of NBEs as follows.

(1)From analysis of data collected in two thunderstorm days during the 2012 field campaign in Jianghuai Area of China, 1395 positive NBEs and 144 negative NBEs were observed, suggesting that both negative and positive NBEs can occur in the relatively lower altitude regions. –NBEs tended to originate at heights of 13-20 km with the mean altitude of 16 km. +NBEs occurred at 7-20 km with a mean altitude of 9.7 km, and about 4% of +NBEs occurred at heights equivalent to those of –NBEs.

(2) On a statistical basis, –NBEs had a mean normalized to 100 km electric field peak of 12.3 V/m, which is significantly larger than the mean value of 8.7 V/m for +NBEs, seemingly implying that –NBEs were more energetic than +NBEs. However, our results suggested that –NBEs were more likely to associate with electric fields of extreme value, which resulted in a larger standard deviation for –NBEs(7.6) than that for +NBEs(3.6).

(3)Time waveform characteristics, including the initial rise time, the initial peak width, the initial peak width at half maximum and the event duration were studied for both negative NBEs and positive NBEs based on their electric field waveforms. Generally speaking, time features of negative NBEs were significantly smaller than those of +NBEs. It was interesting to note that, positive NBEs occurring at the same heights as negative NBEs were similar to the latter in time waveform features, although they were different in electric field amplitudes.

(4) Current moment and charge moment for NBE discharges were also derived from narrow bipolar electric fields. The mean peak current moment of 29.6 kA-km for positive NBEs was slightly less than 36.0 kA-km for negative NBEs, owing to the fact that negative NBEs were more likely to associate with extremely large values. However the mean charge moments was almost the same for both negative NBEs(0.25 C-km) and positive NBEs(0.27 C-km). Based on the estimated channel length (500-700 m) both negative NBEs and positive NBEs involved in charge transfer of the order of 0.4-0.5 C.

A question may be raised as that whether +NBEs and –NBEs were essentially the same discharge process, for example, they were all caused by the relativistic electron avalanche and were possible associated with the Terrestrial Gamma-ray Flashes[17]. Since +NBEs generally occurred at altitudes quite lower than –NBEs, that is to say, they were under different ambient conditions (at least different air pressure), in part it may explain the different between time features of both +NBEs and –NBEs. However, +NBEs which occurred at altitudes common to –NBEs we also observed and they were less associated with extreme large electric field amplitudes than –NBEs did, although they were similar in charge moment, possibly suggested that a far from complex mechanism should be considered and further observations are needed.

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