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Research paper

# Characteristics of Narrow Bipolar Pulses observed from lightning in Sri Lanka

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ABSTRACT

A detailed study on electric field characteristics of Narrow Bipolar Pulses (NBP) observed in Sri Lanka is presented here. NBPs analyzed in this work were recorded at a coastal location in the Southern part of Sri Lanka (Matara: 5.95 °N, 8.53 °E), from five highly active consecutive thunderstorm days during the month of May in 2013. The waveforms were recorded with a 10 ns resolution within a 100 ms time window. Both positive and negative NBPs were observed in this study with the negative type being the most frequent. Parameters presented in this study were the rise time (Tr), zero crossing time (Tz), the duration of slow front (Ts), the full width of half maximum (FWHM), the pulse duration and the ratio of amplitude of overshoot to the corresponding peak amplitude (Os/Pa). The corresponding average values of negative NBPs for these parameters were found to be 0.58 μs, 3.01 μs, 0.20 μs, 1.38 μs, 19.21 μs and 0.19 respectively. Similarly, for positive events corresponding values were 1.38 μs, 4.66 μs, 0.48 μs, 1.93 μs, 16.42 μs and 0.37 respectively. The above values conforms to a much narrower bipolar events when compared to previously reported values which is considered to be caused by the propagation effects of signals captured by the apparatus.



## 1. Introduction

Broadband electric field analysis of lightning has identified pulses of very narrow nature with strong radio frequency radiation mainly in sub tropical and tropical regions. These are known as Narrow Bipolar Pulses (NBP) or Compact Intra Cloud Discharges (CID) as they are considered to be associated with lightning activity inside thunderclouds. But a proper explanation on the origin of these events inside a cloud is yet to be discovered. NBPs have been reported with both polarities and are identified as Positive Narrow Bipolar Pulses (PNBP) and Negative Narrow Bipolar Pulses (NNBP) (Willett et al., 1989; Smith et al., 1999, 2004; Eack, 2004). Classification of the polarity depends on the sign convention used. In this study we use the atmospheric sign convention where, NBPs which have the same initial polarity as of the electric field change shown by downward negative charges are considered as positive.

The first historic observation of these activities was by Le Vine (1980) which were observed as highly energetic lightning events at high and very high frequency bands which did not accompany any other known signals. Since majority of the recorded pulses occurred after first return strokes, Le Vine (1980) speculated this to be an activity related to K processes.

Cooray and Lundquist (1985) published results of a study where similar pulses were observed in a similar tropical location (Sri Lanka) with much wider durations and of greater frequency of occurrence. But, it was Willett et al. (1989), who first carried out a detailed analysis of the electric field and its time derivative changes of NBPs. The classification of pulses based on polarity and the fact that these events had no association with other lightning processes were the main findings of their study. In addition, they observed that amplitudes of NBPs were comparable to the values of first return strokes in cloud to ground (CG) lightning observed in the same experiment. Also they reported that these pulses radiated much stronger radio frequencies when compared to first return strokes. Thus the above study gave the NBP events much more recognition in the area of lightning research.

Medelius et al. (1991) published another study where similar events were identified using wide band electric field sensors at the Kennedy Space Center. Over 150 narrow pulses with close characteristics to that of NBPs were identified in this study. Similar to Willett et al. (1989), the data consisted of pulses of both polarities with the negative type outnumbering the positives by a ratio of 16 to 1.

The source locations of NBPs were identified by Smith et al. (1999). According to them, the pulses originated from the most active areas of a thunderstorm which was in close proximity to

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high reflectivity cores located between 8 and 11 km above sea level. Three broadband (3–30 MHz) data acquisition systems and multiple station electric field change meters were used to measure the relative time of arrival (TOA) values for the signals reflected from the ionosphere and Earth when calculating this height parameter. They reported that High Frequency (HF) emissions from NBPs were found to be nearly ten times more powerful than that of normal lightning discharges. In conclusion they stated that NBPs were not related to any of the CG or cloud to cloud (CC) discharges and it was some form of unidentifiable activity which originated within the most active areas of the thundercloud.

Rison et al. (1999) proved the claim of Smith et al. (1999) in the same year by using a three dimensional very high frequency (VHF) TOA lightning location system. They showed that the discharge processes which gave rise to NBPs occurred between the main negative and main positive charge centers of the cloud and also speculated that these events were actually the initial stages of an otherwise normal intra-cloud discharge. According to Suszcynsky and Heavner's (2003) study, the strength of convective updrafts in the thunderstorms was considered as the driving factor for the flash rates and the source heights of the NBPs. They also inferred a statistical correlation between NBP flash rates and CG flash rates and also that the heights of NBPs rose with the increasing flash rates. Eack (2004) carried out studies on close range NBP waveforms and concluded that on average a NBP event transferred 0.3 C of charge over a distance of 3.2 km with the discharge wave front propagation speed of one-half the speed of light.

Sharma et al. (2005) study on cloud flashes in Sweden provided a comprehensive analysis on the cross correlations among various parameters of NBPs. They observed that the amplitude of the overshoot having a linear relationship with peak amplitude but none of the other parameters had such a relationship with the peak amplitude. Also a linear correlation was seen between rise time and FWHM, rise time and zero crossing time and the FWHM and zero crossing time.

Jacobson and Heavner (2005) suggested that NBPs could be used as proxies for severe convection in thunderstorms. They further confirmed the fact that NBPs originated from the same thunderstorm system where other lightning activities took place with the characteristic of being spatially more compact and isolated compared to any other lightning activity. Additionally they speculated that these events were initiated by extensive air showers of energetic cosmic rays.

After Cooray and Lundquist (1985), the next study on NBPs in the Sri Lankan region was carried out by Sharma et al. (2008). They observed only Positive Narrow Bipolar Pulses (PNBP) and not a single Negative Narrow Bipolar Pulse (NNBP). They speculated that the meteorological conditions and the height of the thunderstorms have control on the polarity of the NBPs and its event frequency during the recorded period. Their temporal parameters of the NBPs recorded were significantly small compared to the previous study by Cooray and Lundquist (1985). The speculation of Sharma et al. (2008) on the propagation effects of the NBP signal was later proved by Cooray et al. (2014a) where a similar model was verified using actual data collected in the same region in 2013.

The most recent complete temporal analysis of NBPs in the tropics was carried out by Ahmad et al. (2010) where a large number of such events were recorded from a location in Malaysia. Similar to the current study, a significant number of parameters pertaining to both NNBPs and PNBPs were analyzed in Ahmad et al. (2010). Their results were too affected by the propagation effects of the signal due to the location of their sites being approximately 30 km inland from the seashore. In addition, Nag et al. (2010) examined the wideband electric fields, magnetic and electric field derivatives and the narrow band VHF radiation bursts produced by NBP events. They concluded that majority (73%) of the NBP events was isolated from any other lightning process and roughly 24% of them were found to occur prior to, during or following the CG or other IC lightning. Also they found evidence of some NBPs to actually occur above cloud tops in clear air or in convective surges (plumes) overshooting the tropopause and penetrating deep into the stratosphere. Wu et al. (2011) carried out a comparative statistical study based on polarity of NBPs. The positive NBPS were found to occur in comparatively higher altitudes than the negative ones. Also the occurrence of positive NBPs were found to be rare and they showed to be more temporally compact and more isolated than the positive NBPs. A study done by Wu et al. (2014) has presented that these NBP events were found to initiate lightning. These are named as INBPs (Initiator Narrow Bipolar events). They found them to occur in lower heights (less than 10 km) than the normal NBP events. According to their study, majority of the INBPs developed into intracloud flashes while a very few resulted in ground flashes.

The studies on the theoretical aspect of NBPs began in the early 2000 s and are rapidly progressing to date. Gurevich et al. (2002) theorized that NBPs could be generated by the simultaneous action of runaway electron avalanches and extensive air showers. The transmission line model was modified by Watson and Marshall (2007) to reproduce an observed NBP waveform. Nag and Rakov (2010) proposed a bouncing wave model in describing the source of NBPs. In addition, Cooray et al. (2014b) presented the possibility that NBPs could be produced by relativistic avalanches using actual data of nearby and far away NBPs by utilizing them in mathematical equations which provided agreeable results. Also recently, Da Silva and Pasko (2015) proposed that NBPs might be generated by the initial lightning leaders inside compact areas of strong field inside of thunderclouds.

The present study was carried out by using data recorded during the South-West monsoon period in early May 2013 with over 150 events which included both NNBPs and PNBPs. Only events which were isolated were considered for this study. A coastal location was selected as the study site. A statistical analysis based on the polarities and temporal features of NBPs is presented in this study.

## 2. Measurements

The data presented were recorded in 2013 at Matara (latitude 5.95 °N, longitude 80.53 °E), a location in the coastal belt in southern part of Sri Lanka which was approximately 50 m from the sea shore. The measurements were carried out during the period which spanned from mid April to mid May (onset of South-West monsoon season). The period from 1st to the 5th of May were the most active time period of this study, thus the data presented were obtained specially from that period.

The data were obtained from a combination of two different antenna systems that was employed with the intention of capturing both the horizontal and vertical electric field signatures of lightning activities. A flat plate parallel antenna system with identical dimensions as in (Fernando and Galvan, 2000) and the nontraditional spherical antenna system with identical dimensions as in (Thomson et al., 1988) were both set to capture data simultaneously. The dimension of both antennas was significantly small when compared to the measured signals wavelengths. Thus as mentioned in (Fernando and Galvan, 2000), it did not impact the measured values of the signals. Since this study focuses on the details of NBP's vertical field characteristics, the data obtained from the vertical plate of the spherical antenna was used along with data from the flat plate antenna. Simultaneous measurements showed that the data obtained were temporally identical but there is a clear difference in the magnitude. This was due to