Electric field signatures of narrow negative bipolar pulse activities from lightning observed in Sri Lanka

T. A. L. N. Gunasekara, U. Mendis,
M. Fernando, U. Sonnadara
Department of Physics, University of Colombo, Colombo 3, Sri Lanka

V. Cooray
Department of Engineering Sciences
Uppsala University
Uppsala, Sweden

Abstract - Isolated Narrow Bipolar Pulses (NBP) have been observed in the past in sub tropical and tropical regions. This study presents detail electric field characteristics of NBP pulses observed in Sri Lanka in the tropic. NBP analyzed in this work were recorded at Matara (5.95 °N, 8.53 °E), southern coast of Sri Lanka from four highly active thunderstorm days in May 2013. The waveforms were recorded with a 10 ns resolution within a 100 ms time window. In contrary to previous observations at the same geographical region, both positive and negative NBP pulses were observed in this study. Parameters related to Narrow Negative Bipolar Pulses (NNBP) are presented in this study since majority of the observations were in that category. The parameters measured for NNBP's were rise time (Tr), zero crossing time (Tz), the duration of slow front (Ts), the full width at half maximum (FWHM) and the ratio of amplitude of overshoot to the corresponding peak amplitude (Os/Pa). The corresponding average values for these parameters were found to be 0.49 µs, 2.83 µs, 0.18 µs, 1.18 µs and 0.17 respectively. The above values conforms to a much narrower bipolar pulses when compared to values reported in earlier studies.

Keywords - Lightning; Electric field signatures; Narrow Negative Bipolar Pulses

I. INTRODUCTION

Narrow Bipolar Pulses which are also known as Compact Intra-cloud Discharges (CIDs) is a special type of intra cloud lightning activity with a relatively small temporal distribution (in the microsecond scale). NBPs were initially reported in 1980 [1] and later by many other studies [2-8]. Nearly all of these studies showed that NBPs could not be assigned to one specific activity of cloud or ground lightning and thus the exact origin remains unclear. Nevertheless the studies carried out to date provide some basic properties to identify the NBPs from recorded electric field data.

According to [7], only Narrow Positive Bipolar Pulses (NPBP) were observed in Sri Lanka but not a single Negative Bipolar Pulses (NNBP). However, in this study majority of the NBP recordings were from NNBP activities. The data were recorded on four consecutive days in May 2013 during the South-West monsoon season.

II. MEASUREMENT

The data presented in this paper were recorded in Matara (latitude 5.95° N, longitude 80.53 ° E) a popular tourist destination at the coastal belt in southern part of Sri Lanka. Antenna system was mounted at about 50 m height from the level of the ocean. Measurements were carried out from end of April to beginning of May (onset of South-West monsoon season) in 2013. The vertical electric fields were sensed by parallel plate antenna which was fed to a high speed data acquisition unit (Yokogawa SL1000, 4 channels) through a high speed, high bandwidth buffer circuit based on MAX460 integrated circuit. The decay time of the buffer system was around 18 ms. RG-58 coaxial cables with proper 50 Ω terminations were used to connect the buffer and the data acquisition unit with lengths around 10 m. The data acquisition unit was set to trigger in window mode enabling to trigger for both positive and negative signals. The trigger threshold was set to 50 mV.

III. RESULTS AND DISCUSSION

The selected four thunderstorm days (May 1st, 2nd 4th and 5th 2013) were the most active during the measurement period. During the four days 145 isolated NBP were observed. Out of this sample 139 were NNBP and 6 were PNBPs. In addition, a large number of non isolated NBP events were also observed which were not considered in the present analysis.

Fifty NNBP with minimum distortion were selected for the detailed analysis. A typical record of a NNBP is shown in Fig. 1 and the expanded view of the same is shown in Fig. 2 . Table 1 shows the range, arithmetic and geometric mean values of the NNBPs measured in this study.

Majority of studies conducted on NBP events has reported details of only NPBP activities. This was evident in [8] where a historical comparison of both positive and negative components in similar studies are given. Thus for ease of comparison, a similar tabular form as in [8] was used to present our data (see Table 1). The comparison with previous studies are presented in Table 2.

978-1-4799-3544-4/14/$31.00 ©2014 IEEE

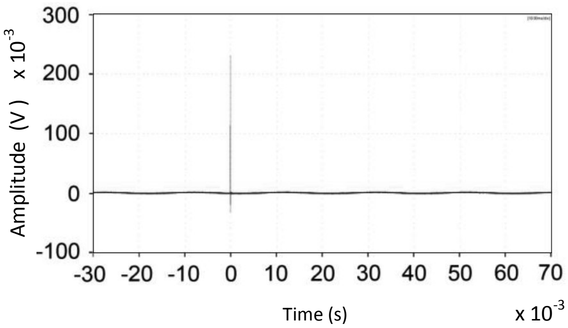

Figure 1. Typical negative narrow bipolar pulse observed in this study. No other activity was observed within a total time window of 100 ms (recorded on 04 May 2013).

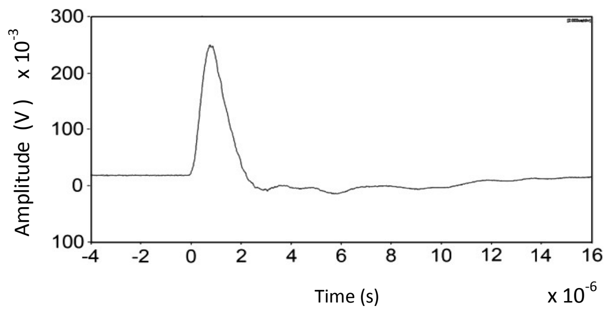

Figure 2. Fine structure of the NNBP expanded from Fig. 1

Table 1. Summarized values for the major parameters measured from the NNBP records.

Characteristic	Range	Mean Value	Geometric Mean value
Rise Time (Tr) (10 - 90%) (µs)	0.35 - 0.73	0.49 ± 0.10	0.48
Slow front duration (µs)	0.06 - 0.55	0.18 ± 0.08	0.16
Zero Crossing time (Tz) (µs)	2.16 - 3.93	2.83 ± 0.43	2.80
Full Width at Half Maximum (FWHM) (µs)	0.99 - 1.72	1.18 ± 0.17	1.17
The ratio (Overshoot/Peak amplitude)	0.11 - 0.28	0.17 ± 0.04	0.17
Pulse Duration (µs)	11.09 - 27.20	18.63 ± 3.16	18.36

Table 2. Comparison of NNBP's features of present study with previous studies

Reference	Rise Time (µs)	Zero Crossing Time (µs)	FWHM (µs)	Ratio O_s / P_a	Pulse Duration (µs)
Present Study (2014)	0.49 ± 0.10	2.83 ± 0.43	1.18 ± 0.17	0.17	18.63 ± 3.16
Ahmad et al. (2009)	1.6 ± 1.0	9.0 ± 45	2.2 ± 0.7	0.28	24.6 ± 17.1
Medelius et al. (1991)	1.82 ± 0.87	-	1.83 ± 0.63	-	-

The pulse duration varied from 11.09 to 27.20 µs but as seen in Fig. 3, majority of the pulses were in 16 - 24 µs interval. The resultant mean value was 18.63 µs with a geometric mean of 18.36 µs. These values were comparatively low to values reported in study [8].

The Zero Crossing Time (Tz) had a mean value of 2.83 µs, which is almost 70% less than the value reported in [8]. It varied with a minima of 2.16 µs to a maxima of 3.93 µs (Table 1). Fig. 4 depicts that majority of the events had values between 2.4 µs to 3.2 µs.

Rise Time (Tr) varied within a range of 0.35 µs to 0.70 µs. But as seen in Fig. 5, majority of pulses fall in the 0.40-0.55 µs range. A mean value of 0.49 µs and a geometric mean of 0.48 µs, which was nearly one third the values reported by [4] and [8] was obtained for Tr. Thus the "narrowness" of the pulses is significant.

The full width at half maximum (FWHM) summed up to a mean value of 1.18 µs which was nearly half the value of the studies of [4] and [8]. The data had a range of 0.99 - 1.72 µs but the Fig. 6 depicts a skewed distribution where majority of values fell in the 1.1 -1.2 µs interval.

Ratio of Overshoot to Peak amplitude resulted in a mean of 0.17 once again giving a value of 30% of earlier reported results [8]. It too presents a skewed graphical distribution (Fig. 7) with majority of values in the 0.14 - 0.22 range.

All of the temporal parameters had a common feature of being considerably shorter when compared to previous studies (Table 2). This property is considered to be due to meteorological differences or the effect of ground conductivity [8].

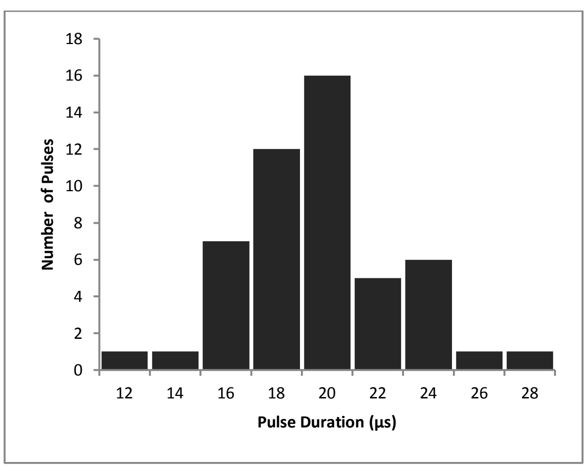

Figure 3. Pulse duration distribution

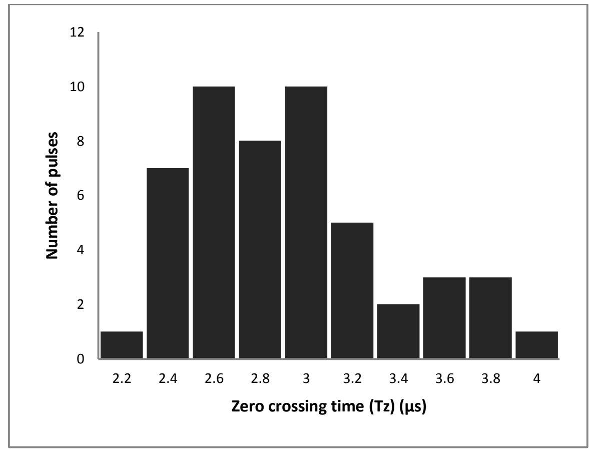

Figure 4. Zero Crossing Time (Tz) distribution

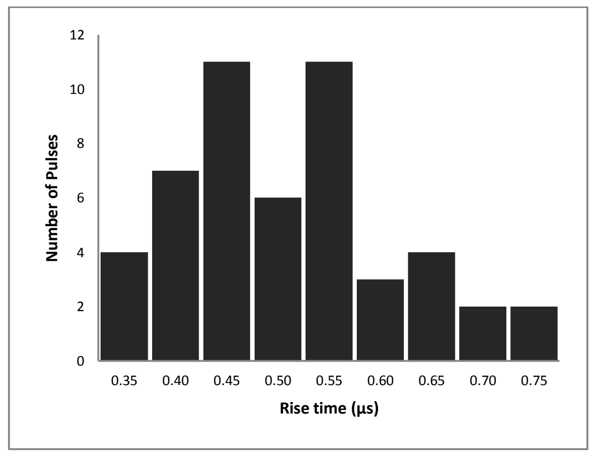

Figure 5. Rise Time (Tr) distribution

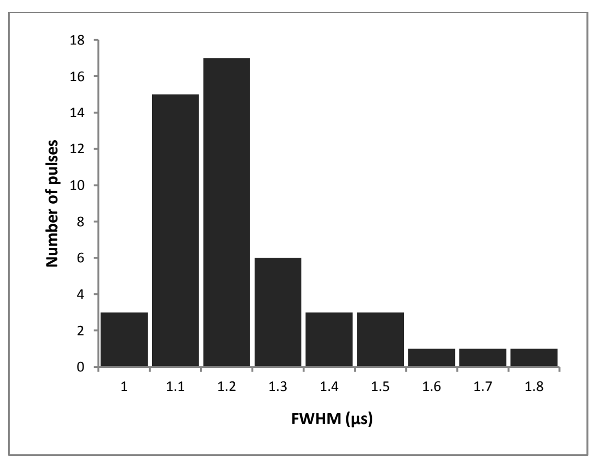

Figure 6. Full Width at Half Maximum distribution

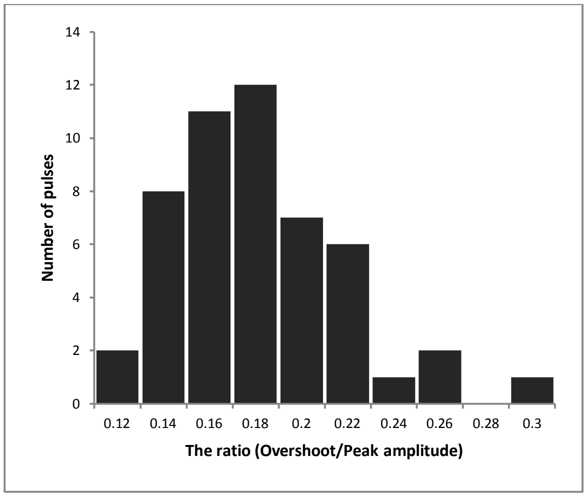

Figure 7. Overshoot to Peak amplitude ratio distribution

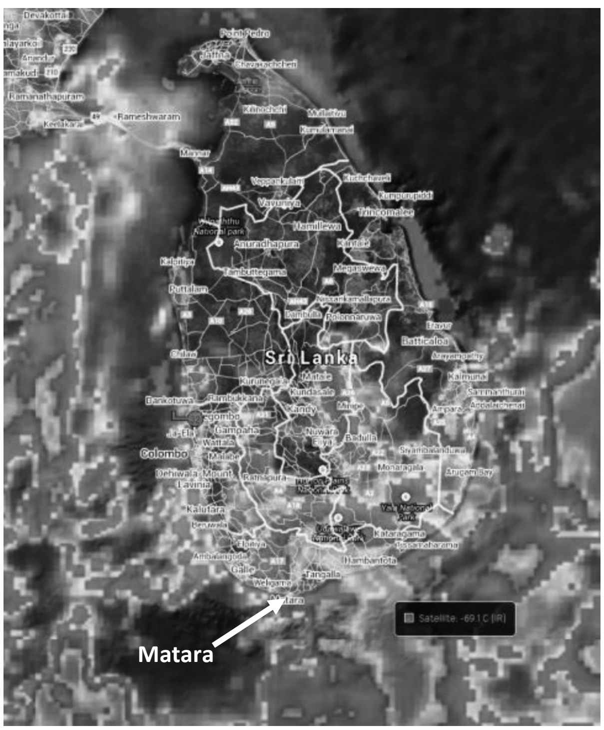

Figure 8. Cloud distribution on the 1st May 2013 at 16:00 UTC. The areas in red denote cooler regions which are considered to be as the origins of lightning activity. According to the scale the approximate distance between the charge centre and measurement site was 80 km. (image obtained from http://www.wunderground.com)

In theory, if an electric signal is to propagate over a finitely (less) conducting land area, the resultant wave signature is expected to be wider due to the propagation delay. This has been mathematically modeled and shown [9]. Due to the relatively high conductivity of sea water, attenuation on electric field signatures propagating over sea is comparatively negligible.

The satellite weather images (Fig. 8) obtained during the data acquisition periods suggests that majority of the NBP events recorded originated from active cloud centers located approximately 20-80 km away over the southern Indian ocean. Since the antennas were situated about 50 m from the shoreline, the NBP signals propagated mostly over a large body of sea. According to previous study [8] their site was located 30 km inland from shore and thus the signals they encountered propagated mostly over finitely conducting land. This meant that signals obtained in the previous work [8] was further attenuated than the present work which would result in larger values for the temporal parameters
.

IV. CONCLUSION

The scarcity of NPBP events observed in this study which indicate a complete opposite picture compared to [7] could be attributed to the charge distribution pattern of the thunder cloud on the given dates. Thus it is possible to conclude that we could expect NBPs with both polarities associated with lightning activities in Sri Lanka. However, depending on thunderstorm properties one polarity of the NBP may dominate on a given day.

The other key characteristic of the current measurements was the significantly shorter values obtained for all the temporal parameters when compared to past studies. This was identified to be caused by the cloud centre's location with respect to the measurement site which was largely over sea. The propagation effects were identified as the causality of this property.

V. ACKNOWLEDGEMENT

Authors wish to acknowledge Dr. J.A.P. Bodhika, Department of Physics, University of Ruhuna for facilitating the measurements at Matara and Mr. W.P. Gunarathna, the staff technical officer of the workshop of Department of Physics, University of Colombo for assisting in the construction of equipment. This work was funded by the University of Colombo research grant AP/3/2012/CG/24.

REFERENCES

[1] D. M. Le Vine, "Sources of the strongest RF radiation from lightning," Journal of Geophysical Research 85, pp. 4091–4095, 1980.

[2] V. Cooray, S. Lundquist, "Characteristics of the radiation fields from lightning in Sri Lanka in the tropics," Journal of Geophysical Research 90, pp. 6099–6109, 1985.

[3] J. C. Willett, J. C. Bailey, E. P. Krider, "A class of unusual lightning electric field waveforms with very strong HF radiation," Journal of Geophysical Research 94, pp.16255–16267, 1989.

[4] P. J. Medelius, E. M. Thomson, J. S. Pierce, "E and DE/DT wave shapes for narrow bipolar pulses in intracloud lightning," Proceedings of the International Aerospace and Ground Conference on Lightning and Static Electricity, NASA Conference Publ., vol. 3106, pp. 12-1–12-10, 1991.
[5] D. A. Smith, X. M. Shao, D. N. Holden, C. T. Rhodes, M. Brook, P. R. Krehbiel, M. Stanley, W. Rison, R. J. Thomas, "A distinct class of isolated intracloud lightning discharges and their associated radio emissions," Journal of Geophysical Research 104, pp. 4189–4212, 1999.
[6] S. R. Sharma, M. Fernando, C. Gomes, "Signatures of electric field pulses generated by cloud flashes," Journal of Atmospheric and Solar-Terrestrial Physics 67, pp. 413–422, 2005.
[7] S. R. Sharma, M. Fernando, V. Cooray, "Narrow positive bipolar radiation from lightning observed in Sri Lanka," Journal of Atmospheric and Solar-Terrestrial Physics 70, pp. 1251–1260, 2008.
[8] N. A. Ahmad, M. Fernando, Z. A. Bahaudin, V. Cooray, H. Ahmad, Z. A. Malek, "Characteristics of narrow bipolar pulses observed in Malaysia," Journal of Atmospheric and Solar-Terrestrial Physics 72, pp. 534-540, 2010.
[9] V. Cooray, M. Fernando, L. Gunasekara, S. Nanayakkara, "Propagation effects on radiation fields known as narrow bipolar pulses generated by compact cloud discharges," unpublished.