INTERNATIONAL CONFERENCE ON LIGHTNING PROTECTION
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

Time Derivative of Electric Field Radiation Generated by Compact Intra-cloud Discharge

R.Abeywardhana, M.Fernando, U. Sonnadara
Department of Physics
University of Colombo
Colombo 3, Sri Lanka
abeywardhana.jamrc@gmail.com

V.Cooray
Department of Engineering Science
Uppsala University
Uppsala, Sweden
vernon.cooray@angstrom.uu.se

***Abstract*— Time derivatives of electric field radiation (dE/dt) generated by Narrow Bipolar Pulses (NBP) in two tropical thunderstorms are investigated and two types of pulse characteristic in dE/dt signal were identified. One type is with high-frequency chaotic noise bursts while the other type exhibit rather regular high-frequency bursts. According to the frequency spectrums of dE/dt signatures which are obtained using S-transformation, those two types of NBPs imply significant variation in higher frequency distribution. These variations in dE/dt signatures may be due to different physical behavior of compact intra-cloud discharge (CID).**

Keywords- lightning; Compact intra-cloud discharge; narrow bipolar pulse; time derivative of electric field

I. INTRODUCTION

The Bipolar shape pulses with very short duration in electric field records generated by CID which was termed as narrow bipolar pulses was first reported by Le Vine [1]. Later Willett et al., [2]; Smith et al., [3]; Ahmed et al., [4] and Gunasekara et al., [5], have analyzed nature of NBPs in radiation electric field. NBPs have been identified in both negative (NNBP) and positive (PNBP) polarities which defined according to the atmospheric sign convention. Most of NBPs occur in isolation without any associated electric field pulse. However, Nag et. al. [6] reported that about 6% of total NBPs in his study occurred as a part of cloud to ground flash activities. The chance of detecting NBPs is higher in the initiation stage of a thundercloud. NBPs in radiation electric field are considered to be associated with some lightning activity inside the thunderclouds. However, a proper explanation on the origin of these events inside clouds is yet to be revealed.

Gunasekara et al. [5] conducted a study on electric field characteristic of NBP in the same region of present study. According to them, electric fields of NNBP are narrower than PNBP with FWHM is in the range of 0.48-2.38 µs while the mean value is 1.38 µs. Zero crossing time is in the range of 2.16 - 6.4 µs with a mean value of 3.1 µs.

Willett et al. [2] presented analysis of dE/dt signature of NBPs. The time derivative of radiation electric field of NBP has exhibited high frequency noise superimposed on bipolar shape pulse that one might expect by studying electric field signatures [2]. Also, its spectral energy at high-frequency is higher than return storks.

NBPs have recognized as a source of strong RF radiation thus they can affect highly sensitive electric and electronic equipment and networks. The knowledge of time derivative of radiation electric field and its energy distribution is more important when considering the way, they affect electrical component. The present study is carried out to find the different characteristics of dE/dt signatures associated with NBPs.

II. MEASUREMENTS

Electric field and its time derivative generated by NBP were recorded at the measurement site that was located in Matara (5.9367º N, 80.5738 º E) at southern coastal belt of Sri Lanka. The measurements were carried out during the south-west monsoon period, which spanned from October to Late November. The measuring system was consisted with a flat plate antenna system similar to the one used in [7]. Antenna system was located approximately 50 m away from the Indian ocean. Electric field measurements were recorded by a digitizer (pico6402B) with 12-bit resolution and a 3.2 ns sample interval with 100 ms recording length. The time derivatives were recorded by Tektronix MDO3024 with 8-bit resolution and 0.4 ns sampling interval with 4 ms sample window. Unfortunately, there was no evidence on the location of NBPs except for cloud images (Fig. 1).

III. RESULTS AND DISCUSSION

The electric field and its time derivative data presented in this study are recorded during two thunderstorms in 21st November 2015 and 25th November 2015. According to the visual evidence both were heavy thunderstorms occurred over the sea. The satellite images (Fig. 1) confirmed the existence of heavy cloud above the sea about 200 km away from the measurement site. The sky over the measuring site was also covered with thick cloud.

Two electric fields and their time derivative associated with isolated NBPs are presented in Fig. 2 and Fig. 3. The electric field signatures (Fig. 2(a)) imply characteristics of a typical

NBP [5]. Although the electric field appears to be relatively smooth pulse, the time derivative of the same NBP (Fig. 2(b)) shows high-frequency noise associated with slower varying bipolar shaped pulse. Willett et al. [2] have observed the same characteristic in dE/dt signatures of NBPs which had been propagated 45 km over the sea surface.

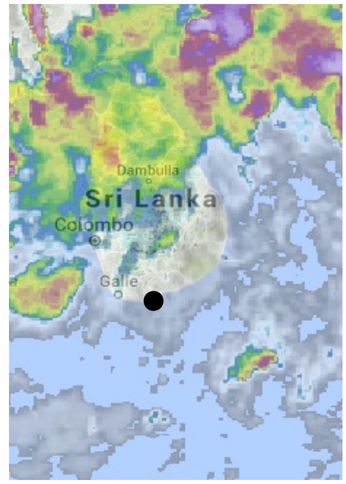
Fig. 3(a) and Fig. 3(b) show electric field and dE/dt signatures of another observed NBP. The electric field pulse is relatively smooth similar to Fig. 2(a), but characteristic of its dE/dt signature deviate from observations of [2]. It shows rather regular sub-microsecond pulse burst which begins immediately before a slow bipolar pulse.

According to Fernando and Cooray [9] in general, dE/dt signature implies sub-microsecond pulse burst superimposed on main characteristic pulse (which is similar to mathematical time derivative electric field record) same as we observed in dE/dt signature of NBP pulses. They found that the sub-microsecond pulse burst can be observable only for few hundreds of meters due to propagation effect over finitely conduction surface. According to those details and the cloud images (Fig. 1), NBP in Fig. 3 should be occurred over sea or near measuring site.

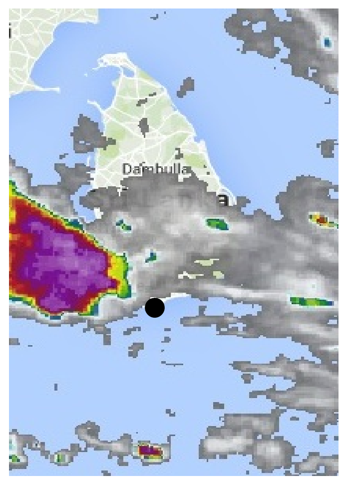
Six of each type of NBPs were selected to study characteristic of their radiation electric field and dE/dt signatures (Table 1). According to the parameters in Table 1, NBP with regular noise dE/dt are narrower than NBP with chaotic noise dE/dt. Cooray et al., [8] have shown NBP could be narrower than the values reported in the literature due to propagation effect. Narrower pulse shape may be observed when it propagates over highly conductive surface like sea. Considering narrowness of the NBP with regular noise (Fig. 3(a)) and considering the suggestions given in [8], this NBP should be not affected by propagation effects.

Both dE/dt signals in Fig. 2(b) and Fig. 3(b) are filtered using high pass digital filter with 1 MHz cut-off frequency (Fig. 4(a) and Fig. 4(b) respectively). According to those filtered waveforms, the high-frequency components in dE/dt show significant differences in wave shapes. The frequency spectrums which have obtained using s-transformation shows that high-frequency noise in dE/dt signal with chaotic noise distributed over duration of NBP (Fig. 5(a)). However in the case of regular noise dE/dt, higher frequency component of the signal is concentrated at the first few hundred nanoseconds of pulse (Fig. 5(b).

Considering above observations dE/dt signatures of NBP show different characteristic even the electric field pulses are identical. Further studies are required with location details of NBP and larger sample size, to determine whether the observed variations in high frequency component are due to their different physical origins.



(a)

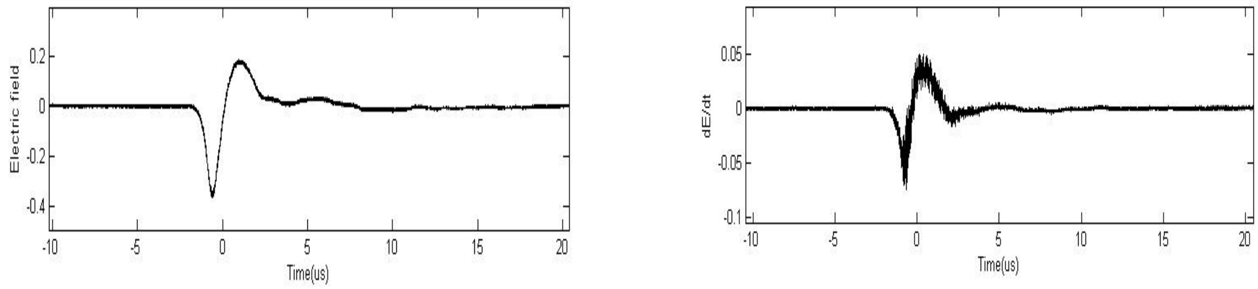


(b)

Figure 1. Satellite image obtained during the active times of the thunderstorm in (a) 21/11/2015 and (b) 25/11/2015. Dark dot shows the location of measurement site

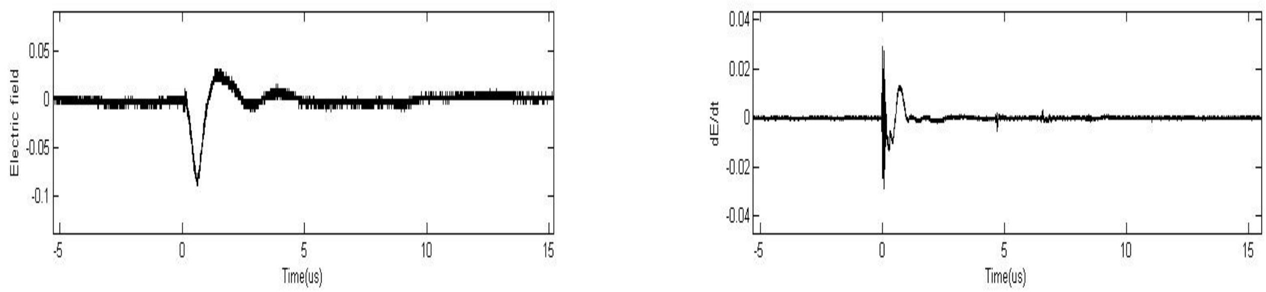
TABLE I. CHARACTERISTIC OF RECORDED RADIATION ELECTRIC FIELD AND ITS TIME DERIVATIVE.

	Reference	Regular noise dE/dt	Chaotic noise dE/dt
Electric Field	**Full width at half maximum-FWHM (us)**	0.87	1.90
	Rise time (us)	0.48	1.09
	Zero crossing time (us)	1.07	2.46
	Pulse duration (us)	2.42	7.02
Time Derivative of Electric Field	**Full width at half maximum-FWHM (us)**	0.29	1.43
	Rise time (us)	0.17	0.40
	Zero crossing time (us)	0.57	1.84
	Pulse duration (us)	0.91	3.73



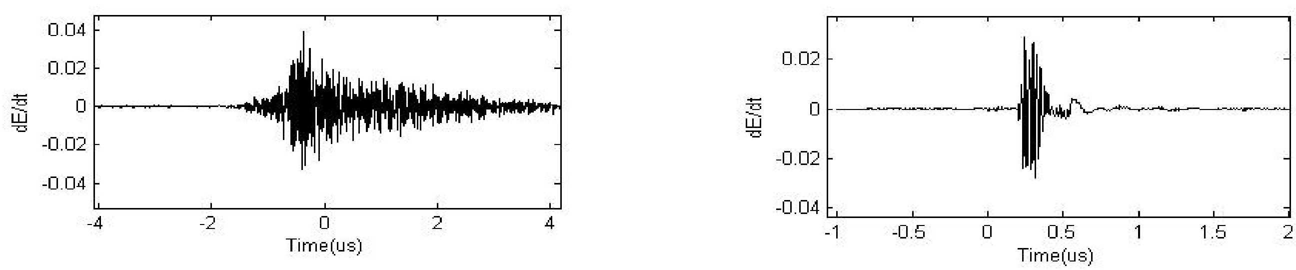
(a) (b)

Figure 2. NBP recorded in 21-Nov-2015, in the forming stage of a thundercloud (a) electric field record and (b) time derivative of electric field.



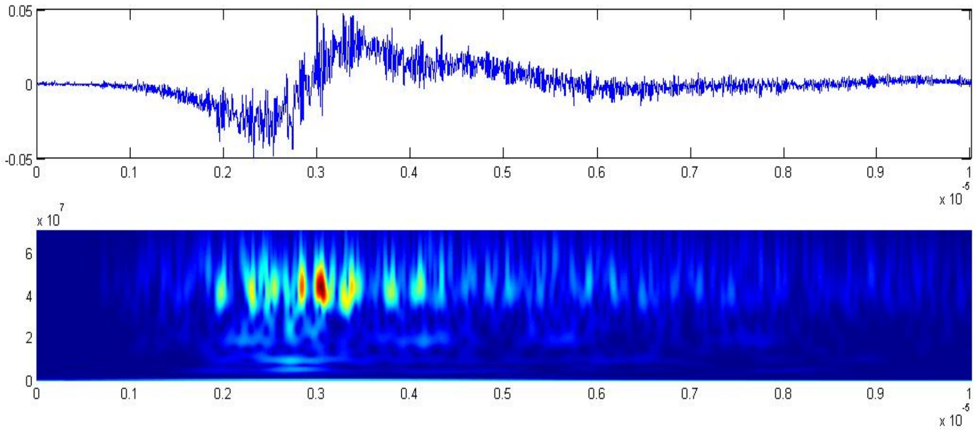
(a) (b)

Figure 3. NBP recorded in 25-Nov-2015, in the last stage of a thundercloud (a) electric field record and (b) time derivative of electric field.

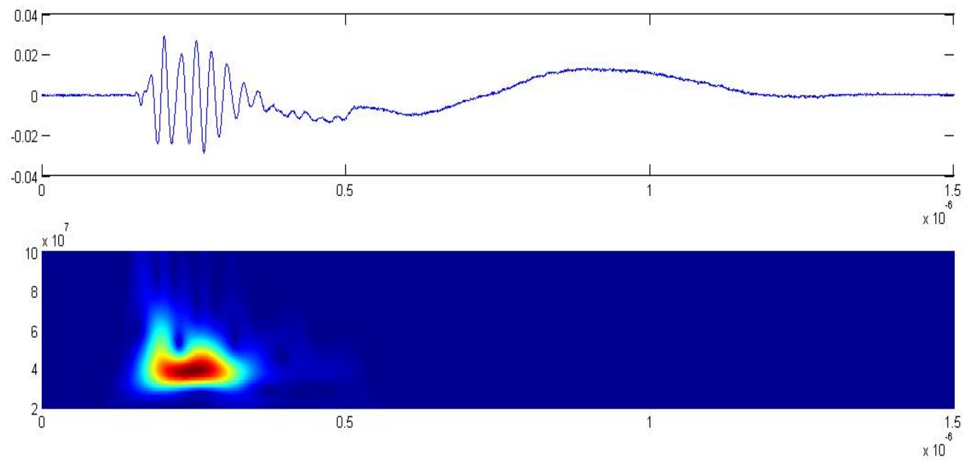


(a) (b)

Figure 4. using a low pass digital filter with cut-off frequency of 1 MHz the dE/dt signals (a) in (Fig 1(b)) and (b) in (Fig. 2(b)) are filtered.



(a)



(b)

Figure 5. using S-transformation frequency spectrum of (a) dE/dt signal in Fig. 1(b) and (b) dE/dt signal in Fig. 2(b) are illustrated.

IV. CONCLUSION

Recorded electric fields and their time derivatives of NBPs have been studied. The measurements are taken in two tropical monsoon thunderstorms in Sri Lanka. Although all the NBP electric fields have characteristics of typical CID in literature, corresponding dE/dt signals show two different types. One type is identical to the dE/dt characteristics reported in [2]. That is high-frequency noise with relatively high amplitude superimposed on a slow bipolar pulse which is similar to mathematical time derivative of recorded electric field. Its frequency distribution shows high-frequency noise distributed throughout the pulse duration, and it is higher than the other type of dE/dt of NBP.

The other type of dE/dt signatures imply noise of high-frequency regular pulse burst as a substitute of chaotic noise. Its high-frequency components have concentrated at the start of the bipolar shape pulse. Also, the corresponding electric field signatures are significantly narrower than the other type.

The observed significant difference in narrowness of electric field and high-frequency component of dE/dt records could be due to the origin of these NBPs are two different physical processes.

ACKNOWLEDGMENT

This research was funded by the University of Colombo research grant AP/3/2/2014/RG/09. The assistance given by

U Mendis, and JAP Bodhika in data collection is highly appreciated.

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