Journal of Atmospheric and Solar-Terrestrial Physics 173 (2018) 57–65

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Horizontal electric fields of lightning return strokes and narrow bipolar pulses observed in Sri Lanka

T.A.L.N. Gunasekara [a,*], M. Fernando [a], U. Sonnadara [a], V. Cooray [b]

[a] Department of Physics, University of Colombo, Colombo 3, Sri Lanka
[b] Department of Engineering Sciences, Uppsala University, Uppsala, Sweden

A B S T R A C T

Simultaneous measurement of both vertical and horizontal electric field signatures of lightning was carried out in an elevated location in Colombo, Sri Lanka. The experimental setup used in this work was similar to an earlier study carried out by a different group in the late 1980s. To our knowledge, this is the first instance that such a study is conducted in this region. Data were acquired during the active months (April–May) of the southwest monsoon period in 2014. Lightning flashes from the most active thunderstorm was analyzed by selecting 65 Return Strokes (RS), 50 Negative Narrow Bipolar Pulses (NNBP) and 40 Positive Narrow Bipolar Pulses (PNBP). The wave shapes were initially validated against results of a previous study and subsequently via a theoretical method as well. Since the direction and the distance information was not available, rather than the amplitudes, ratios of the peak amplitudes of vertical electric field (Ev) and corresponding horizontal electric field (Eh) were compared. The average ratio for the return stroke was 0.024 ± 0.008. The same for the NNBP was 0.041 ± 0.004. The PNBP had a ratio of 0.031 ± 0.006. The average 10%–90% rise times (Tr) for Ev for RS, NNBP and PNBP was 2.124 ± 1.088 μs, 0.734 ± 0.077 μs and 1.141 ± 0.311 μs respectively. The Tr values for Eh for RS, NNBP and PNBP were 1.865 ± 1.200 μs, 0.538 ± 0.061 μs and 1.086 ± 0.423 μs.

1. Introduction

A lighting flash causes significant change in the global atmospheric electrical circuit. These changes are studied by analyzing their recorded electric field signatures. These recordings are further segregated based on its directional components as vertical electric field (Ev) and horizontal electric field (Eh) changes.

Typically the magnitude of Eh surpasses Ev in the immediate vicinity of the lightning strike (Miki et al., 2002). But at longer distances this becomes the opposite, where Ev becomes significantly high compared to Eh (Thomson et al., 1988a). Thus when obtaining Eh recordings of distant flashes, it becomes extremely difficult since a minute tilt in the recording apparatus would cause the recorded Eh to be interfered or overshadowed by the Ev signature, which makes the Eh impossible to identify. This practical issue is the main reason for the physically obtained data sets of Eh to be limited to just five in number up to date (Shoory et al., 2011).

When considering the lightning generated electromagnetic field interactions with power lines, underground cabling and other networks related to power and communication, the study on characteristics of Eh is considered to be the more important than that of Ev (Cooray and De la Rosa, 1986; Nucci et al., 1993; Rachidi et al., 1999). Also the phenomena of surface flashover at point of strike of lightning flashes are considered to be facilitated by this Eh as well (Cooray, 2010).

The first known instance of measured Eh was presented by Thomson et al. (1988a). The authors utilized a unique experimental antenna which was of spherical shape (Thomson et al., 1988b). They were able to record simultaneous Ev and Eh data of 42 lightning return strokes of 27 flashes at distances ranging from 7 to 43 km. They observed that the ratio between amplitudes of Eh and Ev to be 0.03 ± 0.007. The overshadowing effect of Eh from Ev was experienced in their study and mathematical adjustments were utilized to rectify it.

The second observational data set was from Michishita et al. (1996). Eh of Lightning flashes that occurred far (16–150 km) from the observational site were recorded by using a broadband sensor whilst the Ev was recorded using the parallel plate antenna (Galvan and Fernando, 2000). They observed that a 0.5% of contamination from Ev on Eh present in their data.

In contrast to Michishita et al. (1996) study, Miki et al. (2002) studied the Eh of very close proximity lightning flashes. They used triggered lightning with measurement distances of 0.1–1.6 m between the source and the observation point with the sensors being elevated 2 m above ground level. They witnessed that for lightning flashes in the near vicinity; Eh became larger in magnitude with respect to Ev. This observation was quite important in proving the fact that even without a direct lightning strike; the close proximity changes in Eh could be more

* Corresponding author.
E-mail address: lasitha.niwanka@gmail.com (T.A.L.N. Gunasekara).

https://doi.org/10.1016/j.jastp.2018.04.010
Received 17 December 2017; Received in revised form 19 April 2018; Accepted 20 April 2018
Available online 22 April 2018

devastating than the Ev in the same region. In addition, their data set included channel base current recordings and the Ev, Eh data showed the typical V shaped wave forms as well.

Barbosa et al. (2008) carried out measurements of Eh and Ev of rocket triggered lightning by utilizing special semispherical electrodes buried just beneath ground surface at 60 m away from the triggered location. Their main concern was the step and touch potentials that are generated by a lightning return stroke in immediate vicinity of its strike point. With the growing number of tall metallic towers in urban areas, the study of horizontal field changes in these locations were considered to be necessary for providing sufficient protection. Similar to Miki et al. (2002), the base currents too were recorded simultaneously. They modeled the electric fields generated by the superposition of induced and conducted components and compared it with the actual recordings. It was concluded that the modeled output was in excellent agreement with the actual as long as the conduction component of it was included in the calculations.

The last known measured data set of Eh was recorded by Mosaddeghi et al. (2010). They studied data of lightning strikes to the 100 m tall Gaisberg tower in Austria. Field measurements were done from 20 m away from the tower base, whilst the return stroke currents were simultaneously measured from the top of the tower. The observed Eh wave shapes were of similar to that of the Ev but with a characteristic difference identified by a short negative pulse of the order of 1 μs, which began with a fast negative spike followed by a positive one. Also they observed that E field changes due to the return stroke to be larger on average than to its leader E field changes.

Aforementioned difficulty of physically obtaining Eh drove majority of the studies to focus more on theoretical means to obtain the Eh characteristics. Shoory et al. (2011) has summarized these approaches. Accordingly, exact equations implemented using software algorithms can be used to obtain numerical solutions. For finitely conducting homogenous ground, a method which involves Sommerfeld integrals (Sommerfeld, 1926) in the frequency domain has been identified as successful (Banos, 1966). This method is able to provide the Eh value for locations above, on and below earth surface exactly (Cooray, 2010). But it involves highly mathematical computations which ultimately made it cumbersome to solve. A similar approach was the usage of Maxwell's equations for the same. This method used the Finite Difference Time Domain (FDTD) technique and the Method of Moments (MoM) together which is also computationally complex.

This gave rise to the use of simplified equations that were comparatively less complex to solve and were essential when calculating Eh for especially field-to-transmission line coupling evaluations (Shoory et al., 2011). The wave-tilt formula (Zenneck, 1915), Norton formulas (Norton, 1937) and Cooray - Rubenstien (CR) formula (Rubinstein, 1996) are considered to be the prominent under this category. The measured Ev, along with the wave tilt formula was used by Master and Uman (1984) to obtain theoretical values for Eh. The accuracy in Norton formulas was found to be adequate for lightning flashes that strike a few kilometers from the point of observation. These formulas were further simplified by approximations which resulted in less complex time domain equations. This aspect was initiated by Cooray (1992). The formula which was derived by Cooray (1992) used an expression for the surface impedance of finitely conducting ground and it was found to be accurate for small distances as short as 200 m in between the flash and the observer. This was later modified by Rubinstein (1996) which gave rise to the popular Cooray-Rubenstein (CR) formula that increased the computational efficiency of the original equation. Validity and limitations of the CR formula was analyzed in the frequency domain by Wait (1997). The CR formula was again revised in 2002 by Cooray (2002). He further derived a much simplified formula, specifically for surface and underground Eh values in 2010 (Cooray, 2010).

According to the authors knowledge after Mosaddeghi et al. (2010) no known data set for Eh measurements are available. In this study, the authors have obtained data of both Eh and Ev simultaneously by utilizing a method similar to Thomson et al. (1988a). This is considered to be the latest and the only data set that contains Eh and Ev data of both lightning return strokes as well as of the cloud flash events. Also this is the first time such Eh recordings have been obtained from this region, which is considered to be one of the most active regions for lightning in the world.

In this study we present results pertinent to the horizontal component of the electric fields associated with Narrow Bipolar Pulses (NBPs) and return strokes. NBPs are the radiation fields generated by compact cloud discharges and the characteristics of the vertical field associated with these pulses were described in several recent studies (Nag et al., 2010; Ahmad et al., 2010; Gunasekara et al., 2016).

2. Measurements

The southwest monsoon season begins in the first week of May annually. During the initial few days active thunderstorms are formed which affect the western and southern areas of the island. Thus, the city of Colombo (latitude 6.93° N, longitude 79.86° E) is an ideal location for lightning related experiments.

The study was carried out in an elevated location in Colombo, approximately 1 km from the west coast of Sri Lanka. The antenna was fixed on the roof top of the 3 storied building which house the Department of Physics at the University of Colombo. This location opens up to a large empty space due to an adjacent sports ground. Thus, any distortions or reflections were at minimum on the signals as it propagated from its origins to the capturing antenna sensors.

The sensor utilized in the experiment was a spherical, omni directional antenna (Weerawarne, 2010). It was a replication of an antenna which was developed by Thomson et al. (1988b). Dimension wise the antenna was similar to that of the original. But the rest of the setup consisted of superior electronic components which provided high bandwidth and high resolution. The spherical antenna was equivalent to three flat plate antennas which are aligned along the three axis of a three dimensional plane. The measured vertical E field (Ev) was obtained by setting the antennas vertical plate to face the sky. The remaining plates were aligned where the sensor plates would be along the directions of North and East to capture the horizontal E field change in the direction of North and East respectively. The antenna was erected in a PVC pylon structure and was supported by nylon cables. The centre of the sphere was elevated approximately 3 radiuses above the roof top level. The effective elevated height of the antennas centre was around 13.64 m from the ground level including the height of the building. Three dimensional spirit levels were used to balance the sphere in order to mitigate tilt errors. Thus, except for the total elevation of the setup, up to this stage, all the dimensions of the antenna were kept in line with the Thomson et al. (1988b) study.

Each of the three plates was connected to a buffer circuit that drove the captured signals to the Data Acquisition Unit (DAU). This buffer circuitry was based on the circuits utilized for parallel plate antenna measurements (Galvan and Fernando, 2000). It was modified by replacing the main buffer chip with MAX460; a high input impedance, wider bandwidth IC of military grade. The buffer circuits were housed in three separate metal boxes that were placed inside the spherical antenna. Three separate RG - 58 coaxial cables with proper 50 Ω terminations were used to transmit the buffer output to the high speed DAU (PicoScope 6404B, 4 channels) situated approximately 10 m away from the antenna. The DAU was set to trigger with 50 mV in window mode in order to capture both positive and negative signal variations. The both the horizontal and vertical fields were captured with a time constant of 18 ms. Data captured were of a 3.2 ns resolution within a 200 ms total time window.

The lack of a lightning location system placed some limitations in the data analysis stages. Mainly the measured values could not be normalized since accurate directional and distance data were not available. According to the time stamps of the data, the first return stroke signature was recorded around 2.35 p.m. (local time). The last data record utilized