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Statistical analysis of electric field parameters for negative lightning in Malaysia

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ABSTRACT

This paper presents a comparative study on the electric field and its derivative parameters of negative lightning in Malaysia and other regions. This study is the first in Malaysia where the parameters of negative electric field and its derivative are thoroughly analyzed. 104 negative lightning flashes containing 277 negative return strokes occurring within 10–100 km from the measuring station and recorded during monsoon period in the state of Johor, Malaysia had been analyzed. It was found that 73% of the recorded flashes are multiple strokes with an average multiplicity of 2.6 strokes per flash. For first return strokes, the arithmetic mean (AM) of initial peak electric field and the AM of initial peak electric field derivative are 21.8 V/m and 11.3 V/m/μs, respectively. The initial peaks of electric field and its derivative for first return strokes are larger than those for the subsequent return strokes. Comparison of overall results with those obtained earlier in Sri Lanka, Germany, Sweden, Japan, Florida indicates that several electric field and its derivative parameters are affected by propagation media and geographical region. Similarity of results with other countries having the same climatic condition is also observed.

1. Introduction

Electrical discharges generated in the atmosphere by cumulonimbus clouds, volcanic eruptions, dust storms, and snow storms are usually referred to as lightning discharges. Lightning discharges can be separated into two main categories, namely, the cloud-to-ground (CG) flash, and the in-cloud (IC) flash. Despite the significant interest in the in-cloud discharge and several other transient optical phenomena in the atmosphere, the cloud-to-ground discharge remains the most remarkable, primarily because it is relatively easier to study compared to the IC discharges. Furthermore, most lightning threats on human life and property come from CG lightning, and hence its importance from the application and lightning protection point of view.

Characteristics of lightning flashes in temperate and subtropical regions have been extensively studied in the past three decades (Cooray and Lundquist, 1982; Cooray and Lundquist, 1985; Fisher and Uman, 1972; Heidler and Hopf, 1998; Ishii and Hojo, 1989; Krider et al., 1996; Lin et al., 1979; Master et al., 1984; Rakov and Uman, 1990; Rakov and Uman, 2003; Weidman and Krider, 1978; Weidman and Krider, 1980; Willett et al., 1998; Willett and Krider, 2000). Several parameters of the generated electric fields by the first return stroke were analyzed such as the slow front duration, the 10–90% fast transition duration, the slow front amplitude, and the peak magnitude. (Weidman and Krider, 1978) noted the slow front and the 10–90% fast transition durations are 2–8 μs and 0.2 μs, respectively. Slow fronts have been suggested to indicate the presence of an upward connecting leader (Rakov and Uman, 2003). In another work, (Nag et al., 2012) observed that based on simulation work, the slow front in a far distance electric field waveforms is primarily consisted of the radiation component. However, the slow front in a near distance field may consist all three field components, namely the static, induction and radiation electric fields (Nag et al., 2012). Analyzes on the electric field amplitudes are usually reported as ratios of selected measured parameters. For example, the reported ratios of the slow front amplitude to the peak for the first stroke are 0.4–0.5 (Weidman and Krider, 1978), 0.4 (Cooray and Lundquist, 1982), and 0.3 (Master et al., 1984). Similar parameters were also analyzed for the fields generated by the subsequent return strokes. It is reported that subsequent return strokes which are preceded by dart leaders also exhibit slow fronts (Weidman and Krider, 1978). However, the slow front amplitudes are generally smaller than those for the first stroke. Further similar studies and analyzes in other regions, such as in Malaysia, can help to better understand the electric field characteristics of lightning.

Apart from the electric field, another key lightning characteristics is the multiplicity of strokes. Detailed analyzes on the number of stroke per flash and interstroke intervals had been performed by (Rakov and Huffines, 2003; Sonnadara et al., 2014)

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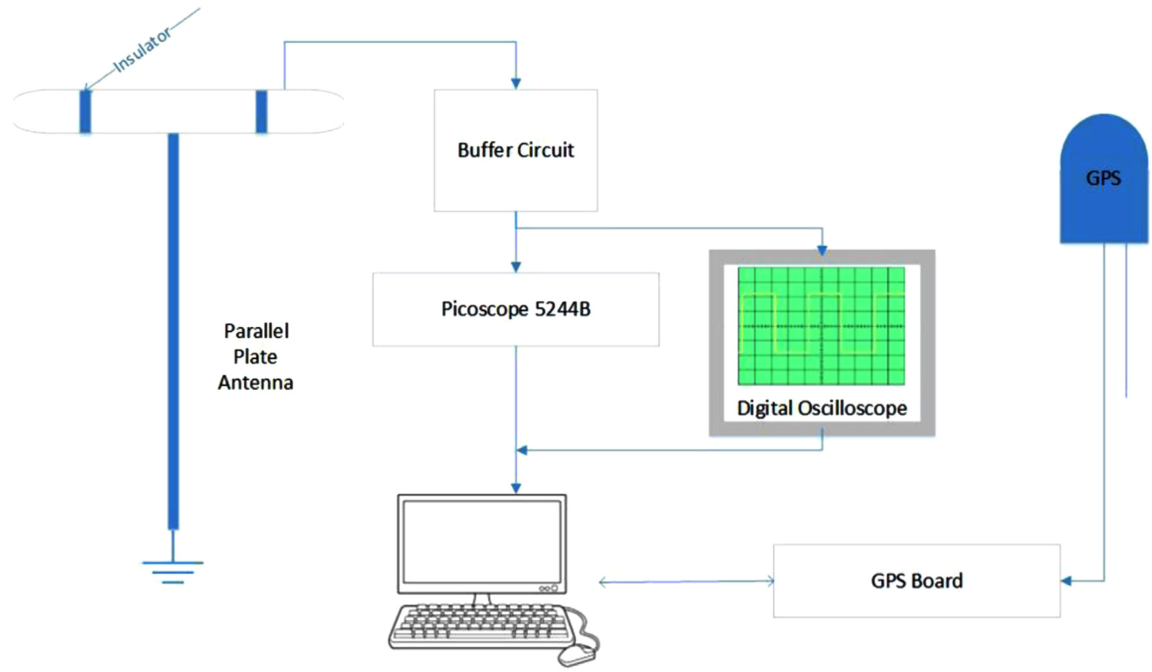

Fig. 1. Schematic description of the lightning detection system.

and (Antunes et al., 2015) using "accurate-stroke-count" studies and high speed cameras. (Rakov and Huffines, 2003) claimed that the accurate-stroke-count studies are based on data from relatively small number of storms, but for all practical purposes, they can be used as the ground truth, because the potential effect of the storm-to-storm variation is expected to be smaller than the effect of using different variation field. Motivated by their analyzes on the number of stroke per flash and interstroke intervals, (Baharudin et al., 2014) conducted an experiment to provide a statistical analysis on the negative cloud-to-ground flashes in Malaysia. However, detailed analyzes on the electric field parameters of the measured flashes were not carried out.

Recently, the lightning electric field was further analyzed in terms of the ionospheric and attenuation effects as well as the introduction of improved signal denoising techniques for different geographical regions. (Haddad et al., 2012) examined the effect of lightning distance (from the measuring sensors) of 265 first- and 349 subsequent-negative return strokes in Florida. It was found that for lightning distances greater than 100 km, the electric field waveform, measured during day time, is oscillatory (instead of normally pulsed shape). Furthermore, the positive half of the second cycle was suggested to be related to the so-called one-hop ionospheric reflection of the lightning field. In another study done by (Rojas and Cortés, 2014) in Colombia, a novel signal denoising technique was presented, and it was shown that an improved characterization and interpretation of lightning field parameters could be achieved. (Zhang et al., 2012a, 2012b) in China on the other hand mentioned that electric field peak does not show obvious attenuation on rough ground surface and rough ocean surface.

Even though most lightning activities take place in tropics, only a few studies have been conducted in tropics to measure lightning flashes behavior. In Sri Lanka, the radiation field for stepped leader, return stroke and cloud flashes was studied briefly by (Cooray and Lundquist, 1985), and statistical information of negative flash was studied by (Cooray and Jayaratne, 1994). Although Sri Lanka is located in tropical region, it is an island and surrounded by sea water, which may be the reason of cloud formation in the country being different from tropical main land such as Malaysia.

This paper presents investigation on the parameters of electric field generated by negative lightning in Malaysia, since there is a lack statistical data in tropical region, especially in Malaysia. In order to further improve lightning locating system or protection from lightning, the characteristics of negative lightning are worth to be investigated. Return stroke model also can be developed in future using these clarified Malaysian-based parameters. This work leads not only to the extensive tabulation of different electric field parameters of lightning flashes, but also parameters on electric field derivatives. It is important to note that this study is the first in Malaysia where the parameters of negative electric field and its derivative were thoroughly analyzed, apart from studies by (Arshad et al., 2014; Baharudin et al., 2014). (Baharudin et al., 2014) focused on the multiplicity of negative lightning and did not study in detail about the parameters. (Arshad et al., 2014) studied some of the parameters for negative lightning but the collected sample was insufficient to make strong conclusion. Therefore, this study caters research on negative lightning electric field parameter in Malaysia as a tropical country, and at the same time compares the values with those of other geographical regions.

2. Methodology

Lightning electric field measurements were performed in May 2015 which is within the monsoon months (May–September, 2015) at the Universiti Teknologi Malaysia. Universiti Teknologi Malaysia is located in the southern part of Malaysian Peninsular with tropical climate. Lightning generated vertical electric fields and their time derivatives were measured using three 1.5-m-tall circular parallel plate antennas. Each circular parallel plate antenna was connected to an integrator and a unity-gain, high-input-impedance amplifier. The bottom plate was grounded through a galvanized steel wire. Even though both slow and fast fields were considered, the slow field waveforms are not discussed in this paper. This is because this study focuses on the radiation component of the electric field and not the static component which is usually dominant in the slow field waveforms. The antennas were installed on the roof of a selected two-stories building (1°33'38.1"N 103°38'36.2"E). The configuration of the measuring system is shown in Fig. 1. The setup is similar to the