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Lightning Measurement in Sarawak, Malaysia: First Results

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***Abstract*—Malaysia is one of the country with highest lightning activities in the world. Regrettably, studies on lightning characteristics is still lacking especially in the Eastern part of Malaysia, which is Sabah and Sarawak. In this study, the characteristics of electric field radiation recorded during lightning measurement campaign in Sarawak had been analyzed. The field measurement was done using parallel plate antenna attached with electronic buffer circuit. The data was recorded using a PicoScope and monitored in computer. Nineteen samples of negative first return strokes were successfully recorded during this measurement. Their electric fields waveform parameters namely peak amplitude, zero crossing time, zero to peak and 10%-90% rise time were thoroughly analyzed. All those values are 8% to 166% larger in comparison to the data obtained from lightning measurement done in the Peninsular Malaysia. It is suggested that various topology and meteorology pattern are among factors that contribute to the discrepancies.**

Keywords—lightning, negative lightning, return stroke, parallel plate antenna, lightning electrical field, lightning characteristics.

I. INTRODUCTION

Lightning occurred when there were excess positive and negative charges developed in the cloud. There are large volumes of positive charge in the upper region and a small positive charge pocket at the lower regions of clouds while negative charges are located at the center of the cloud. Lightning activities can be generally classified into four; namely, intracloud, intercloud, cloud to air and cloud-to-ground (CG) flashes. Based on the initiating charges, CG flashes are categorized into positive and negative lightning [1] . Generally, those charges are sources of electrical energy and voltage is defined as the amount of energy per charge [2]. This study is analyzing voltage versus time signal graph from the lightning electrical field radiation. Thus, most of the information extracted from the graph can be related to the energy produced by the lightning signal. The following parameters were analyzed in this study namely normal electric field peak voltage (E_n), zero crossing time (T_{ZC}), zero to peak rise time (T_{ZP}) and 10% to 90% rise time (T_{10-90}). All of these parameters are important in designing lightning protection system and devices especially in estimating the operating threshold voltage or current. For instance, the peak value of electric field amplitude is vital in designing the insulating material for lightning protection and earth termination system. This is because, the higher the field amplitude, the higher the induced voltage will be. Therefore, the insulating material used for lightning protection should be designed to withstand the maximum lightning electric field peak amplitude. Meanwhile, the T_{ZC} corresponds to the time taken for the total energy produced as energy is the amount of charge transferred through voltage in a time interval [3]. Melting and heating effect of a surge protection device is depending on the total charge [4] . Meanwhile, T_{ZP} reflects to the time taken for the return stroke to reach its maximum peak amplitude. The amplitude change is at the highest rate in between 10% to 90% of the front portion electric field radiation. Thus the T_{10-90} reflects the time taken for the abrupt increase in the lightning energy. Plus, return stroke rise time increases with decreasing peak of the signal amplitude [5, 6]. Briefly, the zero crossing and rise time of lightning signal are very vital in determination of the response time and the energy capacity on lightning arresters, and facilities protection respectively [4, 7]. Therefore, all the aforementioned parameters are important in order to have a better design in lightning protection systems especially to be applied in Malaysia.

Many studies had been conducted to investigate the influence of locations to the characteristics of lightning. For example, Gomes et al. [8] analyzed inland data from Sweden, approximately 70 km from the Baltic sea. They have found similarities between the pulse structures of preliminary breakdown pulse (PBP) trains obtained by Ushio et al. in Hokuriku district area which was located very near to the Sea of Japan [9]. Besides, Qie et al. [10] conducted a measurement at high latitude forest region in Da Hinggan Ling province of China. T_{10-90} and T_{ZP} were found 36% and 47% higher respectively compared to the data obtained by Schumann et al. [11] in a tropical country. Schumann and his

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team had set up the measurement at 635 m of altitude in Brazil. Meanwhile, Baharudin et al. [12] did a research in Johor, Malaysia located at 30 km away from the Tebrau Straits and compared the PBP/RS ratio to data obtained in Florida. It was observed that PBP/RS ratio in Florida was 1.6% higher than Malaysia. Therefore, their findings supported the hypothesis that the PBP/RS ratio increases with increasing latitude. Wooi et al. [13] also measured lightning parameter in Johor, Malaysia and obtained 30% to 40% higher value for T_{10-90} and T_{ZP} compared to the lightning generated in the temperate countries. Hamzah et al observed unusual value of zero crossing duration which was in the range of 0.66 ms to 7.96 ms for the data collected in Selangor, Malaysia [14]. This observation was compared to the data obtained from Sweden and Sri Lanka that acquired 49 µs and 89 µs respectively [15]. Thus, they deduced that T_{ZC} duration is higher for countries closer to equator. Even lightning electric field characteristics in the tropical region itself differ according to the geographical location of the lightning events. This fact sparks an interest and therefore motivated us to conduct further investigation on the lightning characteristics in the tropical region. This time in the Eastern region of Malaysia, specifically in Sibu, Sarawak located in the Island of Borneo. To the best of our knowledge, there is no lightning data was ever collected and analyzed from this region. Since this measuring location is located close to the South China Sea, it is believed that the result might be significantly affected by the signal propagation, updraft, and sea breeze and may differ from those data obtained from previous measuring location in the Peninsular Malaysia.

II. MEASUREMENT

This measuring station was set up in the vicinity of University College Technology Sarawak (UCTS) (2°20'29.0"N 111°50'38.8"E) which is located 60km from South China Sea. The measuring equipment as illustrated in Fig. 1 were used similar to those described by Galvan and Fernando [16] except for the buffer amplifier used. In this study, the electronic buffer used was OPA633KP instead of LH0033 used in Galvan and Fernando set up. OPA633KP is a high speed op amp that provides higher bandwidth and slew rate compared to LH0033. It comes with 260MHz of bandwidth and 2500 V/µs of slew rate [17] whereas LH0033 is limited up to 100MHz of bandwidth and 6000 V/ms of slew rate [18]. The reason of using a fast buffer amplifier is to isolate the high impedance of the antenna and offers enough power to drive a signal from the antenna through the coaxial cable for transmitting the signal to PicoScope. Meanwhile, a parallel plate antenna was used to capture the radiation component of the electric field from lightning. It was mounted on top of a pole with a height of 1.5 m as shown in Fig. 2 and was placed about 30 m away from the monitoring room. Earthing cable from the pole was connected to the earthing pit near the monitoring building. The resistance of the earthing pit measured was 4.75 Ω which met the ideal value recommended by Institute of Electrical and Electronics Engineers (IEEE) [19]. The plate of the antenna was connected to an electronic buffer circuit through 100 cm of RG58 coaxial Bayonett Neill-Concelman (BNC) cable. Then, the output from the buffer circuit was transmitted to the PicoScope via 160 cm of universal serial bus (USB) cable and all recorded signals were saved in the personal computer installed with the PicoScope software. The PicoScope was set to 500 mV at the front edge threshold as a triggering level. The horizontal axis was set to 200 ms/div in AC form so that a total of 2000 ms can be displayed throughout the entire frame. The trigger setting was in single mode in order to have the most recent captured signal be displayed in the monitor. Alarm setting was set in sequence from beep, save current buffer and restart capture for the measuring system to automatically capture and save the wanted signals continuously. During the measurement campaign, a total of 19 negative first return strokes were successfully recorded in March and July 2020. The analysis of electric field parameter was done according to the atmospheric sign convention where a positive field change is considered as negative return stroke and vice versa.

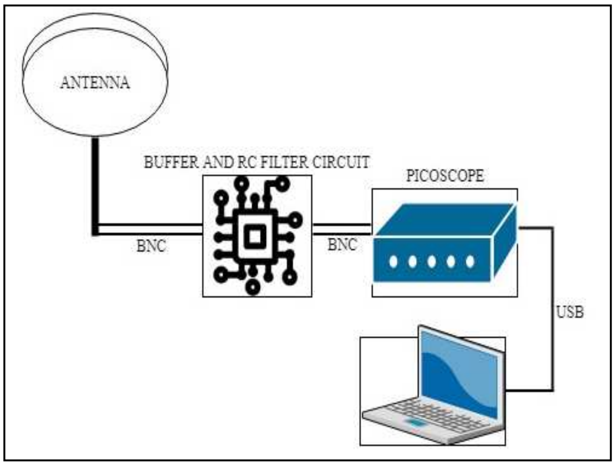

Fig. 1: Plate antenna and electronic circuit connection diagram.

Fig. 2: Parallel Plate Antenna

III. DATA ANALYSIS

Voltage measured (V_m), zero crossing time (T_{ZC}), zero to peak rise time (T_{ZP}) and 10% to 90% rise time (T_{10-90}) captured by the antenna can be retrieved from Picoscope Software as shown in Fig. 3. The voltage measured value was then used to calculate the normal electrical field, E_n which is dependent to the antenna height. This is because different effective antenna height, d_{eff} will produce different measuring system factor, F_{meas} which relationship is conveyed in equation (1). While equation (2) interpret its relationship between the voltage measured, V_m and normal electrical field, E_n aforementioned. All the derivation details were thoroughly explained in [16] by Galvan and Fernando. They conducted a calibration process by employing various height of antenna to the ground and the results are as shown in Fig. 4. Since the same antenna height of 1.5 m was used in this study, the equation for the normal electric field, E_n as stated in equation (3) is applicable.

$$F_{meas} \propto \frac{1}{d_{eff}} \tag{1}$$

$$F_{meas} = \frac{E_n}{V_m} \tag{2}$$

$$E_n = 20.6037 \times V_m \tag{3}$$

With equation (3), the data acquired from this study were illustrated in Fig. 5 for normal electrical field, whereas Fig. 6, 7 and 8 presented the T_{ZC}, T_{ZP} and T_{10-90}, respectively. Observed that data acquired for the E_n and T_{10-90} is more precise in distribution compared to the data for T_{ZC} and T_{ZP}. The highest value for T_{ZC} is 367.6 μs which is considered as an outlier of the data. This finding is slightly lower than the data acquired by Wooi et al. [20] in Johor which was 384.7 μs. The value was extracted from 130 first return stroke (FRS) of negative lightning which acquired from May until September 2015. Meanwhile, Haddad et al. [21] obtained less than 100 μs averagely for 265 first negative lightning data recorded in the vicinity of the University of Florida campus during May and June 2009. Cooray [15] recorded 91 FRS data in Sri Lanka and observed less than 200 μs for the T_{ZC} value. Besides that, 28.1 μs is the longest rise time for T_{ZP} which is also the outlier for the data obtained in this study. This value is 40% and 22% higher compared to the aforementioned Wooi's and Haddad's findings respectively.

Table I shows the comparison of this study to the data obtained in Johor by Wooi [20]. It was found that all the average values of the electric fields waveform parameters acquired in Sibu were higher than in Johor. The average electric field amplitude recorded in this study is 57.9 V/m which is higher than in the peninsula region by a factor of 2.7. Generally Johor and Sibu have similar average temperature but Sibu tend to experience higher daily temperature which was up to 40ºC [22]. This finding had supported the suggestion made by Rust et al. when warm season storms tend to generate higher lightning electric field amplitude that positive CG flashes are naturally produced [23]. Besides, Miyake et al. [24] and Pinto et al. [25] also reported that warmer season produced higher lightning electric field amplitude. According to Cooray [26], T_{ZC} can be influenced by the vertical length of the channel that initiated the discharge [26]. The longer the vertical channel, the longer the T_{ZC} produced. The vertical channel for a lightning is approximately equal to the height of the initiate charge layer in the thundercloud. Thus the lightning vertical channel can be estimated by using cloud base height value. The value is directly proportional to the gap between surface temperature and dew point [27]. The larger the gap the higher the cloud based height. Based on the data presented in [28], the gap value during data acquisition was 2.7 ºC and 5.1 ºC for Sibu and Johor respectively. Thus, cloud base height in Sibu was inferred to be shorter than Johor. Interestingly, T_{ZC} in Sibu is 46% higher than data collected in Johor which is not in agreement with the above discussion. Since, this estimation is based on vertical lightning channel, there is possibility that the lightning occurred in Sibu propagated in tortuosity channel which had longer propagation distance that produce longer T_{ZC}. Since Sibu is a warmer state than Johor, this study supported earlier research done by Cooray and Lundquist in 1985 [15]. They found that Sri Lanka as a warmer country had 82% longer T_{ZC} than Sweden. As reported in [21, 29], T_{ZC} and other rise time value for lightning are influenced by lightning propagation distance. The inference is congruent to the findings in this study if the possibility of the lightning in Sibu propagated in tortuosity channel is reasonable. In Sibu, the data shows 24% and 8% higher value respectively for both T_{ZP} and T_{10-90} parameters even in comparison to data from Johor. Interestingly, the results for both T_{ZP} and T_{10-90} in this study were found different than a conclusion made by Nag and Rakov in 2014 [30]. Their study suggested that T_{ZP} and T_{10-90} tends to be shorter in a warmer climate and vice versa. The inference also supported by Ishii and Hojo [31] when they found that T_{ZP} was 10% shorter in summer than in winter. In separate report, Rakov and Uman observed T_{10-90} within 5 μs in summer [32], whereas Ishii observed 12.3 μs for the same parameter in winter [33].

The discrepancy between the result of current study and Wooi et al [10] can be explained as follows. Sibu is located in Borneo Island surrounded by South China Sea whereas Johor is located at the southern tip of Peninsula Malaysia near to Johor Strait, bounded by Singapore and Indonesia in the south and the west, respectively. Both island and land temperatures are affected by sea breeze. The sea breeze is a coastal phenomenon that influences meteorological conditions including air temperature, wind speed and direction, humidity and cloudiness [34]. The sun heats up both the ocean surface and the land during the day. However, water heats up much more slowly than land and so the land temperature will be warmer compared to island region. Water has higher heat capacity than land that ocean can maintain the heat after the sun sets. Thus, land loses heat quickly and produces strong updraft at night compared to island. The air over the island is warmer during the night than the air over the land. This causes island to experience smaller temperature variation compared to land that this region tend to be warmer day and night.

In addition, data from Japan and Florida were also tabulated in Table I. Japan is considered an island which surrounded mostly by Sea of Japan and North Pacific Ocean. Florida is a part of peninsula which surrounded by Gulf of Mexico, Atlantic Ocean and the Straits of Florida. Despite the sea breeze and updraft events around the island, Japan experience lower temperature and higher humidity compared to Florida. Unlike Sibu in Borneo Island, which tend to have high temperature and humidity. These differences were probably because of the different latitude region where Japan and Florida are located in Subtropical region whereas Sibu and Johor are in the tropical region which is closer to the Equator. However, the data comparison between Japan and Florida are almost identical to the comparison between Sibu and Johor. All the lightning parameters in Japan were up to 3 factors higher than Florida except for its T_{ZC}. This was most probably because of Florida is a warmer country compared to Japan [35].

Japan and Sibu are islands but Sibu is closer to the Equator that might lead to the following differences in the data observed in both regions. All the lightning parameters collected in Japan are higher than Sibu. The most significant difference is T_{10-90} observed in Japan, which is 193% higher than Sibu. This is followed by E_n value in Japan which is 20% more than the value measured in Sibu. The slightest difference between Japan and Sibu lightning data is observed on the T_{ZP} and followed by T_{ZC}, where Japan lightning data are 5% and 7% respectively higher compared to Sibu data. Japan is farther from Equator that experience lower temperature than Sibu. However, it also produced lower humidity that creates drier air. This conditions tend to generate a higher electrostatic discharge like lightning phenomenon [36]. Thus, Japan lightning data produced higher amplitude of E_n value compared to Sibu. As discussed before, T_{10-90} and T_{ZP} are influenced by surface temperature [30]. Japan tends to produce higher value for both aforementioned parameters because the country has lower temperature than Sibu. However, Sibu experienced warmer days throughout the year compared to Japan that the lightning in Sibu produced shorter T_{ZC}.

In a nutshell, most of the lightning parameters are influenced by the variations of temperature and humidity. Warmer season or region tends to generate higher value of E_n. Yet, the value also can be high when the condition is drier or less humid. T_{ZC} , T_{ZP} and T_{10-90} are mostly influenced by the same factors namely temperature and propagation distance. Those parameters are possible to be shorter in warmer conditions. Besides that, the longer the distance, the longer the parameters value produced. When the propagation distance is considered in vertical channel, a cloud base height is the factor that influence the value of T_{ZC}, T_{ZP} and T_{10-90}. This factor is also estimated by using temperature and dew point. Whereby, dew point can be calculated by using humidity. Countries closer to the equator tend to be warmer. Obviously, lightning electric field characteristics was influenced by the latitude differences as well. Besides than the electric field value, other characteristics of lightning also proved to have correlation with latitude. As in [37], interstroke intervals from the convective thunderstorm in Malaysia with lower latitude were slightly higher compared to higher latitude like Sweden. A research done in Australia observed that the lightning activity decreased with the increased distance to the equator [38]. Latitude differences not only affected return stroke characteristics but also preliminary breakdown pulse as analyzed by [39]. However, other influencing factors that can be considered in analysing lightning electrical field characteristics are the variation of return stroke speed along the channel [40], soil conductivity [29], lightning channel radius [41], current attenuation along the channel [42] and channel geometry [43].

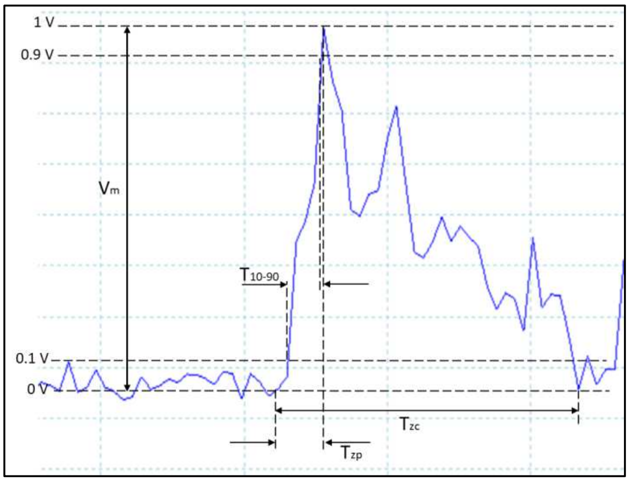

Fig. 3: Negative lightning electric field for Sample 1

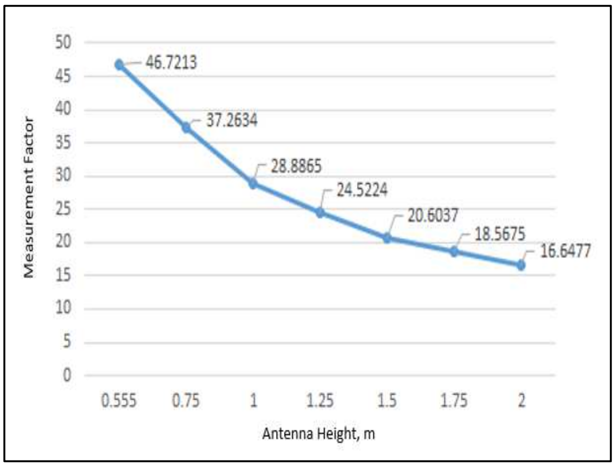

Fig. 4: Measurement Factor For Different Height Of The Antenna [16]

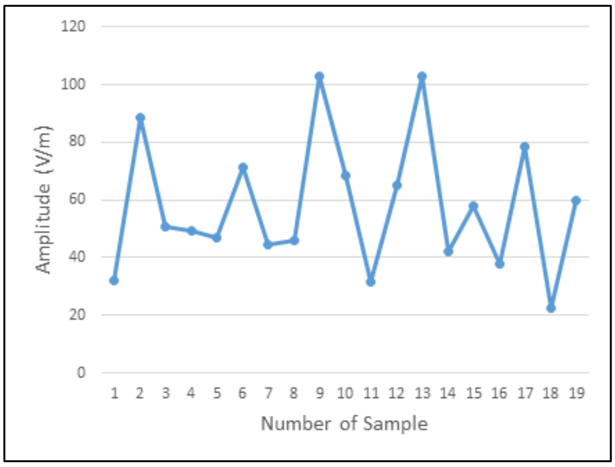

Fig. 5: Acquired data for normal electrical field, E_n

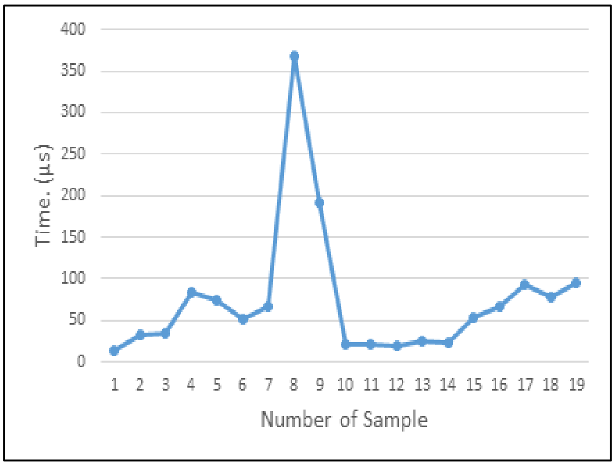

Fig. 6: Acquired data for Zero Crossing Time (T_{ZC})

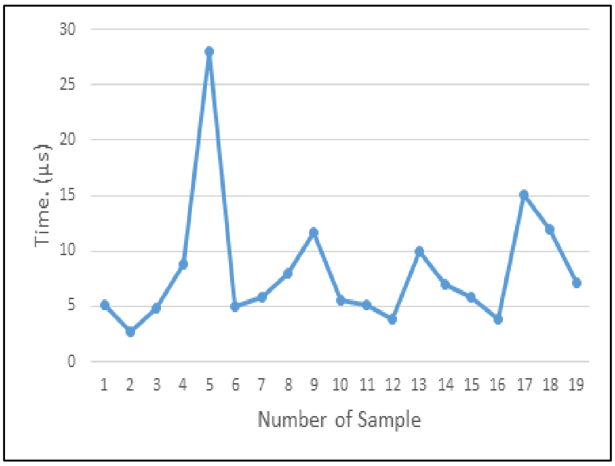

Fig. 7: Acquired data for Zero to Peak Rise Time (T_{ZP})

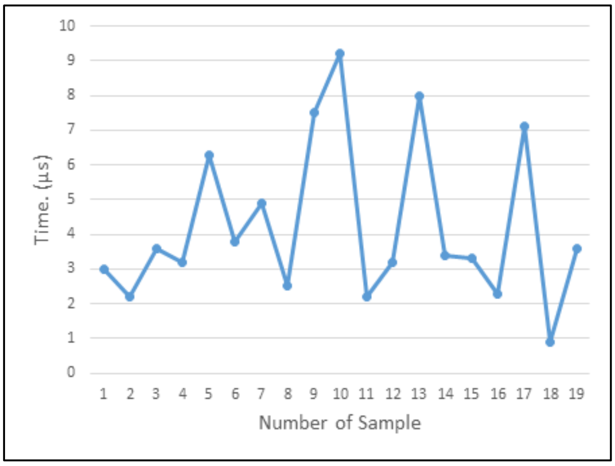

Fig. 8: Acquired data for 10% to 90% rise time ($T_{10\text{-}90}$)

TABLE I. COMPARISON OF LIGHTNING PARAMETERS BETWEEN ISLAND AND PENINSULA REGION

Research	Climate	Region	E_n (V/m)	T_{ZC} (µs)	T_{ZP} (µs)	$T_{10/90}$ (µs)
This study	Tropical	Sibu (Island)	57.9	74.1	8.2	4.2
Wooi [20]		Johor (Peninsula)	21.8	50.7	6.6	3.9
Ishii [31]	Subtropical	Japan (Island)	-	79.0	8.6	-
Ishii [33]			70.0	-	-	12.3
Haddad [21]		Florida (Peninsula)	29.7	89.0	7.7	-
Nag [44]						4.2

IV. CONCLUSION

Remarkably, this experimental work had enhanced the understanding on the effect of sea breeze and updraft to the characteristics of lightning electric field radiation especially in Malaysia. Importantly, both sea breeze and updraft influenced average temperature experienced in regions nearby depends on their topology. Besides that, latitude influence on lightning properties was more understandable when different latitude region produced different meteorology pattern such as the relationship between temperature and humidity. In this study, four important parameters of lightning characteristics namely normal electric field peak voltage (E_n), zero crossing time (T_{ZC}), zero to peak rise time (T_{ZP}) and 10% to 90% rise time (T_{10-90}) were measured from 19 negative first return strokes samples obtained in Sibu, Sarawak. It was found that all the average value of the electric fields waveform parameters acquired in Sibu were higher than Johor. The highest different factor is 2.7 for the E_n. This was followed by 1.5 for T_{ZC}, 1.2 for T_{ZP} and 1.1 for T_{10-90}. Despite its warmer temperature, Sibu produced lightning with longer T_{ZP} and T_{10-90}. This was most probably due to longer propagation distance for lightning in Sibu compared to Johor. Significantly, high different factor of normal electric field value between Peninsula and Sarawak was obtained in this study. Therefore, another study on lightning protection standards implemented in Malaysia should be conducted. This is to confirm whether the standards used throughout Malaysia are relevant or not.

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