CHARACTERISTICS OF LIGHTNING ELECTRIC FIELDS OVER LAND AND SEA OBSERVED IN SARAWAK, MALAYSIA

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Abstract: *Many researchers around the world have investigated the lightning electric field characteristics of return strokes occurring over the sea and land. However, such studies are never carried out in East Malaysia, which is surrounded by the South China Sea. Therefore, this paper presents the characteristics of lightning electric fields overland and at sea observed in Sibu, Sarawak. In this measurement, a total of 42 negative cloud-to-ground lightnings (24 from over the land and 18 from over the sea) were considered for further analysis. The samples were collected at distances ranging from 26 to100 km using a parallel plate antenna. Four parameters of the first return strokes were measured, namely, normal electric field (E_n), zero-crossing time (T_{zc}), zero-to-peak rise time (T_{zp}), and 10-90% rise time (T_{10-90}). The lightning that was captured over the sea in Sarawak had an E_n value that was 2% lower, T_{zc} that was more than twice longer, T_{zp}, and T_{10-90} that were 7% and 23% shorter, respectively, when it was on land. The results obtained in Sarawak (East Malaysia) compared with those from Kuala Perlis (West Malaysia) revealed the attribution of roughness to variations in lightning parameters. It has been observed that when the roughness of the propagation medium increases, E_n and T_{zp} decrease. Whereas, T_{10-90} increases with increasing propagation medium roughness. On the contrary, T_{zc} is independent of the roughness of the propagation medium due to its strong negative correlation with E_n. In terms of correlations between lightning parameters and propagation distance, E_n measured at both sea and land in Sarawak has a negative correlation with propagation distance. Meanwhile, T_{zc}, T_{zp} and T_{10-90} observed from the land show a positive correlation with propagation distance. In contrast, the same three parameters observed from the sea have a negative correlation with propagation distance. In summary, the patterns of lightning characteristics mentioned above are very useful in identifying the origin of the lightning event.*

Keywords: *cloud-to-ground lightning,first return stroke, normal electric field, propagation distance, propagation medium*

1. INTRODUCTION

Investigations into lightning characteristics have shown that the temperature, topography, spatiotemporal, and climatic regions throughout the earth generate distinct lightning occurrences and features. The impact of location on the characteristics of lightning has been the subject of numerous studies. Gomes and Cooray (2004), for instance, examined the data from Sweden's inland, which was approximately 70 km from the Baltic Sea. The findings of the study are comparable to those of Ushioetal., who reported on the preliminary breakdown pulse structures discovered in the Hokuriku area near the Sea of Japan (Ushio, Kawasaki, Matsuura, & Wang, 1998). In addition, Qie et al. (2013) took lightning measurements in a high-latitude forest zone in China, while Schumann et al. (2013) collected data at 635 m above sea level in Brazil. In comparison, the 10–90% rise time and the zero-to-peak rise time are 36% and 47% greater in China than in Brazil, respectively. Besides that, Wooi et al. (2015) studied the lightning parameters in Johor, Malaysia, and found 30–40% higher values for the 10–90% rise time and zero-to-peak rise time when compared to the lightning in temperate countries. Furthermore, Hamzah et al. (2014) discovered an unexpected value of zero-crossing time at a range of 0.66 to 7.96 ms for the data collected in Selangor, Malaysia. The findings were compared to the data from Sweden and Sri Lanka, which obtained 49 µs and 89 µs, respectively (Cooray & Lundquist, 1985). It was concluded that the length of zero-crossing was longer in countries that were closer to the equator. While most of the investigators were focused on studying the association between lightning occurrence and environmental variations, there are still many unanswered questions on lightning characteristics that correlate with the environmental variations in Malaysia. As a result, this paper describes the characteristics of the lightning electric field overland and at sea as observed in Sibu, Sarawak, which is in East Malaysia. The results were also compared to those from West Malaysia, and the correlation between lightning parameters and propagation distance in various mediums was investigated in this study. The lightning data in this study was captured using a parallel plate antenna integrated with a fast field circuit. Four lightning parameters, namely, normal electric field (E_n), zero-crossing time (T_{ZC}), zero- to-peak rise time (T_{ZP}), and 10 to 90 percent rise time (T_{10-90}), were then analyzed in a software called PicoScope.

2. MEASUREMENT

The first lightning measurement station in East Malaysia was installed in the vicinity of the University of Technology Sarawak (UTS) (2° 20’ 31.2” N, 111° 50’ 53.1” E), about 60 km from the South China Sea. The station was in the Sibu district of Sarawak State. The electric field produced by lightning flashes was captured using a parallel plate antenna integrated with an electronic circuit known as a fast field circuit, as shown in Figure 1. The antenna is 1.5 meters high, and it was connected to the fast field circuit through a 60 cm RG58 Bayonet Neill-Concelman (BNC) cable. Then, the output from the circuit was transmitted to a PicoScope 5244D via a 30-meter identical BNC cable. Using a 160-cm Universal Serial Bus (USB) cable and a computer that already had PicoScope Version 6 software pre-installed, the lightning waveform captured by the PicoScope was transmitted and stored. An insulated, pure copper grounding cable was used to connect the antenna’s bottom plate to the ground. For the PicoScope software, it was set to a maximum voltage of 5 V and a front edge threshold of 500 mV, which is the level that the signal must cross to trigger a capture. The waveform was set to 200 ms/div in Alternating Current (AC) form with two seconds in total of the display time frame, whereas the pre-trigger control was set to 50% so that the waveform starts to appear at the center of the timeframe window. To display the most recent captured signal on the monitor, the trigger mode was set to a single mode. For the measuring system to automatically capture and store the desired signals continuously, the alarm setting was setup in a sequence starting with the beep, saving the current buffer, and restarting capture. 42 negative first return strokes (FRS) were recorded for this study and were collected between March and July 2020. This study applied the atmospheric sign convention concept, where a negative return stroke was identified as a positive field change.

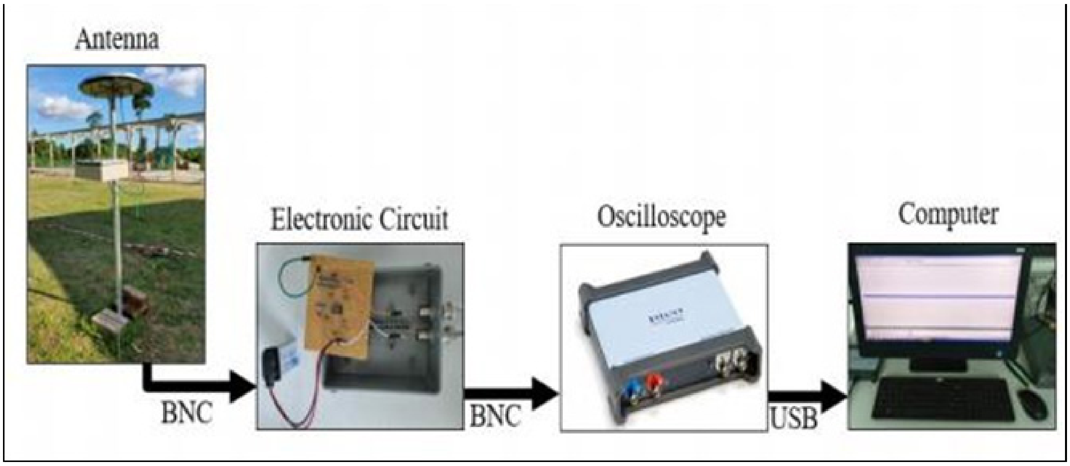

Figure 1. The block diagram of the lightning measurement setup in Sibu, Sarawak

Figure 2 depicts four parameters measured by the FRS pulse. They were displayed using PicoScope Version 6 software. The time duration for a lightning channel to rise from 0 V or the reference line to reach its speak value and return to the point where it crosses the reference line again is known as zero-crossing time (T_{ZC}). It also carries information about the zero to peak rise time (T_{ZP}) and the10 to 90 percent rise time (T_{10-90}). The amount of time for the waveform to rise from the zero electric field line to the peak of the waveform was noted as T_{ZP}. Meanwhile, the time taken for the waveform to rise from 10% to 90% of the measured voltage (Vm) was noted as T_{10-90}. The Vm is the magnitude of the voltage peak from the RS pulse. It was measured from the reference line of the waveform until the maximum voltage. The value of Vm was then used to compute the normal electric field (E_n), by using Equation 1. The details of the equation's derivation have been extensively described by Galvan and Fernando (2000).

$$En = 20.6037 \times Vm \quad (1)$$

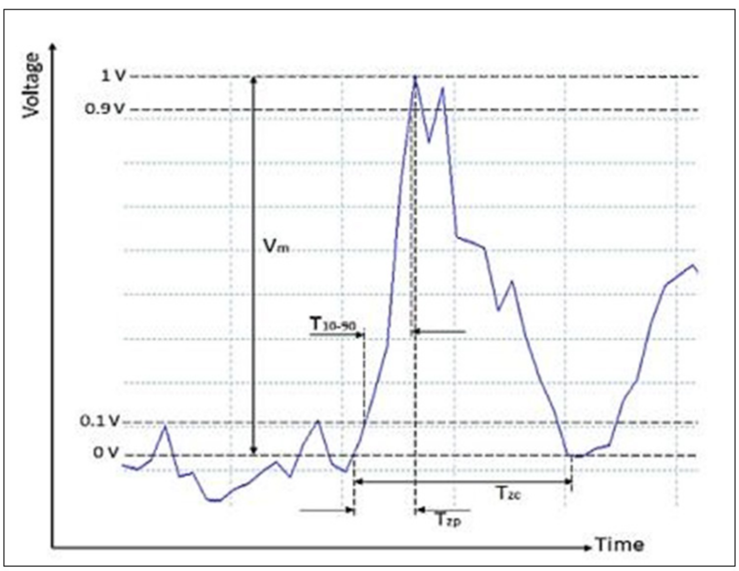

Figure 2. Return stroke characteristics measurement (Ramlee, 2021)

The E_n amplitude indicates the induced voltage from the lightning, which can be applied in the selection of insulating materials for lightning protection (Kusim, 2009). Meanwhile, T_{ZC} represents the time it takes to generate total energy, which is defined as the amount of charge transferred through voltage in a given time (Lumen, 2013). Additionally, the amount of charge determines the melting and heating impact of a Surge Protection Device (SPD) (Rakov et al., 2013). The time it takes for a stroke to reach its peak amplitude is known as T_{ZP}. The amplitude change occurs at the fastest rate between 10 and 90% of the front portion electric field radiation, so T_{10-90} represents the time required for a sudden increase in lightning energy. In a nutshell, the parameters are critical in developing lightning protection systems and devices, particularly when calculating the operational threshold voltage or current.

3. NEGATIVE CLOUD-TO-GROUND LIGHTNING OVER LAND AND SEA

In this study, a total of 76 negative cloud-to-ground (CG) lightning data points, comprising 42 FRS and 34 subsequent return strokes, were collected between March and July 2020. Only 42 negative FRS were considered for further analysis to investigate the lightning characteristics that propagate in different mediums (land and sea). A total of 24 FRS were observed to propagate over land, while 18 FRS propagated over sea. Since the location of this study was close to the South China Sea, it was believed that the medium of propagation, namely sea water and land soil, might significantly influence the variations of the lightning characteristics. Numerous scholars have looked at how the propagation medium affects the electric field properties of both positive and negative CG lightning that strikes overland and at sea. A lot of research has been done on the lightning electric fields that are made by stepped leaders (Nag & Cummins, 2017), return strokes (Nag & Cummins, 2018), and subsequent return strokes (Said, Cohen, & Inan, 2013).Additionally, Abdul Malek et al. (Abdul-Malek, Yusof, Wooi, & Sidik) recently completed a thorough investigation on different electric field characteristics for negative CG lightning striking over sea and land. The research was set up in Kuala Perlis, Malaysia, on West Malaysia's northern shore. The investigation used a total of 40 and 30 negative FRS recorded from over the sea and land, respectively. The lightning data were collected in May 2019 at a distance of 8 to 100 km. The results of the study conducted in Sibu (this study) were compared to those of the study conducted in Kuala Perlis to examine the variations in lightning characteristics caused by different propagation mediums in Malaysia. It was found that the average results from the analysis of this study contravene the findings in Kuala Perlis in four parameters, as shown in Figure 3.

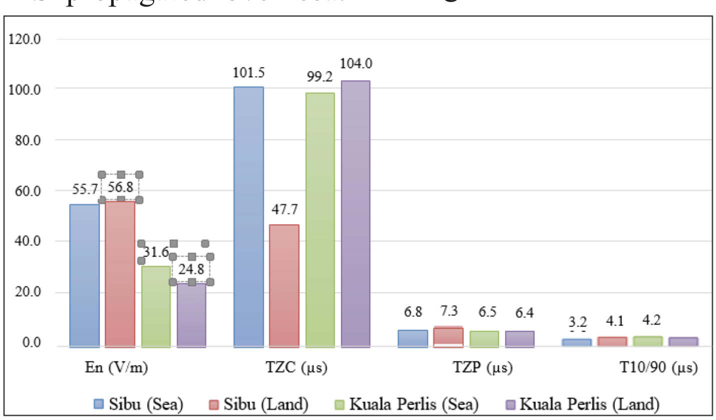

Figure 3. Lightning characteristics comparison between Sibu and Kuala Perlis

The E_n values are normalized to a 100-km observation distance to standardize comparability with prior investigations. Additionally, this was done to clear the parameter's dependence on the propagation distance. In Sibu alone the E_n value of the lightning captured over the sea was 2% lower than over the land. Lightning that was collected over the sea created T_{ZC} that was twice as much as if it was on land. When compared to the land, the T_{ZP} and T_{10-90} of the lightning that struck over the sea are 7% and 23% lower, respectively. A comparison of lightning data from sea and land in Kuala Perlis produced a completely different outcome from a comparison in Sibu. The lightning data obtained from over the sea in Kuala Perlis had an En value that was 27% greater than lightning collected on land. However, lightning captured over the sea had a 5% shorter T_{ZC} than those collected on land. In comparison to the land, the T_{ZP} and T_{10-90} of the lightning measured over the sea are both 1.6% and 11% greater, respectively. This variation may be due to the environmental differences between Sibu and Kuala Perlis. Sibu is more influenced by variations from the South China Sea, while Kuala Perlis receives variations from the Andaman Sea and Malacca Strait. Geographically, Kuala Perlis receives more wind from the Andaman Sea than the Malacca Strait. Whereas, Sibu is subjected to winds that originate mostly from the South China Sea. According to Lukačovič (2019), wind speeds in the Malacca Strait ranged from 14 to 32 km/h and up to 43 km/h in the Andaman Sea. In addition, Kuala Perlis also experienced a rainy season during data acquisition (Diebel, 2020). Meanwhile, the South China Sea wind speed was up to 32 km/h during data acquisition. Windy seas create more turbulence on the sea surface, which attenuates the electromagnetic signals propagating through it (Ding, 2019). Therefore, it is reasonable that Sibu observed E_n or the lightning recorded over the sea is 76% higher compared to that collected in Kuala Perlis.

In comparison to Kuala Perlis, Sibu has a 2% higher T_{ZC} value, as determined by lightning strikes over the sea. However, it cannot be compared in the different region due to the fact that this parameter is closely related to the value of peak amplitude. According to Lu, Cummer, Blakeslee, Weiss, & Beasley (2012); and Rakov & Dulzon (1991), higher peak amplitude leads to a higher charge capacity. Consequently, the higher total charge resulted in a faster lightning speed (Cooray, 1993), thus, a shorter T_{ZC} (Shoory, Rachidi, Rubinstein, Moini, & Sadeghi, 2009). Therefore, a high value of E_n observed in both lightning data from Sibu land and Kuala Perlis sea, resulting in a shorter T_{ZC}. According to (Y. Zhang et al., 2018), T_{ZP} exhibits a negative correlation with the propagation medium roughness. This study agrees with the inference that lightning collected over the sea near Kuala Perlis produced a 4% shorter T_{ZP} compared to lightning collected over the sea near Sibu. When comparing, the T_{10-90} value for the lightning data collected in similar medium propagation, from over the sea near Kuala Perlis produced 31% longer time compared to those from Sibu. This finding is in agreement with the research conducted by Zhang et al. at Qingdao buoy station near the East China Sea (Y. Zhang et al., 2018). Thus, it can be inferred that the roughness of the nearby sea has a positive influence on the parameters. However, when comparing the T_{10-90} value for lightning data collected in different mediums of propagation, it also revealed a positive correlation to the electric field amplitude. As suggested by Paul et al. (Paul, Heidler & Schulz, 2019), higher electric field amplitude produced longer T_{10-90}.

As mentioned above, the sea near Kuala Perlis is rougher than that near Sibu. Thus, it can be summarized that E_n and T_{ZP} are lower when the roughness of the propagation medium is higher. Meanwhile, T_{10-90} is higher when the roughness of the propagation medium is higher. On the other hand, previous literature (Cooray, 1993; Lu et al., 2012; Rakov & Dulzon, 1991; Shoory et al., 2009) suggests that TZC has a good negative relationship with En , and it can be understood that it has no relationship with the roughness of the propagation medium.

4. CORRELATION BETWEEN LIGHTNING PARAMETERS AND PROPAGATION DISTANCE IN DIFFERENT MEDIUM

This paper also reports the correlation between four lightning parameters (E_n, T_{ZC}, T_{ZP}, and T_{10-90}) and the propagation distance in different medium propagation in Sibu. Interestingly, most of the lightning characteristics examined over the sea exhibit different behaviour in relation to the propagation distance than on land. As presented in Appendix 1 (i), the value of E_n for the lightning observed on Sibu land has a negative correlation with the lightning propagation distance. A similar correlation exists between E_n for the lightning observed over the sea and lightning propagation distance, as shown in Appendix 2 (i). This is obviously due to the signal attenuation that comes from the roughness of the ground and the sea. According to Hidayat and Ishii (2006), electromagnetic waves originating on land are more attenuated than those originating on the sea due to the longer propagation path across lossy ground. Additionally, because of its high salt content, seawater has a higher conductivity than normal soil, making it a good conductor and allowing lightning to propagate more easily in seawater. Besides, the lightning electric field is shown to have a greater amplitude as the ground's conductivity improves (Li et al., 2016). Since the measurement station in this study is located on land and far from the sea, the lightning originating from the sea propagated through a mixture of sea and land propagation mediums. Therefore, the negative correlation between E_n and the lightning propagation distance may be due to the lightning electrical fields that tend to abruptly drop towards the boundary between the sea and the land region, as suggested in (Q. Zhang, Jing, Yang, Li, & Tang, 2012). As a result, this study demonstrates that the propagation distance has a stronger negative correlation with En produced by the lightning observed over the sea. Thus, when the measuring station was placed far from the water, the lightning electric field propagating over the sea underwent more attenuation than that striking over the land. Nevertheless, strong winds may cause the sea surfaces to become rough, that attenuating and dispersing high frequency components of lightning electromagnetic fields (Q. Zhang, Yang, Li, & Wang, 2012).

Interestingly, all three other parameters, namely, T_{ZC}, T_{ZP} and T_{10-90} for the lightning collected on Sibu land have a positive correlation with the propagation distance, as shown in Appendix 1 (ii), (iii), and (iv) respectively. Even though there is obviously one outlier, T_{ZC} value is also an important value to reflect the correlation. According to Frost (2020), if the outlier value due to natural variation is an accurate observation belonging to the population under study, that value should not be eliminated. Although it is an oddity, it effectively demonstrates the potential uncertainty related to the lightning phenomenon. The average value of T_{ZC} measured from the land of Sibu lightning events is 47.7 µs. The highest value for the parameter is 367.6 µs, which is regarded as an outlier of the data. This result is a little less than the lightning data Wooi et al. (2016) collected in Johor, which highest value was 384.7 µs. The correlation found in this study is in good agreement with (Zhang, Yang, Jing, Li, & Wang, 2012) when the rise time of the field waveform increases with the increasing propagation distance. Meanwhile, the same three parameters for the lightning collected over the sea near Sibu have a negative correlation with the propagation distance, as shown in Appendix 2 (ii), (iii), and (iv), respectively. It can be inferred that when the lightning originated from the land and the lightning sensor is located far from the sea, T_{ZC}, T_{ZP} and T_{10-90} in the lightning electric field waveform tend to increase by increasing the propagation distance. Meanwhile, the three parameters tend to decrease by increasing of the propagation distance if the lightning originates from the sea. The variation could be attributed to the boundary between sea and land.

Overall, the correlation between lightning parameters and propagation distance is influenced by the roughness of the propagation medium. The rougher the medium, the more lightning signals are attenuated. However, the roughness of the ground depends on the terrain, whereas the roughness of the sea depends on the strength of the wind on the sea surface. Additionally, the lightning signal tends to abruptly attenuate when it crosses the boundary between the sea and the land. How easily a lightning signal propagates is determined by the conductivity of the medium, so a medium with high conductivity provides a path that has less loss.

5. CONCLUSION

In a nutshell, the negative FRS cloud-to-ground lightning characteristics vary while propagating in different mediums, specifically sea water and land soil. The E_n values decreased as the roughness of the propagation medium increased. Lightning originating from the sea may be disrupted by the sea and land borders when the antenna is located inland and distant from the sea. As a result, the E_n value collected from the sea is less than that collected from the land. Moreover, E_n has a considerable impact on the T_{ZC} value. High E_n resulted in shorter T_{ZC} and vice versa. However, the propagation distance influences both the lightning rise time parameters, T_{ZP} and T_{10-90} more than the roughness of the propagation medium. The greater the propagation distance, the shorter the risingtime. Interestingly, in terms of correlation to propagation distance, three lightning parameters collected from the land, T_{ZC}, T_{ZP} and T_{10-90} tend to increase as the propagation distance increases. On the other hand, if the lightning originates from the sea, the three characteristics tend to decrease as the propagation distance increases. However, when the propagation distance increases, E_n, as measured from both sea and land, decreases. Remarkably, the findings of this study have significant value in locating the origin of the lightning event. Knowing the origin of lightning is critical for studying the characteristics of lightning in a particular region to provide adequate lightning protection. For instance, if a region attracts more lightning from the sea than from the land, the residences nearby the sea are more at risk of being damaged by lightning. Therefore, adequate lightning protection is essential for the residences.

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Notes

The authors declare no competing financial interests.

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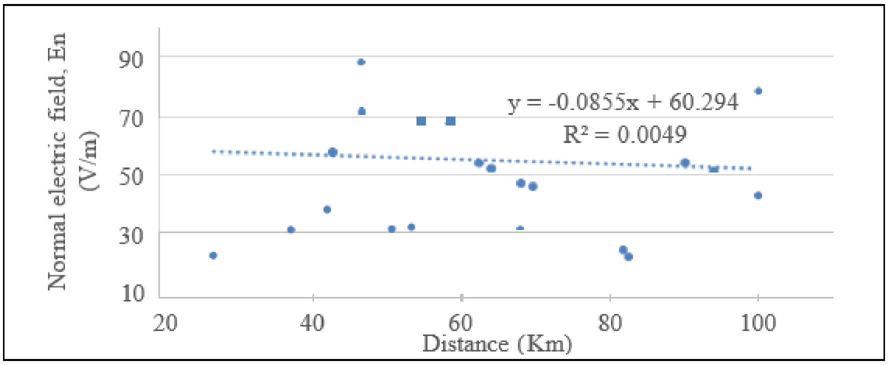
APPENDIX 1

(i)



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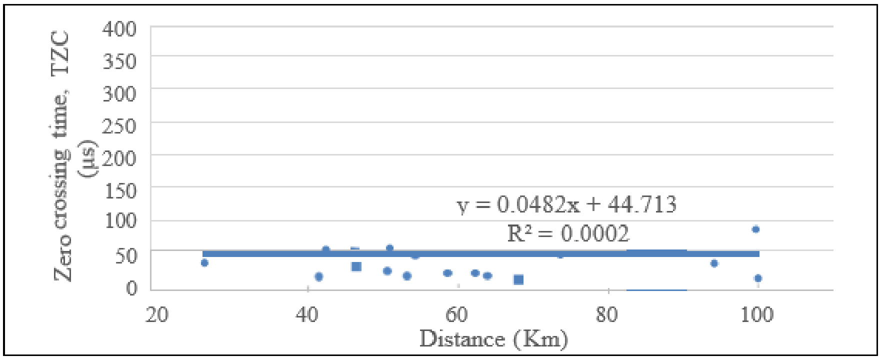

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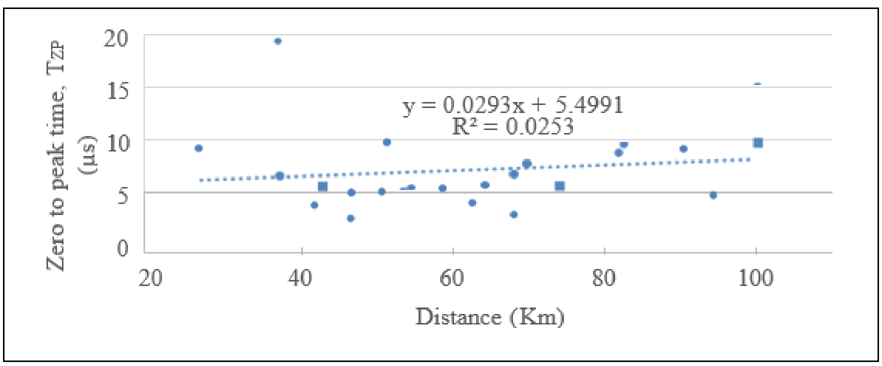

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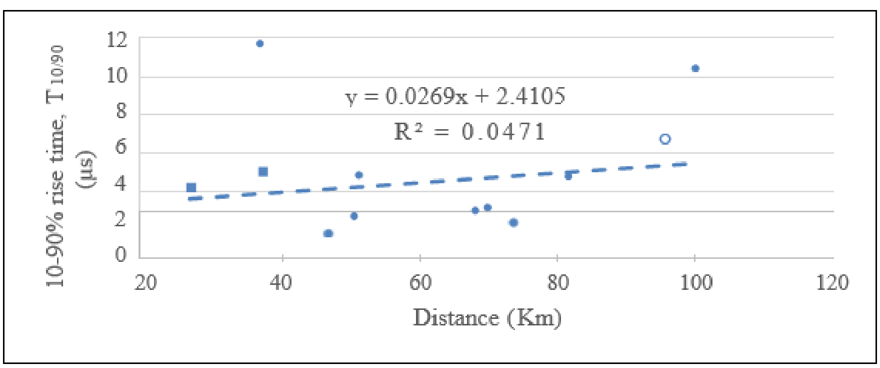
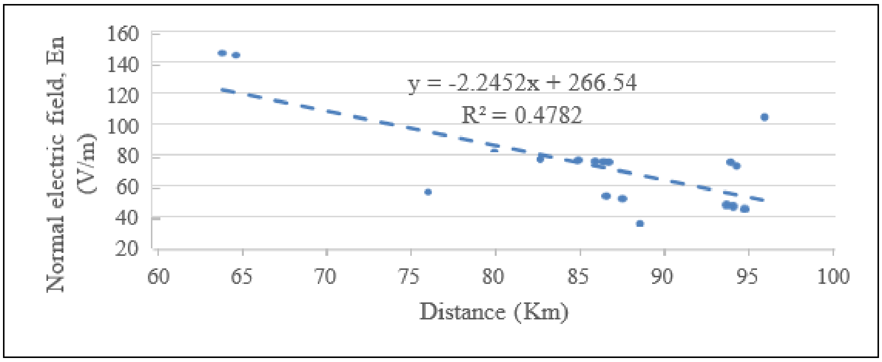


Scatter plot between the (a) normal electric field, (b) zero crossing time, (c) zero peak rise time and (d) 10-90% rise time of the negative CG lightning and the propagation distance for lightning collected over the land in Sibu, Sarawak.

APPENDIX 2

(i)



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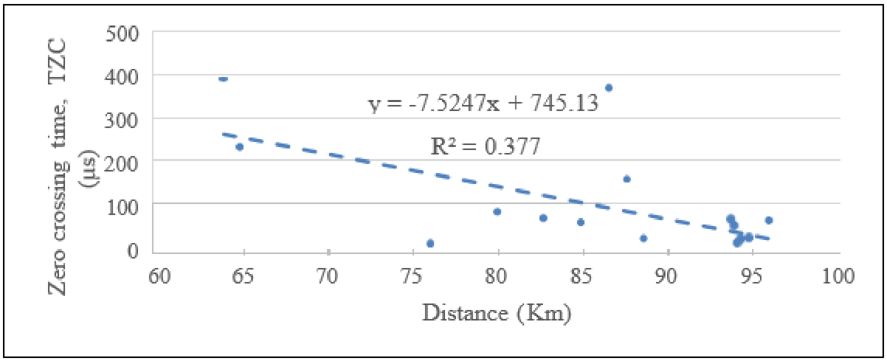
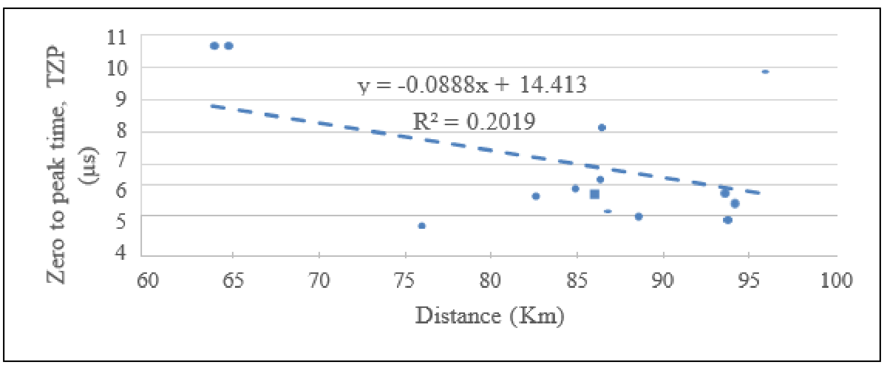
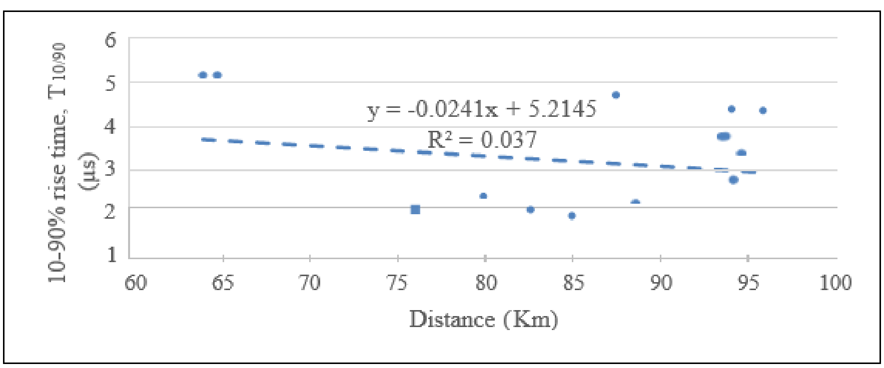


(iii)



(iv)



Scatter plot between the (a) normal electric field, (b) zero crossing time, (c) zero peak rise time, and (d) 10-90% rise time of the negative CG lightning and the propagation distance for lightning collected over the sea near Sibu, Sarawak.