RESEARCH ARTICLE

BORNEO SCIENCE
THE JOURNAL OF SCIENCE & TECHNOLOGY

Journal homepage: https://jurcon.ums.edu.my/ojums/index.php/borneo-science

CONSOLIDATION OF ONSHORE AND OFFSHORE LIGHTNING ELECTRIC FIELD CHARACTERISTICS ACROSS DISTINCT MALAYSIAN REGIONS

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Received: 13 July 2026
Revised: 20 August 2026
Accepted: 25 August 2026
Published online:
26 August 2025

Doi :
10.51200/bsj.v47i2.8014

Keywords:
Cloud to ground lightning;
Negative return stroke;
Lightning electric field;
Lightning characteristics.

ABSTRACT. *Lightning threatens onshore and offshore infrastructure, justifying the need for a clear understanding of cloud-to-ground (CG) lightning electric fields across different environments. This study consolidates published literature on negative CG lightning characteristics in Malaysia, focusing on Peninsular Malaysia (Johor, Kuala Perlis, Malacca Straits) and East Malaysia (Sarawak) to evaluate key electrical and temporal parameters. Malaysian flashes exhibit high multiplicity, ranging from 2.6 to 4.1 strokes per flash and up to 15 strokes. Significantly, Sarawak's average electric field is 2.7 times stronger, and its waveforms last 46% longer than those in Johor. The comparison of onshore and offshore characteristics demonstrates regional variations and reveals important data gaps. In Kuala Perlis, offshore electric field peaks are 27.3% higher than onshore peaks, likely due to the high conductivity of seawater. However, Sarawak's onshore and offshore peaks are practically comparable. These variations demonstrate that no single parameter can reliably distinguish between onshore and offshore lightning across the nation. While datasets from Sarawak, Kuala Perlis, and the Malacca Straits provide preliminary information, thorough measurements are lacking in Sabah and many offshore areas. Ultimately, expanding field measurements across diverse regions is essential to close these knowledge gaps and enhance lightning protection for safeguarding people and infrastructures.*

INTRODUCTION

Lightning is a powerful natural phenomenon that occurs most often during thunderstorms and is characterized by strong electrical discharges in the atmosphere. This transient, high-energy discharge drives atmospheric electricity and significantly affects various natural environments and human-made infrastructure. The electric field characteristics produced during lightning discharges offer important information about the lightning events. The information supports the development of technologies such as surge protection, lightning detection, and early warning systems (Industries, 2018; Wang et al., 2019). A better understanding of these electric fields is important not only for protecting infrastructure but also for helping to keep people safe. Individuals working outdoors are particularly at risk. For example, in Bangladesh, hundreds of people die from lightning strikes every year, with 300 to 400 deaths reported between 2010 and 2016 (Ahmed et al., 2024). Malaysia records over 300 thunderstorm days per year, and areas such as Selangor experience lightning nearly every day (Hananto, 2025). Satellite and ground-based data confirm that locations including the Malacca Straits and Peninsular Malaysia are part of a global lightning hotspot with flash densities ranging from 30 to 50 strokes/km²/year (Albrecht et al., 2016). Due to its frequent thunderstorms, Malaysia is more likely to have lightning-related accidents. Malaysia incurs estimated losses of more than RM 250 million per annum arising from business interruptions and infrastructure damage, mainly due to power outages, which are a significant impact of high electric fields of lightning (Ab Kadir et al., 2012). By inducing transient currents and overvoltages in power and communication cables, these high electric fields threaten detection accuracy, system operability, EMI immunity, and overall operational integrity (Cakil et al., 2024; Nucci et al., 2012). Such lightning impacts can happen in both offshore and onshore environments.

Lightning electric field characteristics are influenced by environmental factors, including terrain elevation, humidity, and propagation medium conductivity (Malagón-Romero & Luque, 2022; Xiang et al., 2024). The electromagnetic waveforms that travel through seawater usually make electric fields that are stronger and rise faster than those that travel through the ground. This is because saltwater has a higher conductivity (Asfur et al., 2020). Therefore, offshore platforms, which are highly exposed in the open ocean, are at greater risk from the powerful electric fields generated by lightning strikes over the sea. The high conductivity of seawater amplifies both the intensity and rise time of lightning electric fields. This amplification increases the risk of electromagnetic interference with sensitive electronic equipment used for navigation, drilling, and communication on offshore platforms, that jeopardized the operations (Cummins & Murphy, 2009; Rakov & Uman, 2003). The fatalities and damage resulting from lightning strikes serve as clear reasons to develop reliable lightning protection and electromagnetic shielding strategies in both onshore and offshore operations. Enhancing protection strategies for essential facilities like power grids, offshore oil platforms, and telecommunication networks requires an understanding of the characteristics of lightning electric fields. Therefore, it is important in lightning research to compare the lightning characteristics across various propagation mediums, particularly onshore and offshore. Unfortunately, there is still little research on the characteristics of lightning electric fields in Malaysia, particularly in East Malaysia. To address this research gap, this study compiles and analyses existing quantitative studies on lightning electric field characteristics from different regions and propagation environments in Malaysia.

The methodology adopted in this review involves consolidating available data from Peninsular Malaysia and Sarawak, with emphasis on negative CG lightning since data on positive CG are limited. The review covers twelve published journal articles, conference papers, and postgraduate research that report quantitative measurements of lightning electric field characteristics in Malaysia. Particular attention is given to parameters such as electric field peak, rise time, zero-crossing time, preliminary breakdown pulses, return stroke current, and stroke multiplicity. Studies that did not provide quantitative information relevant to the comparison were excluded from the consolidated tables. The reported results were then organized according to geographical region and lightning environment (onshore and offshore) to identify regional variations. By consolidating the available findings, the review highlights current knowledge gaps and provides recommendations for future lightning measurement studies in Malaysia. To support this review, it is important to first understand how lightning discharges are classified.

CLASSIFICATION OF LIGHTNING DISCHARGES

Lightning discharges are largely categorized into four types, Cloud-to-Ground (CG), Intra-cloud (IC), Cloud-to-Cloud (CC) and Cloud-to-Air (CA) as illustrated in Figure 1 (Wang et al., 2020). Among these, CG lightning is a particular focus since it has an impact on all types of life, infrastructure and critical systems (Jiang et al., 2023). Based on polarity and the direction of the initial electrical charge, CG lightning is classified into four types: downward negative, upward negative, downward positive and upward positive discharges (Kim et al., 2022). In a downward negative lightning strike, the long leader is negatively charged and propagates down from cloud to ground, initiating the rise of a positive streamer ascending toward the sky from the ground. After the establishment of the channel, a high-current return stroke occurs, called Negative Return Stroke (NRS).

Downward positive lightning, on the other hand, starts with a positively charged stepped leader initiating from the cloud. The connection of an upward moving negative streamer from the ground with the stepped leader would generate a Positive Return Stroke (PRS). Although less common, these discharges release massive amounts of charge and typically happen during severe thunderstorms (Sabri et al., 2024). The most common is downward negative (over 90% of CG flashes) and then downward positive. Upward lightning (either polarity) is not that common and is normally observed during thunderstorms on tall towers and mountains (Dwyer & Uman, 2014). Even though downward negative lightning predominates in Malaysia, positive lightning comprises 14% to 31% of CG flashes, with a mean of 18%, which is notably higher than global averages (Ramlee et al., 2018). That high percentage is significant because CG lightning is usually the strongest and most damaging form of lightning, making it hazardous to infrastructure and safety. Consequently, negative CG flashes, which are the most prevalent discharge of lightning, must be well comprehended. The next section reviews a progression sequence of a typical negative flash, through the phases and electrical properties associated with this event.

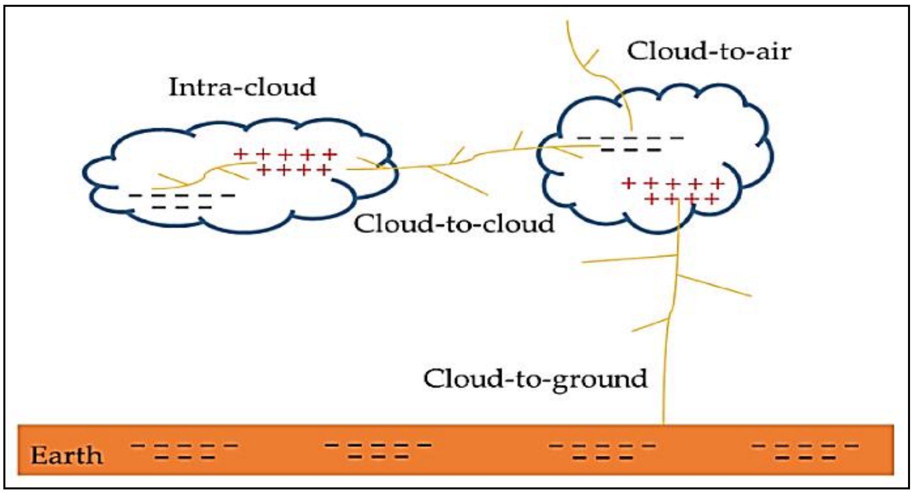

Figure 1. Four classes of lightning discharge (Wang et al., 2020)

PROGRESSION OF NEGATIVE LIGHTNING FLASHES

Typical electric field waveform of a negative CG lightning flash is shown in Figure 2 and proceeds through the main phases: Breakdown (B), Intermediate (I), Leader (L) and Return Stroke (RS). During the breakdown phase, a train of pulses of high frequency in duration of several milliseconds called Preliminary Breakdown Pulses (PBP) is observed first, signaling the beginning of ionization and electrical discharge within the cloud (Wu et al., 2013). The intermediate phase follows this, which is a relatively quiet period lasting up to several hundred milliseconds in the electric field and ending with the start of stepped leaders (Rojas et al., 2017). Stepped leaders make a conductive channel from the cloud to the ground during several tens of microseconds and establish the first return stroke (FRS). (Administration, 2023; Rakov & Uman, 2003).

Additional charge pockets in the cloud that follow the FRS may produce one or more Subsequent Return Strokes (SRS) (Cruz et al., 2025). These follow existing ionized paths and are initiated by dart leaders or dart-stepped leaders, which travel faster than the initial stepped leader due to the existing ionized channel (Stolzenburg et al., 2013). SRS events are often detected as repeated, lower amplitude peaks after the FRS in the electric field waveform (Zhu et al., 2015). They significantly contribute to the total energy delivered by a lightning flash (Li et al., 2013). Lightning multiplicity is defined as the number of return strokes containing the FRS and all SRS occurring in a single lightning flash (McCullar, 2019). The parameter of multiplicity of lightning discharges is crucial because it shows us how many return strokes follow a single breakdown. The total charge transfer, and hence the damage risk, can be several times larger due to multiple return strokes within a single lightning flash. Thus, multiplicity is critical information for accurate lightning modelling, lightning protection systems design and risk assessment.

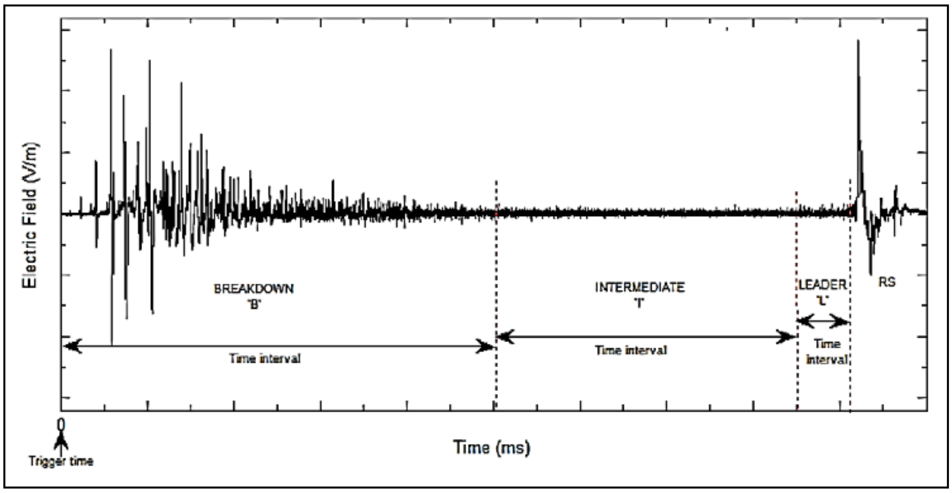

Figure 2. Lightning electrical radiation waveform (Ismail et al., 2015)

NEGATIVE LIGHTNING CHARACTERISTICS

Negative CG lightning exhibits distinct physical, temporal, and electrical characteristics throughout its progression. To provide a comprehensive overview of these characteristics, the following discussion is divided into two distinct subsections. The first subsection examines Multiplicity and Preliminary Breakdown Pulses, detailing the occurrence rate of multiple stroke flashes and the characteristics of early breakdown activity. The second subsection focuses on the First and Subsequent Return Strokes parameters, which describe the time duration, and energy distribution of the main discharge events. Together, these parameters provide a comprehensive picture of the negative lightning characteristics and form the basis for the consolidated data in this study. To ensure clarity and consistency in the subsequent analysis, the key lightning parameters evaluated in this consolidation, along with their standard definitions, are summarized in Table 1.

Multiplicity and Preliminary Breakdown Pulses

The quantitative parameters associated with lightning multiplicity and PBP are summarized in Table 2. A significant finding is the high multiplicity of negative CG flashes. Studies report that 73% to 92% are multiple stroke flashes, averaging between 2.6 and 4.1 strokes per flash. In an exceptional event, the highest recorded multiplicity reaches 15 strokes. Multiple strokes may either reuse an existing lightning channel or establish distinct ground contact points, allowing a single flash to affect multiple locations (Ramlee, 2022). Understanding lightning multiplicity is important for the design of lightning protection systems, particularly for critical infrastructure. Protection systems must account for the possibility of repeated thermal and mechanical stresses produced by successive return strokes within a single flash. Recent studies indicate that neglecting multiple stroke flashes may substantially underestimate lightning exposure and overvoltage risks in overhead transmission lines (Tang et al., 2025).

An important train of pulses in lightning progression, known as PBP, lasts from approximately 560 µs to 84 ms, as shown in Table 2. The presence of PBPs in up to 97% of Malaysian CG lightning demonstrates that this characteristic is exceptionally reliable indicator of lightning initiation in tropical climates. Consequently, the interval between PBP and the FRS, referred to as the PBP-FRS interval, is a critical parameter for predicting the time window to the occurrence of the FRS. The recorded arithmetic mean of the PBP-FRS interval was less than 25 ms, suggesting that the FRS typically follows a PBP within this short timeframe. This parameter is ideal for automated protection mechanisms, such as switching transmission channels or isolating sensitive power grid equipment just milliseconds before the destructive high-current return stroke arrives.

Table 1. Definitions of lightning parameters evaluated in this study.

No.	Parameter	Definition in terms of lightning characteristics
1	Multiplicity	Number of return strokes (FRS and SRS) occurring within a single lightning flash.
2	Percentage of Multiple Strokes	Proportion of flashes that contain more than one return stroke.
3	Flash with detectable PBP	Percentage of flashes where PBPs are observed.
4	PBP-FRS interval	Time between the maximum peak of the electric field in the PBP and the peak of the FRS.
5	Time duration of PBP	Length of the PBP train in terms of time.
6	Electric Field Peak	Maximum electric field amplitude recorded during a stroke.
7	Zero-to-Peak Rise Time	Time taken for the electric field to rise from baseline to its peak.
8	Zero-Crossing Time	Time duration from the start of the return stroke until the electric field waveform crosses zero.
9	10%–90% Rise Time	Time for the electric field to rise from 10% to 90% of its peak.
10	Interstroke Interval	Time gap between successive strokes in a multiple stroke flash.
11	Percentage of SRS Peak > FRS Peak	Proportion of cases where SRS peak exceeds FRS peak.
12	SRS/FRS Peak Ratio	Ratio of peak electric field of SRS to the FRS.
13	Fast Transition Amplitude	Magnitude of the rapid rise portion of the electric field waveform.
14	Peak Electric Field Derivative	Maximum rate of change of electric field with respect to time.
15	Opposite Polarity Overshoot Duration	Time duration of waveform overshoot in the opposite polarity after the main peak.
16	Fast Front Duration	Duration of the steep initial rise of the waveform.
17	CG Peak Current	Peak current in CG return strokes.
18	CG Distribution	Occurrences of CG lightning in the region.
19	Stroke Density	Number of strokes per unit area per year.

Table 2. Multiplicity and Preliminary Breakdown Pulse Characteristics.

Parameter	Sub-Parameter	Value	Total Flashes/Strokes	Location
Multiplicity	Percentage of Multiple Strokes (Wooi CL et al., 2016)	73%	104 flashes	Johor
	Percentage of Multiple Strokes (Baharudin et al., 2014)	84%	100 flashes	Johor
	Percentage of Multiple Strokes (Mehranzamir et al., 2014)	88%	58 flashes	Johor
	Percentage of Multiple Strokes (Salimi et al., 2014)	92%	130 flashes	Johor
	Maximum Multiplicity (Wooi et al., 2016)	15 strokes/flash	1.27 million flashes	Malaysia
	Maximum Multiplicity (Salimi et al., 2014)	14 strokes/flash	130 flashes	Johor
	Maximum Multiplicity (Mehranzamir et al., 2014)	9 strokes/flash	58 flashes	Johor
	Mean Multiplicity (Baharudin et al., 2014)	4.0 strokes/flash	100 flashes /405 strokes	Johor
	Mean Multiplicity (Wooi CL et al., 2016)	2.6 strokes/flash	104 flashes / 277 strokes	Johor
	Mean Multiplicity (Mehranzamir et al., 2014)	4.1 strokes/flash	58 flashes	Johor
Preliminary Breakdown Pulse (PBP)	Flash with detectable PBP (Baharudin et al., 2012)	97%	24 strokes	Johor
	Flash with detectable PBP (Ramlee, 2022)	57%	24 strokes	Sarawak
	PBP-FRS Interval (Baharudin et al., 2012)	58 ms	24 strokes	Johor
	PBP-FRS Interval (Ramlee, 2022)	24 ms	24 strokes	Sarawak
	Time duration of PBP (Baharudin et al., 2012)	12 ms	24 strokes	Johor
	Time duration of PBP (Ramlee, 2022)	3 ms	24 strokes	Sarawak
	Maximum PB Time Duration (Salimi et al., 2014)	84 ms	130 flashes	Johor
	Minimum PB Time Duration (Salimi et al., 2014)	560 µs	130 flashes	Johor

First and Subsequent Return Strokes

Table 3 consolidates the important electrical and temporal parameters associated with both FRS and SRS. The analysis of FRS characteristics shows a notable range across measurements from Johor and Sarawak. The mean electric field ranged from 21.8 V/m in Johor to 57.9 V/m in Sarawak, indicating 2.7 times stronger fields in Sarawak. Practically, this means protection systems such as shielding for telecommunication towers, and power lines must be designed to handle stronger electric fields instead of relying on a single national standard. It also highlights the possibility that local weather conditions influence electric field strength, making it essential to develop localized maps of lightning danger.

The zero-to-peak rise time ranged between 6.6 µs (observed in Johor) and 8.2 µs (observed in Sarawak), while the zero-crossing time varied from 50.7 µs to 74.1 µs across the same regions. This variation indicates 46.2% longer waveform durations in Sarawak. The 10% to 90% rise time showed a smaller range, from 3.4 µs to 4.2 µs. Consequently, infrastructure in Sarawak is exposed to extended electrical stress during lightning events. Prolonged transient overvoltages and electromagnetic fields increase thermal stress on surge protection devices (SPDs), raising the risk of failure in sensitive electronic equipment. These findings demonstrate regional variations in lightning characteristics, with Sarawak typically having stronger and slower rising return strokes than Johor. The variations are likely due to the temperature discrepancies between regions, as high temperatures tend to result in higher lightning electric field strength (Ismail, 2019). Also, variations in cloud base height during lightning propagation can influence the zero-crossing time in a directly proportional relationship observed between the two parameters (Ramlee, 2022).

Ramlee et al. specifically measured and analyzed parameters for both FRS and SRS in Sarawak (Ramlee, 2021a). The study discussed how electric field peak voltage, zero-crossing time, zero-to-peak rise time, and 10% to 90% rise time varied for both FRS and SRS across daytime and nighttime conditions. The discussion complements the general characteristics of SRS previously identified by Baharudin et al. (Baharudin et al., 2014). The analysis of 305 strokes shows that the mean interstroke interval of 86 ms highlights how lightning discharges can occur in rapid succession, requiring protection systems to withstand multiple strokes within fractions of a second. The average peak electric field of SRS is only 73% of the FRS, indicating that the initial stroke is generally the strongest and most destructive. However, 19% of SRS exhibited higher peak electric fields than their preceding FRS in the analysis. This observation exposes a complex and unexpected energy distribution of the multiple stroke lightning. Therefore, surge protection devices must be designed not only for the first stroke but also for the cumulative stress of successive discharges. These complexities highlight the need for broader datasets to better characterize multiple stroke behaviour.

However, the quantitative findings in Table 2 and Table 3 are derived from a limited number of primarily onshore studies in Malaysia. Furthermore, the available studies vary substantially in sample size, measurement duration, instrumentation, and observation conditions. Datasets from Sarawak are much smaller than those from Peninsular Malaysia because the region relied on a single lightning station established in 2018 (Ramlee, 2022). Despite these data constraints, this consolidation aims to highlight regional patterns and identify critical research gaps, underscoring the need for larger statistical samples from East Malaysia in future field campaigns. Additionally, the lack of detailed offshore measurements prevents a comprehensive comparison of lightning characteristics between onshore and offshore environments. Hitherto, only three published studies address this comparison, as discussed in the next section.

Table 3. First and subsequent return strokes characteristics.

Parameter	Sub-Parameter	Value	Total Flashes/Strokes	Location
First Return Stroke (FRS)	Mean Electric Field (Wooi CL et al., 2016)	21.8 V/m	104 flashes / 277 strokes	Johor
	Mean Electric Field (Ramlee, 2021b)	57.9 V/m	19 strokes	Sarawak
	Mean Electric Field (Ramlee, 2021a)	57.8 V/m	20 strokes	Sarawak
	Mean Zero-to-Peak Rise Time (Wooi CL et al., 2016)	6.6 µs	104 flashes / 277 strokes	Johor
	Mean Zero-to-Peak Rise Time (Ramlee, 2021b)	8.2 µs	19 strokes	Sarawak
	Mean Zero-to-Peak Rise Time (Ramlee, 2021a)	7.3 µs	20 strokes	Sarawak
	Mean Zero-Crossing Time (Wooi CL et al., 2016)	50.7 µs	104 flashes / 277 strokes	Johor
	Mean Zero-Crossing Time (Ramlee, 2021b)	74.1 µs	19 strokes	Sarawak
	Mean Zero-Crossing Time (Ramlee, 2021a)	70.3 µs	20 strokes	Sarawak
	Mean 10%-90% Rise Time (Wooi CL et al., 2016)	3.9 µs	104 flashes / 277 strokes	Johor
	Mean 10%-90% Rise Time (Ramlee, 2021b)	4.2 µs	19 strokes	Sarawak
	Mean 10%-90% Rise Time (Ramlee, 2021a)	3.4 µs	20 strokes	Sarawak
Subsequent Return Stroke (SRS)	Mean Interstroke Interval (Baharudin et al., 2014)	86 ms	305 strokes	Johor
	Percentage of SRS Peak > FRS Peak (Baharudin et al., 2014)	19%	305 strokes	Johor
	SRS/RS Peak Ratio (Baharudin et al., 2014)	0.73	305 strokes	Johor

ONSHORE AND OFFSHORE LIGHTNING FIELD PARAMETERS

Table 4 reveals that several waveform parameters exhibiting different trends between Kuala Perlis, Sarawak and Malacca Straits. The electric field peak demonstrates the clearest regional contrast. In Kuala Perlis, the offshore electric field peak is 27.3% higher than the corresponding onshore value, indicating stronger electric fields offshore. This supports studies showing that seawater's high conductivity allows electromagnetic fields to travel efficiently, creating stronger electric fields offshore than onshore (Omari et al., 2025). In contrast, Sarawak exhibits almost identical electric field peaks for onshore (56.8 V/m) and offshore (55.7 V/m) lightning, with a difference of only 1.9%. Specifically, the onshore electric field peak in Sarawak is approximately 2.3 times higher, and the offshore electric field peak is 1.8 times higher than the value reported in Kuala Perlis. This difference is likely caused by the distance between the lightning strikes and the measurement station (Ramlee et al., 2024), as well as signal weakening across the land and sea boundary (Xiao et al., 2025). Besides electric field peak (V/m), lightning peak current (kA) also reflect the same lightning discharge intensity. The Malacca Straits, lightning characteristics show slight differences between onshore and offshore environments where offshore CG peak current is 17% higher than onshore. Meanwhile, the overall CG distribution in the region is only 2.4% higher onshore compared to offshore, suggesting a nearly equal occurrence of CG lightning in both environments. Similarly, the stroke density is only 7.4% greater onshore, indicating a small increase in lightning occurrence onshore compared to offshore. These findings suggest that local weather conditions may affect electric field strength more strongly than the propagation medium.

The influence of the propagation medium on zero-to-peak rise time appears to be weak and inconsistent. In Kuala Perlis, the offshore zero-to-peak rise time is only 0.6% longer than the corresponding onshore value. In contrast, Sarawak exhibits the opposite trend, with the offshore rise time being 6.8% shorter than the onshore value. Although the direction of change differs between the two regions, the overall differences are relatively small, suggesting that the propagation medium has only a limited influence on the initial development of the return stroke. A more pronounced contrast is observed for the 10% to 90% rise time. In Kuala Perlis, the offshore value is 12.2% longer than the onshore, indicating a slightly slower transition to the peak electric field of the offshore lightning. However, Sarawak exhibits the opposite behaviour, where the offshore 10% to 90% rise time is 22.0% shorter than the onshore. This contradiction reveals that local storm dynamics and regional weather influenced waveform development more than surface conductivity.

The most significant variation occurs in the zero-crossing time. In Kuala Perlis, the offshore zero-crossing time is only 4.6% shorter than the onshore value, which suggests that waveform durations are nearly identical in both environments. Conversely, Sarawak demonstrates a substantial offshore increase, with the zero-crossing time rising from 47.7 µs onshore to 101.5 µs offshore, corresponding to an increase of approximately 2.1 times. This finding suggests that offshore lightning in Sarawak produces electric field waveforms with considerably longer durations than those observed onshore. Since zero-crossing time reflects the duration of the initial electric field pulse, longer waveform durations may increase the period during which nearby electrical and communication systems are exposed to the lightning electromagnetic disturbances (Cooray, 2015). The extended waveform durations observed in offshore Sarawak are likely due to the combined influence of regional atmospheric conditions, cloud base characteristics, and the marine environment (Araki et al., 2021; Ramlee et al., 2024). However, without simultaneous meteorological and electric field measurements, this explanation remains a hypothesis that needs further studies to confirm the causes of the differences between East and Peninsular Malaysia.

Overall, lightning characteristics across Kuala Perlis, Sarawak, and the Malacca Straits reveal distinct regional variations and similarities between onshore and offshore environments. These findings suggest that no single parameter can consistently distinguish onshore from offshore lightning in Malaysia. Instead, lightning characteristics are likely influenced by a combination of the propagation medium, local weather conditions, storm characteristics, and geographical factors (Vadukkoot et al., 2022). Therefore, more onshore and offshore measurements from different regions are needed to better understand lightning behaviour across Malaysia.

Table 4. Consolidation of the lightning characteristics observed onshore and offshore in Malaysia

Parameter	Onshore (Kuala Perlis) (Abdul-Malek et al.)	Offshore (Kuala Perlis) (Abdul-Malek et al.)	Onshore (Sarawak) (Ramlee et al., 2024)	Offshore (Sarawak) (Ramlee et al., 2024)	Onshore (Malacca Straits)(Azaman et al., 2023)	Offshore (Malacca Straits) (Azaman et al., 2023)
Electric Field Peak	24.82 V/m	31.60 V/m	56.8 V/m	55.7 V/m	-	-
Fast Transition Amplitude	17.58 V/m	18.81 V/m	-	-	-	
Peak Electric Field Derivative	18.81 V/m/µs	38.23 V/m/µs	-	-	-	-
Zero-to-Peak Rise Time	6.44 µs	6.48 µs	7.3 µs	6.8 µs	-	-
10%-90% Rise Time	3.78 µs	4.24 µs	4.1 µs	3.2 µs	-	-
Zero-Crossing Time	104.02 µs	99.21 µs	47.7 µs	101.5 µs	-	-
Opposite-Polarity Overshoot Duration	138.72 µs	130.10 µs	-	-	-	-
Fast Front Duration	2.95 µs	1.22 µs	-	-	-	-
CG Peak Current (Geometric Mean)	-	-	-	-	21.9 kA	25.7 kA
Average Return-Stroke Current	31.4 kA	47.7 kA	-	-	-	-
Mean Multiplicity	2.9 strokes/flash	3.3 strokes/flash	-	-	-	-
Overall CG Distribution	43%	57%	57%	43%	51.2%	48.8%
Stroke Density	-	-	-	-	27.2 strokes/km^2/year	25.2 strokes/km^2/year

Note: “-" indicates parameters that were not recorded in the cited literature.

CONCLUSION

This review comprehensively investigates lightning electric field characteristics in Malaysia, both onshore and offshore with a focus on negative CG discharges. The study finds considerable regional and environmental variances in important parameters such as electric field peak amplitude, rise time, zero-crossing time, preliminary breakdown pulses, and stroke multiplicity. It discovers the intense and complex nature of Malaysian lightning through high stroke multiplicity and frequent preliminary breakdown pulses. Furthermore, Sarawak's stronger and longer duration waveforms compared to Johor further emphasize the need for localized protection standards. Offshore observations show mixed results, with some regions recording higher peaks and others nearly identical values to onshore, confirming that no single parameter can reliably distinguish lightning behaviour nationwide. Regional comparisons also reveal differences in lightning distribution patterns across Kuala Perlis, Sarawak, and the Malacca Straits. Although these insights are valuable, data coverage remains limited, particularly in Sabah and several offshore regions. Consequently, this interpretation remains a working hypothesis that requires targeted field studies to confirm the causes of variations between East and Peninsular Malaysia. Therefore, future research should focus on collecting more field data in unexplored areas to improve understanding of lightning behaviour. Such efforts are crucial not just for improving the accuracy of lightning detection and the reliability of protection systems that safeguard people and infrastructure, but also for ensuring that sensitive electronic equipment can function safely and effectively in Malaysia's lightning-prone onshore and offshore environments. Ultimately, this study directly supports Sustainable Development Goal 11 (Sustainable Cities and Communities) by making cities and workplaces safer from lightning, and reducing damage through better protection.

ACKNOWLEDGEMENT

The authors sincerely thank the University of Technology Sarawak (UTS) for funding this study (RESEARCH ID: 1/2024/08) and supporting the experimental work. Special thanks to the Centre for Research of Innovation & Sustainable Development (CRISD), UTS, for their support in the academic writing process. Their guidance and resources greatly improved this research.

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