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Seasonal Distribution of Thunderstorm Activity in the Southern Region of Peninsular Malaysia

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ABSTRACT

This paper comprehensively analyses the thunderstorm activity in southern Peninsular Malaysia from 2011 to 2018 utilizing lightning data from the Lightning Detection Network System (LDNS) managed by TNB-Research (TNBR). Employing statistical analysis with Microsoft Excel and Python 3.9, this study aims to evaluate and characterise the regional CG lightning, considering geographical, temporal and climatic factors and their relation to seasonal variations. Negative cloud-to-ground (-CG) lightning dominates at 98.00 %, with only 2.00 % positive cloud-to-ground (+CG) lightning. Monthly trends exhibit a double-peak characteristic, with primary and secondary maxima in April and October, respectively, coinciding with monsoon transitions. The first inter-monsoon (IM1) emerges as the most active period, with +CG lightning contributing 28.40 % of total CG lightning compared to -CG lightning at 71.60 %. This study emphasizes critical implications, including polarity imbalance, double-peak distribution, and seasonality. The significant disparity between +CG and -CG lightning necessitates further investigation into charge separation mechanisms within the clouds, particularly during IM1. The presence of double-peak feature in the monthly variation underscores the significant influence of monsoon dynamics on lightning activity initiation. The dominance of IM1 in total CG lightning and the high percentage of +CG lightning emphasize the need for enhanced lightning protection measures and preparedness during critical months, improving lightning risk assessment, public safety and infrastructure resilience. Future studies should focus on employing advanced meteorological models to explain the charge separation and polarity variations.

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1. Introduction

Thunderstorms and lightning activities are greatly influenced by factors such as geographical location, climatic conditions, and time of day. Knowledge of these variations is useful for understanding the meteorological processes responsible for lightning occurrence, thunderstorm growth, the planning of activities that take place outside, the predicted consequences of lightning on power reliability, and indication of severe weather. Due to the tropical climate, monsoon variation, topography, and location near the equatorial line, lightning and thunderstorm activities are typical occurrence in Malaysia and these activities take place throughout the whole year [1].

Generally, Malaysia is influenced by two (2) main monsoon seasons that have a significant impact on the weather patterns. The first season is known as the Northeast Monsoon (NEM) season which typically lasts from November to March. The second season is known as the Southwestern Monsoon (SWM) season, and it occurs from May to September. There are two distinct periods, known as the Inter-Monsoon (IM) seasons, that separate the NEM and SWM. The first Inter-Monsoon (IM1) season occurs in April, while the second Inter-Monsoon season (IM2) occurs in October [2].

During the NEM season, low lightning activities occur in the East Coast of Malaysia and West Sarawak which get significant rainfall and wet weather. On the other hand, the climate during the SWM season causes moderate lightning activities to occur in Peninsular Malaysia. During the months of IM1 and IM2, there was a significant increase in thunderstorm activity along the West Coast of Peninsular Malaysia and East Sarawak [3]. This is primarily caused by the formation of active clouds in the region, resulting in a high density of lightning. The lightning density in Peninsular Malaysia has the potential to exceed 24 strokes per square kilometre per year, as shown in the Fig. 1.

In 2021, the Global Lightning Detection Network (GLD360), which is owned and operated by Vaisala, recorded the number of lightning strikes worldwide. Malaysia ranked among the top three countries with the highest number of lightning strikes, recording a total of 17,738,435 strikes. Additionally, Malaysia had the highest lightning density among Southeast Asian countries, with a rate of 54.14 events per square kilometre [4]. Most of the states in Malaysia are considered to have very high flash rate density, with more than 50 flash events per square kilometre per year. This is primarily due to the mountainous topography and its geographical boundaries, which include the Strait of Malacca to the west, the South China Sea to the east, and the Strait of Tebrau to the south [5].

Malaysia receives a significant amount of rainfall each year, with an average of 2000 mm to 4000 mm. The annual temperature in the country ranges from 26 °C to 32 °C, creating ideal conditions for lightning activity caused by thunderclouds [1]. This issue has triggered great concern among the public, industries, and other sectors due to its potential to result in human injuries and fatalities, as well as electronic or mechanical failures, financial losses, forest fires, and agricultural and crop destruction, among other consequences [6].

The rise of urbanisation in various industries, including oil and gas, petrochemicals, and manufacturing, has contributed to the development of thunderclouds that can potentially result in leading a higher occurrence of lightning activity. Lightning can lead to both temporary and permanent power disruptions in transmission and distribution systems. Using overhead power lines instead of underground transmission systems heightens susceptibility to lightning strikes, making it the primary cause of transmission line outages.

According to a study, the proportion of transmission line disruptions in the TNB Transmission Network caused by lightning and thunderstorms varied annually from 39.00 % to 61.00 % for 2001 to 2013. This percentage was considered higher in comparison to previous studies, which recorded only 36.00 % [7]–[9]. Several countries including Brazil, Austria, Indonesia, and China also encountered interruptions in their transmission lines caused by intense and active lightning activity [10]–[13].

Therefore, it is essential to have a comprehensive understanding of lightning and thunderstorm characteristics and activities in various regions to minimise the damage caused by lightning. The temporal and seasonal variations from various regions have been investigated and reported, including Malaysia. Thus, this study presents the seasonal distribution of thunderstorm activity in the southern region of Peninsular Malaysia over an eight-year period, which started from January 1, 2011, until December 31, 2018. The data used for analysis was obtained from LDNS-TNBR and specifically focuses on positive and negative CG lightning. The findings of this study may provide a basic reference for lightning risk assessment and lightning protection in the southern region of Peninsular Malaysia and the surrounding area.

This paper is structured into several sections. Section 2 provides an explanation of the data and methodology used in this study. Section 3 is focused to the analysis of the results and discussions. Finally, in Section 4, the conclusion of this study is provided.

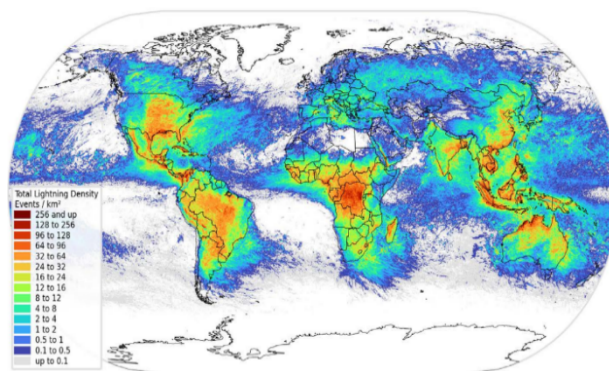


Fig. 1. Lightning Density (Adopted from Vaisala) [4]

2. Methodology

In this section, the explanation is divided into two sub-sections. Section A explains the study area. Meanwhile, Section B presents the data and methods used to analyse the thunderstorm activity in the southern part of Peninsular Malaysia.

2.1 Study Area

This study covered an area of a 100 km radius positioned at the School of Engineering, Universiti Teknologi Malaysia (UTM) Johor in the southern part of Peninsular Malaysia. Johor is situated close to the equator at a latitude of 1.990833 °N, and longitude of 103.482778 °E, it has mountainous topography and is surrounded by 3 main seas; Strait of Malacca, South China Sea, and Strait of Tebrau.

The population of Johor in 2021 is 3.79 million, and it covers an area of 19,166 km². Johor ranks second in Malaysia for having the highest lightning density rate which is 91.3 occurrences per square kilometre per year. The study was focused on the southern region of Peninsular Malaysia due to its recent significant growth in various sectors, including manufacturing, petrochemicals, and the oil and gas industry. Furthermore, there has been an increase in both the number of lightning incidents and the intensity of lightning activity [14]– [18].

2.2 Data and Methods

In this study, the lightning data were recorded using Vaisala LS7002 sensors that consist of information such as date, time, location (longitude and latitude), polarity, and peak current (in kA) for each lightning strike. The LDNS is composed of three (3) main components: the lightning sensors, the central server, and the user interface. The system is equipped with seven (7) active sensors strategically located around Peninsular Malaysia, as depicted in Fig. 2. The lightning sensors utilized the Time-of-Arrival (TOA) and Magnitude Direction Finder (MDF) techniques to accurately detect and analyse the electromagnetic signals generated by lightning strikes.

The central server is a computer system that efficiently collects, processes, and stores the data from the lightning sensors by calculating the lightning parameters based on the data from a minimum of four sensors. The central server also performs quality control, data analysis, and data archiving functions. The user interface is a software application that displays the lightning information and alerts to the users. It is accessible via a web browser or a mobile app. The user interface provides various features, including map view, chart view, report view, and alert view.

Currently, the detection efficiency of the LDNS is up to 95.00 % and the location accuracy is 0.25 km. The detailed information regarding the LDNS-TNBR can be found in the following references [3], [19]. Fig. 3 displays the lightning distribution from 2016 to 2018, The red and yellow dots indicates the distribution of negative and positive lightning occurrence in the region, respectively. The monthly and annual variation, seasonal distribution, and lightning activity in the southern region of Peninsular Malaysia are analysed using Microsoft Excel and Jupyter Notebook in Python 3.9.

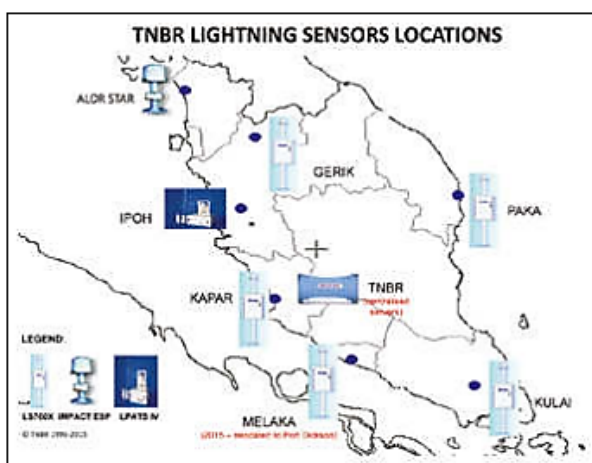


Fig. 2. LDSN-TNBR Sensors Locations [19], [27].

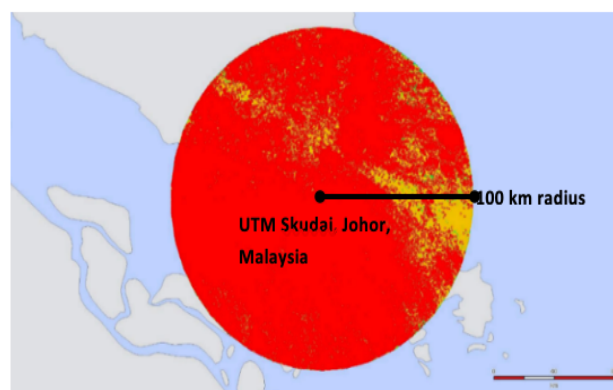


Fig. 3. Lightning Distribution Map Within a 100 km Radius of UTM Skudai, Johor Malaysia from 2016 to 2018 (Source from TNBR).

3. Results

Similar to the previous section, the following results and discussions are divided into two subsections. Section A presents the annual and monthly variation of lightning activity in the Southern Region of Peninsular Malaysia. Meanwhile, Section B presented the seasonal variation of lightning activity in the Southern Region of Peninsular Malaysia.

For the 8 years, a total of 1,371,507 million lightning data were analysed to determine the percentage occurrence of positive (+CG) and negative (-CG) cloud-to-ground strikes. The analysis further investigated their annual and monthly variations across different seasons. This comprehensive approach yielded detailed insights into the spatiotemporal distribution of lightning activity.

3.1 Annual and Monthly Variation of Lightning Activity in the Southern Region of Peninsular Malaysia

The annual variation of CG lightning in Peninsular Malaysia from 2011 until 2018 is illustrated in Fig. 4. Within 8 years of the period, the southern region recorded about 691546 CG lightning activity in 2017, which is the highest compared to other years, while only 8818 CG lightning activity was recorded in 2012. Following the upgrade in 2009, the LDNS demonstrated enhanced capability in accurately detecting the truth signal of CG lightning and effectively separated them from spurious signals. Most of the annual lightning flashes were dominated by -CG lightning flashes and +CG lightning flashes were rarely observed. The mean annual occurrence of -CG lightning flashes is 98.00 % and -CG lightning flashes is 2.00 %, respectively.

The monthly variation of +CG and -CG lightning activity in the southern part of Peninsular Malaysia from 2011 to 2018 is displayed in Fig. 5. The percentage of positive CG lightning is represented by a solid line with circle markers, and the percentage of negative CG lightning is represented by a solid line with square markers, and the total CG lightning is represented in the bar chart. The monthly percentage of -CG lightning is dominated most of the months with 91.00% and above. The number of -CG lightning occurrences had a significant decline from March (94.90 %) to April (68.20 %), and then gradually increased in June (91.50 %). The monthly percentage +CG lightning varies from 5.10 % to 31.80 %.

An interesting finding found that the +CG lightning counts are increasing drastically from March (5.10 %) until April (31.80 %) and then slowly decreasing in June (8.50 %). The variation of total CG lightning showed a double peak in April (main peak) and October (minor peak); both were strongly related to the monsoon season transition from pre-monsoon to monsoon season [20].

In contrast to the mid-latitude region, the total CG lightning in the China and India regions exhibits a single-peak feature in the monthly variation, which occurs during the summer [21], [22]. This variation is consistent with several studies that reported the characteristic double peak feature of CG lightning in tropical countries, including Brazil, Indonesia, Bangladesh, and Sri Lanka [11], [22]–[24]. Prior research conducted in Malaysia has also reported the double peak pattern for monthly variation of CG lightning. The majority of CG lightning occurrences were recorded during the monsoon transition period, specifically from April to May and October to November [7], [25]–[27].

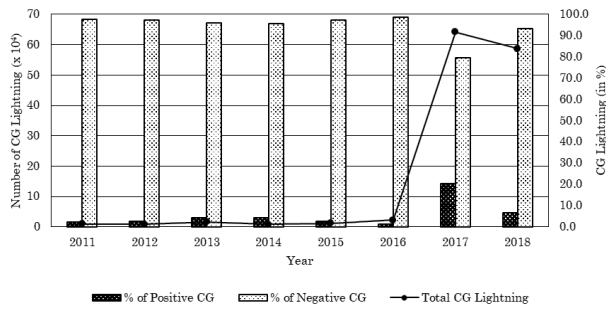


Fig. 4. Annual Variation of Total CG Lightning, Positive and Negative CG Lightning from 2011 to 2018.

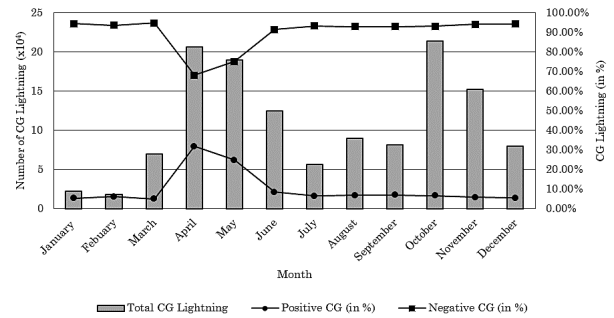


Fig. 5. Monthly Variation of Total CG Lightning, Positive and Negative CG Lightning from 2011 to 2018.

3.2 Seasonal Variation of Lightning Activity in the Southern Region of Peninsular Malaysia

The seasonal distribution of total CG, +CG, and -CG lightning is depicted in Fig. 6. Over 1.3 million CG lightning activity was recorded from 2011 until 2018, but their distribution was far from uniform. A significant amount of CG lightning activity occurred frequently during the transition of monsoon, IM1 and IM2 seasons with 58.40 %, and SWM (dry season). This coincides with intense land surface heating, the occurrence of convective precipitation, and the development of thunderstorms, indicating that the accumulation of electrostatic charge contributes a key part. During the rainy season (NEM), there was a noticeable decrease in lightning activity (14.60 %), possibly due to the lower levels of precipitation and cloud cover that limited the separation of charges. A negative correlation exists between total lightning activity and the percentage of -CG lightning strikes. Notably, over 92.00 % of -CG flashes occurred during NEM, SWM, and IM2, compared to the IM1 season only 71.60 %. However, the percentage of +CG lightning during the IM1 season is much higher compared to the other three seasons. This suggests different charge distribution dynamics within the cloud, potentially influenced by factors such as precipitation scavenging of charged particles.

Electrostatic charges can be triggered when the land surface experiences intense heating and convective precipitation. This instability can lead to the development of thunderstorms and lightning, which is different from the rainy season (NEM). The precipitation patterns within Peninsular Malaysia can vary significantly across locations. While some areas might experience heavier rainfall during the late November-March period, others might not, leading to localized discrepancies in lightning activity. During the NEM season, very low precipitation and less cloud could be the reason for the low number of lightning activities.

The thunderstorm and the lightning activity in Peninsular Malaysia coincide with the monsoon, and it is agreed by other studies that April and October experienced the highest level of lightning activity in this region, and it is agreement that the occurrence of the highest lightning activity rate is during the IM season [3], [7], [19], [27]. These findings were aligned with the results from Sri Lanka, where the majority of lightning flashes (38.00 %) occurred during the first IM season [23], [28]. Nevertheless, it is revealed that the frequency of lightning strikes peaked during the rainy season (late November to March), highlighting the need to reconcile these discrepancies and gain a more comprehensive understanding of the lightning climatology in the region [29].

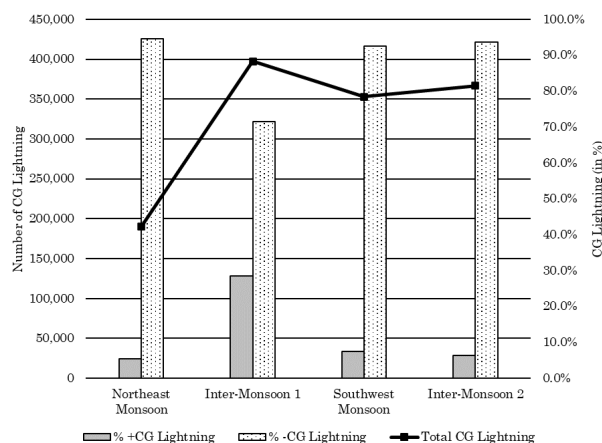


Fig. 6. Seasonal Distribution of Total CG, -CG and + CG Lightning.

4. Conclusions

The thunderstorm activity in the southern region of peninsular Malaysia was analysed, including the seasonal distribution that is based on approximately 1.3 million lightning strikes recorded by TNBR-LDNS from 2011 to 2018. This study focuses on the seasonal distribution and reveals several key findings:

- Annually, about 98.00% was -CG lightning, with more than 92.00 % of -CG lightning occurring during the dry seasons (NEM, SWM, and IM2). Only 2.00 % was +CG lightning and most of it occurred during IM1 season with 28.4 %.
- The majority of lightning activities took place in April and October, with -CG lightning ranging from 68.20 % to 94.90 % and the +CG lightning varying from 5.4 % to 31.80 % for each month.
- Almost 400000 of the total CG lightning occurred during IM1 season. The highest and lowest proportions of -CG were 94.60 % (NEM season) and 71.60 % (IM1 season), respectively. Meanwhile, for +CG lightning contributes the highest with 28.40 % (IM1 season) and lowest at 5.40 % (NEM season).

These findings indicate that the lightning activity in the southern region of Peninsular Malaysia follows interesting trends, similar to those observed in tropical regions. The relationship between lightning activity and geographical location, as well as seasonal distribution, is significant in this area. In the context of Malaysia, thunderstorms are a common issue, with an average of 180-260 thunderstorm days each year. However, the scale of thunderstorms in Malaysia is relatively small compared to cyclone-prone areas.

The findings of this study provide valuable insights into the seasonal distribution and polarity characteristics of lightning activity in the southern region of Peninsular Malaysia, which can be used to improve lightning protection systems and predict thunderstorm activity.

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