Relationship Between Radar Reflectivity and Lightning Flash Characteristics in Peninsular Malaysia

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ABSTRACT

This paper presents the relationship between radar reflectivity and lightning flash rate have been investigated in Peninsular Malaysia between 1 and 6 November 2023. Despite the frequent occurrence of thunderstorms in Malaysia, the relationship between weather radar reflectivity and lightning activity remains insufficiently understood limiting the use of radar observations for assessing thunderstorm electrification and lightning occurrence. Lightning signals captured via a Fast Antenna (FA) system were analysed using PicoScope 6 to classify waveform categories, while radar data in CAPPI format represented storm intensity. A total out of 912 total recorded lightning flashes including positive Cloud-to-Ground (+CG) flashes were nominated around 46.82%, followed by Intra-Cloud (IC) flashes around 30.48%, positive Narrow Bipolar Events (+NBE) around 13.27%, negative Cloud-to-Ground (-CG) flashes around 8.99% and negative Narrow Bipolar Events (-NBE) around 0.66%. The peak convective period occurred on 4 November 2023 consist of 50.33% the weekly data and yielding the strongest positive relationship with a Pearson correlation coefficient of r = 0.3014. The results demonstrate that while radar reflectivity peaks and lightning flash rates are temporally correlated during lifecycle phases, the strength and direction of the correlation vary across individual storms. This study offers critical insights into topical thunderstorm electrification structures for advanced weather forecasting.

Keywords: Lightning Flashes, Radar Reflectivity, Pearson Coefficient

INTRODUCTION

Malaysia experiences frequent thunderstorms due to its tropical climate, making it one of the countries with the highest lightning occurrence rates globally. These storms, particularly during the inter-monsoon transition period are often accompanied by heavy rainfall, winds and lightning activity. Evidence from more than half a century ago shows that scientists had already attempted to understand the relationship between the lightning rate and the vertical structure of radar reflectivity in thunderstorms by using the lightning reports of surface observers and the first generation of weather radar (Liu et al., 2012). Weather radar can resolve many phenomena related to thunderstorms. Since total lightning detection systems were introduced, numerous studies have investigated how total lightning characteristics and behavior relate to severe weather (Goodman et al., 2005).

Radar reflectivity is widely used to represent storm intensity while lightning flash rate reflects the electrical activity within thunderstorms (Deierling et al., 2008; Wiens et al., 2005). Although previous studies have suggested a relationship between these two parameters, there remains limited understanding of how radar reflectivity corresponds to lightning occurrence in the Peninsular Malaysian context. This gap in knowledge is important because accurate forecasting and early warning systems depend on reliable indicators of storm

severity. Without a clear quantitative link between radar and lightning, meteorologists face challenges to protect communities from associated risks caused by dangerous weather.

Several previous studies have been investigated the relationship between radar reflectivity and lightning in different climatic regions. The thunderstorms with stronger radar echoes extending above the freezing level generally produced higher lightning flash rates, indicating that intense convective development enhances cloud electrification (Cecil et al., 2002). Likewise, the lightning frequency is closely related to the upward transport of ice particles within convective clouds, where stronger updrafts increase both radar reflectivity and electrical charge separation (Deierling et al., 2008). Recent studies found that lightning occurrence generally increases when radar reflectivity exceeds 30 d BZ, although the relationship varies depending on storm structure and environmental conditions (Huang et al., 2024). These findings indicate that radar reflectivity can provide valuable information regarding thunderstorm electrification, but further investigation is required for tropical regions such as Peninsular Malaysia where storm characteristics differ from those in temperate climate.

To address this problem, the present study focuses on lightning events recorded between 1 and 6 November 2023 across Peninsular Malaysia. The objectives are to analyze lightning flashes and radar reflectivity during thunderstorms events and determine the correlation between radar reflectivity and lightning flash rate. The data was collected using the Fast Antenna (FA) system for lightning detection and CAPPI radar reflectivity data provided by the Malaysian Meteorological Department. This study enhances thunderstorm monitoring and forecasting by identifying radar thresholds linked to lightning occurrences. Theoretically, it advances the understanding of storm electrification processes in tropical regions. By providing a quantitative assessment of radar-lightning relationships, this research contributes to improve operational meteorology in Malaysia.

METHODOLOGY

Data Sources

This section describes the procedures and techniques used to collect, process and analyze both lightning and radar data to determine the correlation between radar reflectivity and lightning flash rate. The data were collected from two sources: lightning data recorded using the Fast Antenna (FA) system and radar reflectivity data obtained in CAPPI format from the Malaysian Meteorological Department (MetMalaysia). Lightning data were obtained using a Fast Antenna (FA) system, while CAPPI radar data were provided by MetMalaysia. The fast antenna (FA) system used to detect rapid changes in the atmospheric electric field associated with lightning return strokes. It is designed with broad frequency response to capture rapid electric field variations with high temporal resolution and have been used in lightning mapping arrays and impulse charge moment measurement (Wu et al., 2018). The study focused on thunderstorms occurring between 1 and 6 November 2023. Lightning waveforms were analyzed using PicoScope 6 software to classify lightning flashes into IC, +CG, -CG, +NBE and - NBE categories based on waveform polarity and signal characteristics, while the radar data are processed to determine the corresponding radar reflectivity values. The processed datasets are combined to determine the correlation between radar reflectivity and lightning flash rate for selected thunderstorm events using Pearson correlation analysis.

RESULTS AND DISCUSSION

This section presents the findings obtained from the correlation analysis between radar reflectivity and lightning flash rates. The results are summarized in text and supported with tables and figures to highlight the most relevant observations.

The type of Lightning Flashes

The results obtained shows a total of 912 lightning flashes were recorded between 1 and 6 November 2023. The types of lightning flashes were categorized into intra-cloud (IC), Positive Cloud-to-Ground (+CG), Negative Cloud-to-Ground (-CG), Positive Narrow Bipolar Events (+NBE) and Negative Narrow Bipolar Events (-

NBE). Radar reflectivity values (d BZ) were extracted from CAPPI radar data at corresponding times. The Pearson correlation coefficient (r) was computed to evaluate the relationship between radar reflectivity and lightning flash.

Table 1 presents the distribution of lightning flash types recorded from 1 and 6 November 2023. The Positive Cloud-to-Ground (+CG) flashes were the dominant lightning type with 427 occurrences (46.82%), followed by Intra-Cloud (IC) flashes with 278 events (30.48%). Positive Narrow Bipolar Events (+NBE) accounted for 121 flashes (13.27%), whereas Negative Cloud-to-Ground (-CG) and Negative Narrow Bipolar Events (-NBE) represented only 82 (8.99%) and 6 (0.66%) events, respectively. The highest lightning activity occurred on 4 November 2023 with 459 recorded flashes, representing approximately half of the total weekly observations. This indicates that the thunderstorm on that day was considerably more electrically active than the other observed events. Figure 1 shows the distribution of total lightning flash types on 1 November 2023 until 6 November 2023.

Table 1. The types of lightning flashes captured by the lightning system

Date	IC	+CG	-CG	+NBE	-NBE	Total
1 Nov	38	37	20	27	6	126
2 Nov	1	10	15	25	0	51
3 Nov	19	49	28	46	0	142
4 Nov	178	263	7	11	0	459
5 Nov	39	60	6	8	0	113
6 Nov	3	8	6	4	0	21

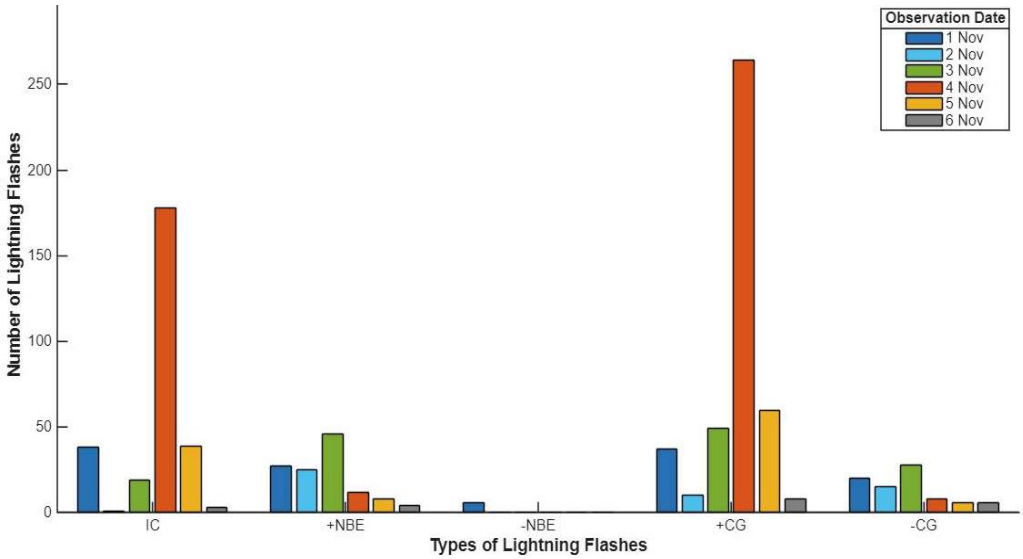


Figure 1: Distribution of lightning flash types on 1 November 2023 until 6 November 2023

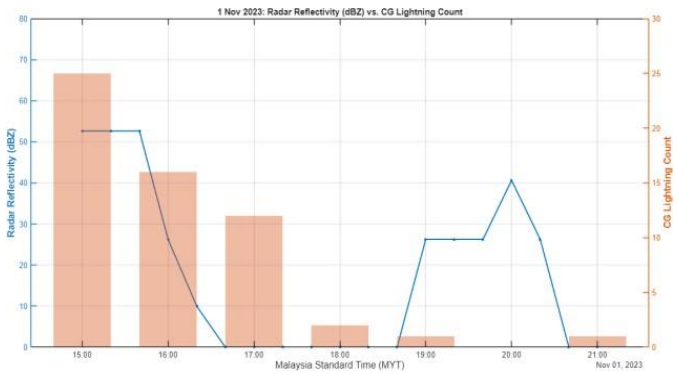
The correlation between radar reflectivity and lightning flash rate

The Pearson correlation coefficient was calculated for each day to quantify the relationship between radar reflectivity and lightning occurrence. Table 2 summarizes the Pearson correlation coefficient between radar

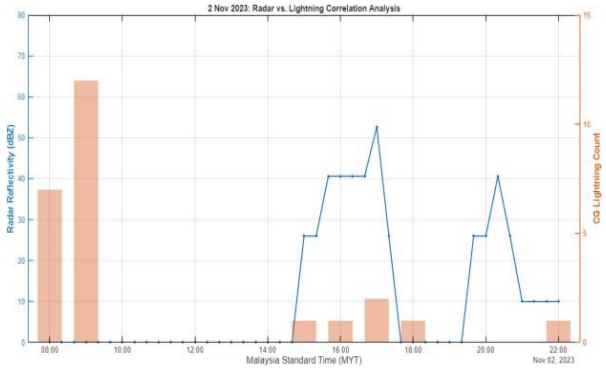
reflectivity and lightning flash rate for each observation day. Positive correlation values were obtained on 1, 3, 4 and 5 November, indicating that lightning activity generally increased as radar reflectivity became stronger. The highest correlation was observed on 4 November (r = 0.3014), suggesting that this storm exhibited the strongest relationship between convective intensity and lightning production. In contrast, weak negative correlations were observed on 2 November (r = - 0.0571) and 6 November (r = -0.0687), indicating little or no linear relationship between radar reflectivity and lightning occurrence. These differences imply that although radar reflectivity is an important indicator of thunderstorm intensity, lightning generation is also influenced by additional atmospheric factors such as cloud microphysics, charge separation processes and storm evolution. To complement Table 2 and Figure 2(a) until Figure 2(f) shows the scatter plots of radar reflectivity against lightning flash rate CG types for each respective day. These figures provide a visual representation of the variability in correlation strength and highlight the differences in storm electrification process across the observation period.

Table 2: The Pearson correlation coefficient between 1 and 6 November 2023

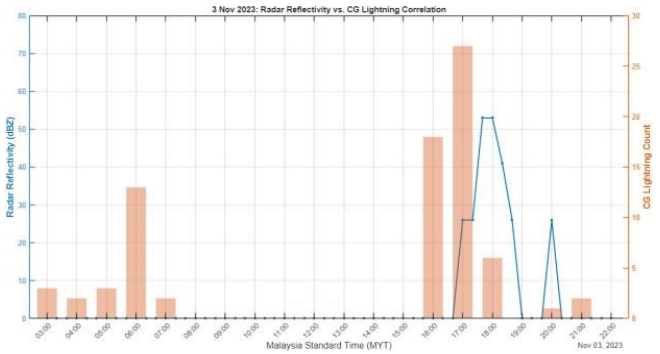
Date	r - value	Interpretation
1 Nov	+0.2938	Moderate positive correlation
2 Nov	-0.0571	Weak negative correlation
3 Nov	+0.2191	Weak positive correlation
4 Nov	+0.3014	Moderate positive correlation
5 Nov	+0.2489	Weak positive correlation
6 Nov	-0.0687	Weak negative correlation



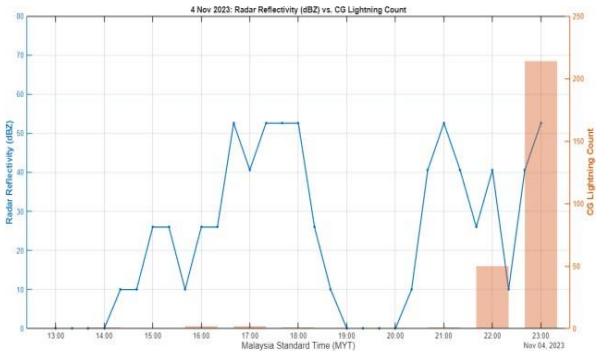
(a)



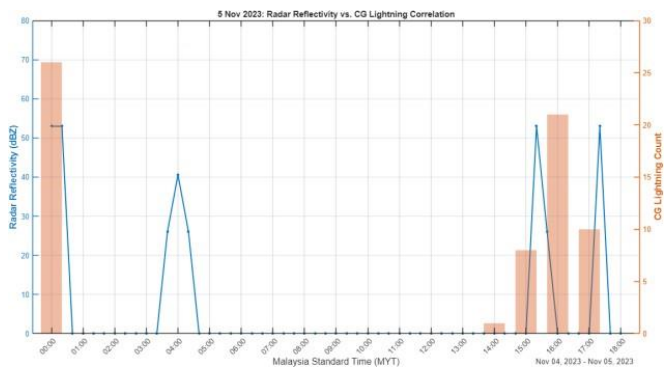
(b)



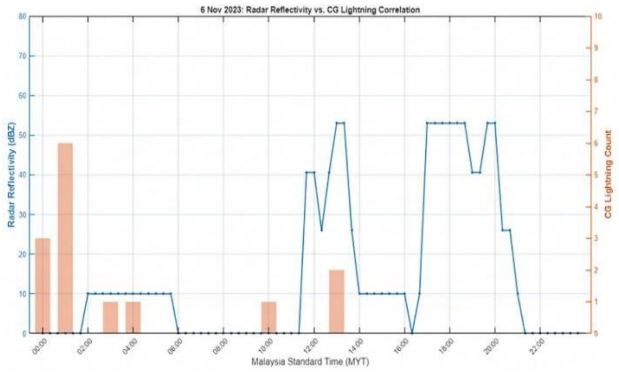
(c)



(d)



(e)



(f)

Figure 2: Radar Reflectivity versus Lightning Flash Rate (a) 1 November 2023 (b) 2 November 2023 (c) 3 November 2023 (d) 4 November 2023 (e) 5 November 2023 and (f) 6 November 2023

The data indicates a correlation between radar reflectivity (dBZ) from the CAPPI data and the lightning flash rate captured by the Fast Antenna (FA) system, although the correlation values varied across storm events. Some cases showed positive correlation, where higher reflectivity coincided with increased lightning frequency, while others showed negative correlation, suggesting that storm structure and atmospheric conditions influence the strength of this relationship. Whenever the radar indicates a surge in storm intensity, a simultaneous increase in the lightning flash rate observed. This pattern is most visible during the massive peak of the storm on 4 November 2023.

It is where the lightning counts spiked for both Intra-Cloud (IC) and positive Cloud-to-Ground (+CG) types. This happens because high radar reflectivity (dBZ) means the cloud is packed with heavy ice particles. Powerful upward winds inside these tropical storms push warm and wet air high into the freezing layers of the sky. When these large, falling ice particles collide with smaller cloud ice particles rising, they rub against each other and separate positive and negative electrical charges. Once these charges build up and become strong enough, they break through the air and create a lightning flash. This matches past research by Deierling et al., (2008), which explains that a high lightning flash rate is a direct sign of powerful upward winds. Simply put, stronger storm holds more ice particles, causing higher radar reflectivity and producing a much higher number of lightning flashes (Deierling et al., 2008).

CONCLUSION

As conclusion, understanding of lightning activity and its relationship with weather radar parameters in this Peninsular Malaysia was fully studied throughout the analysis. It was noticed that the lightning flashes distribution during the six-days observation period between 1 and 6 November 2023 have been successfully categorized into Intra-Cloud (IC), Cloud-to-Ground (CG) and Narrow Bipolar Event (NBE), where the highest recorded total lightning flashes distribution reached during intense storm cells.

The correlation between radar reflectivity and lightning flash rate for selected storm events have been fully determined. The results demonstrated a direct correlation where maximum reflectivity levels ranging precisely from 50 d BZ to 55 d BZ in the mixed-phase layers drive vigorous convective updrafts, accelerating the non-inductive cloud charging mechanism and generating peak flash rates. Statistical using Pearson's coefficient revealed daily correlation variations, yielding weak-to-moderate values of r = 0.2938 (1 November 2023) and r = 0.3014 (4 November 2023), alongside lower localized values of r = 0.2191 (3 November 2023) and r = 0.2489 (5 November 2023). Conversely, a near-zero disconnected relationship of r = - 0.0571 was recorded on 2 November 2023 and r = -0.0687 on 6 November 2023 due to a clear temporal mismatch between independent lightning spikes and rainfall columns.

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