Relationship between Lightning Flashes and Three Flash Flood Events in Malacca Malaysia

Harry Sucitra Roslan[a], Mohd Riduan Ahmad[a], Anthony Sumardi[a], Shamsul Ammar Shamsul Baharin[a], Mawarni Mohamed Yunus[a], Nor Azlan Mohd Aris[a], Ho Yih Hwa[a], Hidayah[b], Mohd Zafri Baharuddin[c], Takeshi Morimoto[d], Yuji Takayanagi[d], Zen Kawasaki[e], and Nor Hadizah Mohd Khalid[f]

[a]Centre of Technology for Disaster Risk Reduction (CDR), Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka (UTEM), 76100 Durian Tunggal, Melaka, Malaysia
[b]Institute of Sustainable Energy, Universiti Tenaga Nasional, Selangor, Malaysia
[c]Institute of Energy Infrastruture, Universiti Tenaga Nasional, Selangor, Malaysia
[d]Department of Electrical, Electronic and Communication Engineering, Kindai University, Osaka, Japan
[e]Graduate School of Engineering, Osaka University, Osaka 565-0871, Japan
[f]Malaysian Meteorological Department, Petaling Jaya, Selangor, Malaysia

Abstract

This study focuses on the analysis of lightning flashes (<30 km) and flash flood events that happened in Malacca Malaysia on October 20th, 2021, between 13:00 and 17:00 local time (UTC+8). Three flash flood events have been observed at three sites namely Kg. Sungai Putat (Site 1), Melaka International Trade Centre (Site 2), and Lebuh Raya Ayer Keroh Lama (Site 3). The observations of lightning activities were using a fast-antenna (FA) system, a constant altitude plan position indicator (CAPPI) radar echo, and cloud top height from Himawari-8 satellite image. The total number of detected lightning in this study is 208 flashes. Out of 208 flashes, 59 positive cloud-to-ground (+CG), 15 negative cloud-to-ground(-CG), 66 positive narrow bipolar event(+NBE), 7 negative bipolar event(-NBE), and 110 intracloud flashes have been identified. The highest reflectivity value was 53 dBZ recorded at Site 1 with estimated cloud top height (CTH) value of around 14 km. The relationship analysis between lightning activity and flash floods demonstrates that tropical thunderstorms generate a greater number of positive cloud-to-ground lightning strikes when cloud top reached 14 km. Moreover, there is a substantial correlation between lightning flash rate and the highest reflectivity value, which exceeds 50dBZ, at all three flash flood locations. Therefore, it is evident that persistent rainfall is a significant contributing factor to the occurrence of flash floods, even if the intensity of the rainfall is not particularly high.

1 Introduction

Malaysia experiences two distinct monsoon seasons such as the Southwest monsoon season, which occurs from late May to September, and the Northeast monsoon season, which takes place from November to March [1]. Typically, Malaysia is rarely affected by catastrophic events such as hurricanes, tornadoes, typhoons, and volcanic eruptions. Nevertheless, water-related issues, such as flooding caused by heavy rainfall are frequently encountered. In Malaysia, floods can be classified into two types such as monsoon floods and flash floods [2].

Flash floods typically result from intense and brief periods of heavy rainfall, characterized by a rapid and rapid increase in water flow, and are commonly observed. Additionally, it resulted in runoff in urbanized regions. The key difference between a flood and a flash flood is the duration it takes for the river flow to revert to its usual state. Flash floods often have a short duration of a few hours, whereas floods, such as monsoon floods, can persist for a week or even longer until water levels recover to their usual flow [2]. Thunderstorms frequently result in flash floods and hailstorms that are highly damaging and fatal situations.

According to a report by the Malaysian Meteorological Department, Malaysia experiences frequent lightning and thunderstorms, averaging over 200 thunder days annually [3], [4]. There is a correlation between lightning and rainfall, which can lead to the occurrence of flash floods [5]. The distribution of rainfall in Malaysia is controlled by the seasonal patterns of wind flow and the local topographic factors [2]. Recent investigations have discovered a strong correlation between the intensity of a storm and the specific types of lightning occurrences within the cloud [6].

This study is part of the international research project "Real-time lightning 3D imaging and forecasting project for sustainable and reliable supply of energy and storm disaster early warning" under the Science and Technology Research Partnership for Sustainable Development (SATREPS) program between Universiti Teknikal Malaysia Melaka (UTeM), Universiti Tenaga Nasional (UNITEN), and KINDAI University in Japan [5]. One of the objectives is to investigate correlation between lightning activities and flash flood events in tropical thunderstorms particularly in Malaysia.

The Malaysian Department of Irrigation and Drainage (DID) has reported that the Melaka Tengah district in Malacca experienced rainfall ranging from 76 mm to 145 mm because of intense precipitation starting from 14:00 on the October 20th, 2021 [6]. The local telemetry station reported a measurement of 145 mm in the entire Malacca, with the Melaka Tengah district getting the greatest measurement

[6]. The most recent data from the National Disaster Management Agency (NADMA) states that the largest number of flood victims who were relocated were in Malacca. This involved a total of 492 individuals from 130 households, all accommodated in 10 relief centres [6].

The consequences of flash floods are wide-ranging including human lives, property, infrastructure, and the environment. It has been reported a firefighter from the Malacca Central Fire and Rescue Station was reported dead after being swept away by a strong flood current in Kampung Sungai Putat during the flash flood on October 20th, 2021 [7].

Several studies have demonstrated that the lightning activity of a thunderstorm can be utilized for local short-term forecasting of intense rainfall or estimating precipitation and flash flood potential. Recent research conducted by [6], indicates a strong correlation between lightning flashes and rainfall rate during a flash flood event that took place in Melaka on 11 August 2020. The authors discovered a total of 980 lightning flashes, with the greatest values observed for rainfall rate (about 50 mm/h) and reflectivity (approximately 50 dBz).

The analysis carried out by [5] demonstrates that the occurrence of flash floods and hailstorms in Peninsular Malaysia is closely correlated with the flash rate of both negative cloud-to-ground (-CG) and positive cloud-to-ground (+CG) lightning flashes, indicating the presence of a severe storm. The investigation discovered a significant correlation between lightning activities and rainfall, with a Pearson correlation coefficient (r value) ranging from 0.7 to 0.8. Recent investigations have discovered a strong correlation between the occurrence of flash floods and the temporal growth of positive CG flashes [8]. The author analysed a storm that occurred in Malacca on 14 September 2016, which generated a total of 87 positive cloud-to-ground flashes. Moreover, [11] analysed 63 instances of positive CG flashes that occurred in Malacca on 20 October 2021. The occurrence of flash floods in Malacca has been determined to be strongly associated with a high frequency of positive cloud-to-ground lightning flashes.

This paper aims to investigate the correlation between lightning activities and characteristics of the thundercloud that responsible for flash flood at three sites in Malacca. The reflectivity values observed from CAPPI radar echo, the lightning flash rate, and the cloud top height observed on Himawari-8 satellite images have been used to evaluate the correlation.

2 Methodology

Three sites of flash flood events are analysed as tabulated in Table 1. The observation station and flash flood event's location are determined by employing Google Earth Pro, as demonstrated in Figure 1. The data used in this study were collected using a wideband fast electric field change sensor (fast Antenna or FA) system, a constant altitude plan position indicator (CAPPI) radar echo, and cloud top height by Himawari-8 satellite images. The lightning data were collected from a single observation station located in Universiti Teknikal Malaysia Melaka (UTeM), (2.314077°N, 102.318282°E).

Figure 2 shows firefighters aiding individuals stranded in flash flood on Lebuh Raya Ayer Keroh Lama (Site 3), while civil defence personnel assist in relocating residents of Kg. Sungai Putat (Site 1) trapped in their homes during the flash flood using rescue boats.

Lightning data was recorded by the FA system. The FA sensor outputs were digitized at a sampling rate of 2.5 MS/s, with a vertical resolution of 12 bits. The data records were triggered by events within a time window of 2 seconds. The pre-trigger delay, which represented 30% of the time window, was set at 600ms. The trigger level was set at 5 V. The timing for every single event was determined using a Global Positioning System (GPS) with a precision of ±20 ns. A single computer was being used to operate the digitizer, presenting all outcomes, and verifying all data possessed identical timestamps. Further information about the instruments used for the electric field (E-field) and magnetic field (B-field) is provided in [10], [11].

The radar echo data have been collected from the Malaysia Meteorological Department (MMD). CAPPI radar echo was generated at 10-minute intervals. Radar can be applied to determine the intensity of rainfall. The reflectivity value can be observed based on the Plan Position Indicator (PPI) display [6], [11]. Reflectivity value and colour palettes represent light rain usually below 35dBZ (light green), moderate rain between 35 and 50dBZ (dark green), heavy rain exceeding about 50dBZ (orange), and hail over 55dBZ (red).

The cloud top height has been estimated by using Himawari-8 satellite images and analysed based on the tropical altitudinal temperature profiles graph. These data are taken from the US Defense Department's "Non-standard atmospheres" [12]. Thus, these data have been employed by numerous researchers in various research studies. To locate lightning strikes, a magnetic direction finder technique (MDF) has been used. The MDF acts as a magnetic sensor which consists of two perpendicular loop antennas with operating frequencies of 400Hz to 400kHz [13]. The two-axis magnetic sensor consists of 4 quadrants (Q) and poles which are labelled as (Q1, Q2, Q3, Q4) in clockwise orientation.

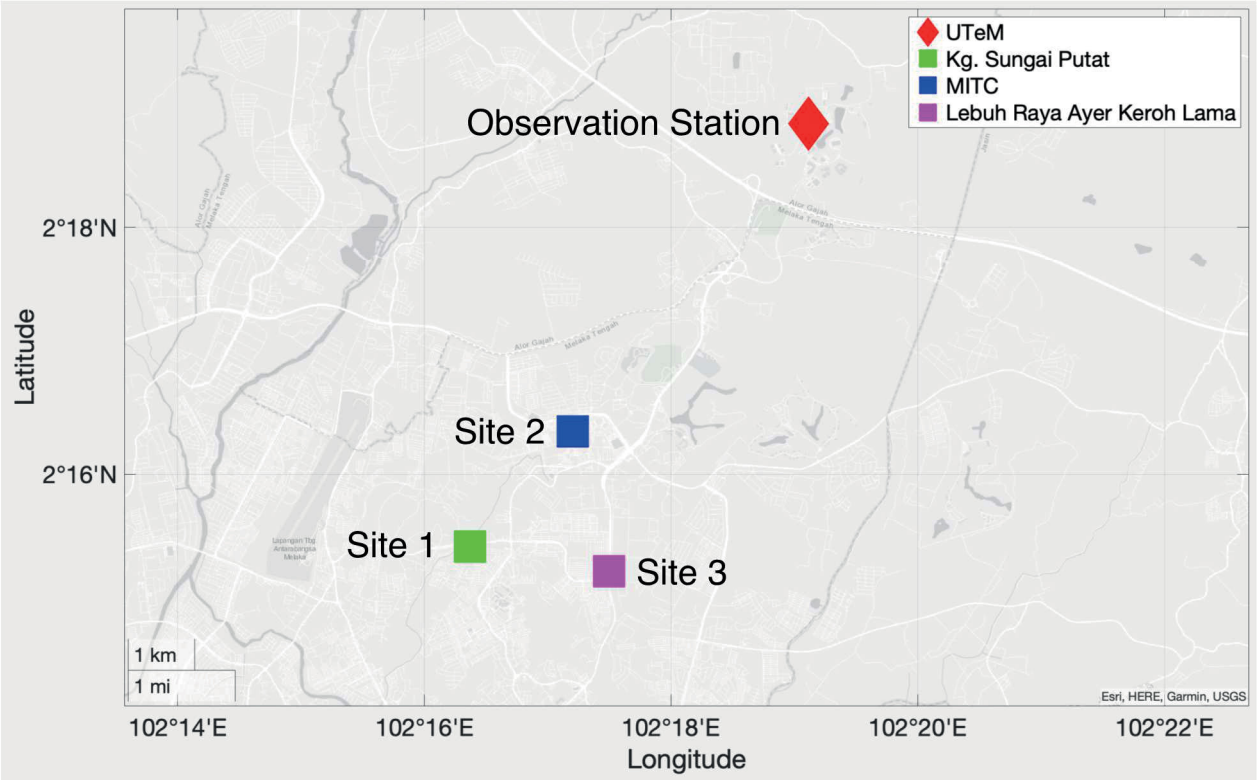

Figure 1 The location of flash flood events on 20 October 2021

Figure 2 Flash floods on Lebuhraya Ayer Keroh (Site 3) and Kg. Sungai Putat (Site 1) [9]

Table 1 Latitude and Longitude of flash flood events

Flash Flood Event	Location	Latitude	Longitude	Distance from Observation Station
Site 1	Kg. Sungai Putat	2.25680	102.27287	8.11km
Site 2	MITC	2.27241	102.28676	5.87km
Site 3	Lebuh Raya Ayer Keroh Lama	2.25342	102.29164	7.16km

3 Results and Analysis

There are a total of 208 lightning flashes that occurred during flash flood events on 20 October 2021 were detected by the FA system from 13:00:00 to 17:00:00 (UTC+8). It consists of 59 positive CG, 15 negative CG (-CG), 66 positive NBE (+NBE), 7 negative NBE (-NBE), and 110 intracloud (IC) flashes. As we can see in Figure 3, all the flash flood events located in Q3.

The total number of lightning was highest in Q2 with 91 flashes followed by 35 flashes in Q4 and 21 flashes in Q3. The maximum reflectivity value for Q4 was 50dBZ and 53dBZ for both Q3 and Q2. This might be related to the movement of the thundercloud which moved from the south to the north and intense in areas of Q2 and Q3 as shown in CAPPI radar echo. The storm intensified between 14:50 and 15:00 and after that slowly decreasing starting from 15:30. The CAPPI radar echo development for the flash flood events is shown in Figure 4. The satellites images development from Himawari-8 satellite is shown in Figure 5.

Figure 6 shows the lightning flash rate for every 10-minute interval starting from 13:00:00 to 17:00:00 mapped to the cloud top height and reflectivity values. The first lightning detection started at 13:00 with two IC flashes. Heavy rain with a reflectivity value of 53dBZ at Site 1 has been observed while at Sites 2 and 3 just had moderate rain with the reflectivity value of 44dBz. On the other hand, the observation station experienced light rain with a reflectivity value of 34dBZ. These conditions for all four sites were constant until 13:10 (10 minutes duration) with cloud top height (CTH) estimated around 14 km. Then between 13:10 to 13:20, increasing number of lightning flashes was detected (two +CGs, four -CGs, six +NBEs, and three -NBEs).

Between 13:20 and 14:30 (80 minutes duration), only light and moderate rains with reflectivity value less than 35dBZ

were observed for all four sites maintained at 14 km but many lightning flashes were detected during this period. A total of 11 +CG, eight -CG, 56 +NBE, four -NBE, and 40 IC flashes have been recorded. It is important to notice that rains continued to shower even though the reflectivity values were relatively low for a duration of 80 minutes.

Starting at 14:30 until 15:30, the reflectivity value has increased significantly from 35dBZ to 50dBZ within one hour period. During this period, flash flood events have been reported at Sites 1, 2, and 3. Heavy rain started to be observed continuously from 14:40 to 15:30 with increasing reflectivity value of 50dBZ and a total number of 10 +CG, 2 -CG, 3 +NBE, and 21 IC flashes have been recorded. The cloud top height estimated at 14 km during the flash flood events. After 15:30, the rain rate started to decrease significantly until 17:00 but the occurrence of flash flood still being reported on the ground until 18:00.

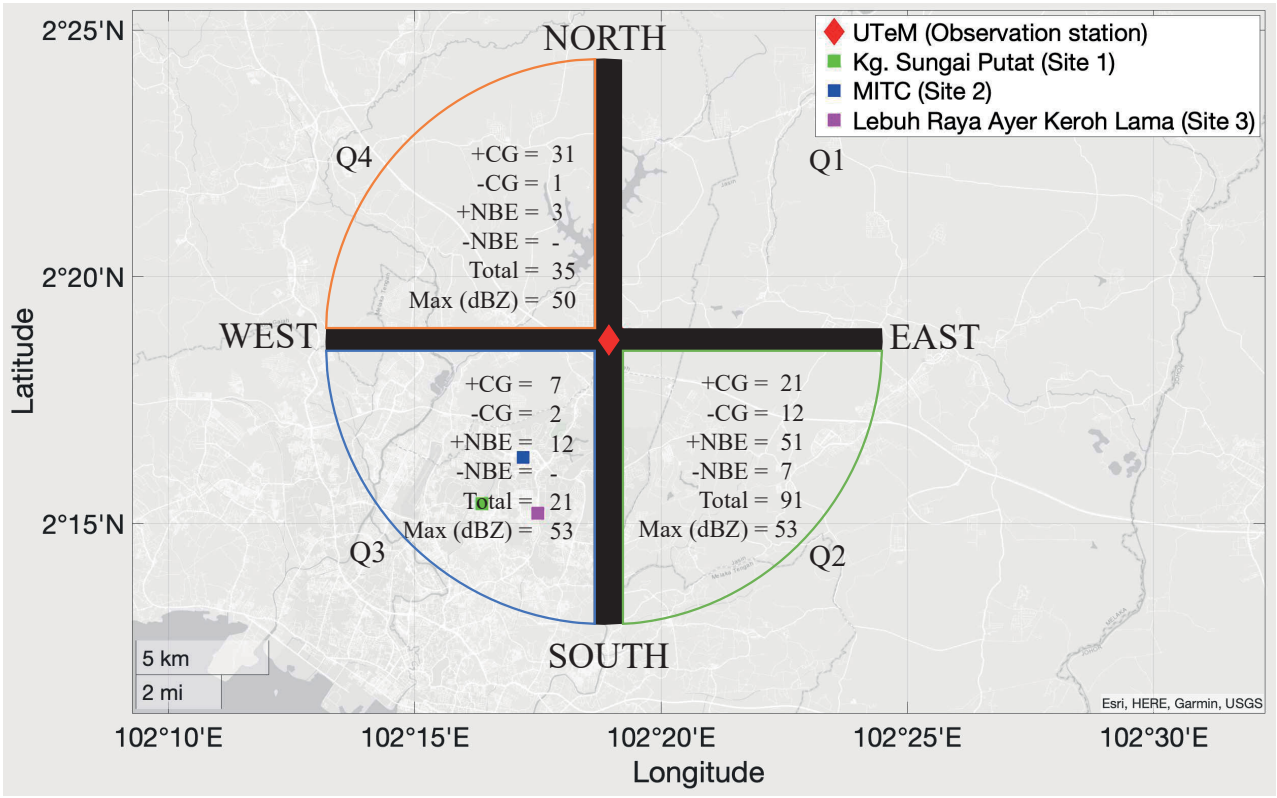

Figure 3 Total number of flashes by quadrants and the locations of flash flood events.

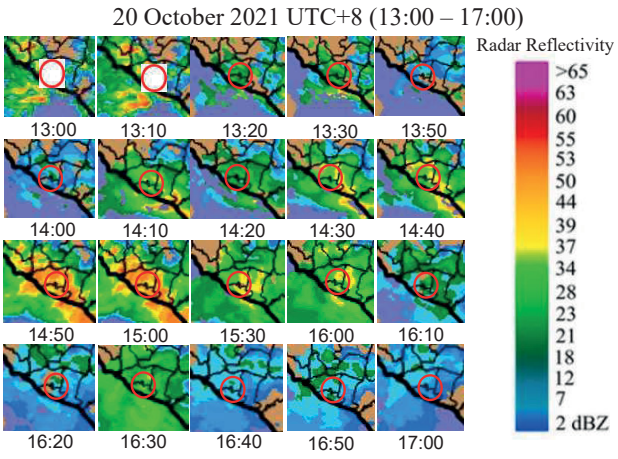

Figure 4 Evolution of CAPPI radar from MET Malaysia

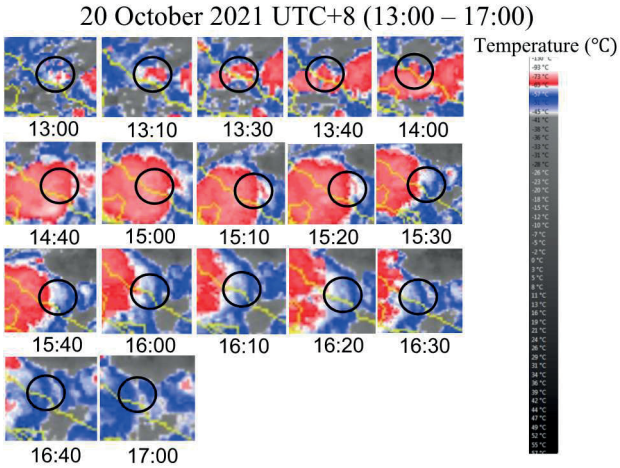

Figure 5 Evolution of satellites images from Himawari-8

Figure 6 The plots of flash rate for the bar graph, reflectivity (dBZ) for flash flood events and observation stations, total lightning flash by quadrant and cloud top height on 20 October 2021 from 13:00 to 17:00 Malaysia Time (UTC+8).

4 Conclusion

The relationship between lightning flashes, radar echo, and satellite images of a tropical thunderstorm on 20 October 2021 from 13:00 to 17:00 (UTC+8) has been evaluated. It has been found that a tropical thunderstorm with cloud top height around 14 km produced many positive CG flashes. This thunderstorm together with reflectivity values above 50 dBZ responsible for flash flood events at three sites in Malacca. Furthermore, even though the rain rate is not extremely heavy, it had been raining continuously for more than an hour, which is a significant factor in flash flood situations.

5 Acknowledgment

This research work is supported by SATREPS (GERAN ANTARABANGSA SATREPS/2023/FKEKK/A00052, A00045, A00047, A00039) in collaboration between Japan Science and Technology Agency (JST, JPMJSA2210) and JICA. It is also promoted by Ministry of Higher Education (MOHE) in Malaysia. The authors express their gratitude to Universiti Teknikal Malaysia Melaka, Universiti Tenaga Nasional, and Kindai University for their collaboration and support.

6 References

[1] N. Bahari et al: Analysis of lightning flash rate with the occurrence of flash floods and hailstorms in Peninsular Malaysia, J. Atmos. Solar-Terresetrial Phys, vol. 250, no. May, 2023

[2] F. S. Buslima, R. C. Omar, T. A. Jamaluddin, and H. Taha: Flood and Flash Flood Geo-Hazards in Malaysia, Int. J. Eng. Technol, no. November, 2019

[3] A. R. Syakura, M. Z. A. Ab Kadir, C. Gomes, A. B. Elistina, and M. A. Cooper: Comparative study on lightning fatality rate in Malaysia between 2008 and 2017, 34th Int. Conf. Light. Prot. ICLP 2018, no. September, 2018

[4] N. Yusop et al: Correlation analysis between lightning flashes and rainfall rate during a flash flood thunderstorm, Ind. J. Electr. Eng. Com. Sci. vol. 28, no. 3, pp. 1322–1329, 2022

[5] T. Morimoto et al: Real-time Lightning 3D Imaging and Forecasting Project in Malaysia for Sustainable and Reliable Supply of Energy and Storm Disaster Early Warning, I, no. June, pp. 1–4, 2023

[6] Mohamed Basyir: DID MELAKA hardest hit by floods, New Straits Times, 2021

[7] Bernama: Fireman who lost consciousness in Melaka flood rescue operation yesterday dies, Malay Mail, Melaka, 2021

[8] D. Periannan et al: Environmental study of tropical hailstorm and its relationship with negative narrow bipolar event and positive ground flashes, Ekoloji, vol. 28, no. 107, pp. 253–257, 2019

[9] K. Koh: 7-hour downpour triggers flash floods across melaka, New Straits Times, 2021

[10] M. R. Ahmad, M. R. M. Esa, V. Cooray, Z. A. Baharudin, and P. Hettiarachchi: Journal of Atmospheric and Solar-Terrestrial Physics Latitude dependence of narrow bipolar pulse emissions, J. Atmos. Solar-Terrestrial Phys., vol. 128, pp. 40–45, 2015

[11] M. R. Ahmad, S. A. S. Baharin, N. Yusop, M. R. M. Esa and M. A. B. Sidik: Occurrence of Positive Cloud-to-Ground Lightning During Flash Flood in Malacca, IEEE Int. Conf. in Pow. Eng. App. (ICPEA), Shah Alam, Malaysia, pp. 1-3, 2022

[12] O. Peer and R. Journal: The physics of the Earth ' s atmosphere II . Multimerization of atmospheric gases above the troposphere, vol. 22, no. January, 2014

[13] S. A. Mohammad, M. R. Ahmad, M. Abdullah, S. A. S. Baharin, S. J. Park, and V. Cooray: Azimuth and elevation factors correction for single station lightning electromagnetic field sensor, Malaysian J. Soc. Sp., vol. 17, no. 4, pp. 378–392, 2021