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STUDY ON EVALUATION OF A MULTI-SOURCE DATA LIGHTNING WARNING TECHNIQUE APPLIED TO SPECIFIC AREAS IN VIETNAM

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INTRODUCTION

Rationale for Selecting the Thesis Topic:

Before it was scientifically explained, lightning instilled real fear in mankind. Statistics from before 1800 show how terrifying lightning could be. For example, on August 18, 1769, in an Italian city, a lightning strike caused an explosion in a 1,030-ton ammunition depot. The explosion destroyed the tower, triggering a rain of debris over the city, destroying one-sixth of the city's houses and killing over 3,000 people. In the United States, the average number of people killed by lightning annually is about 62. Meanwhile, in Colombia, with a population only one-tenth that of the United States, lightning causes approximately 100 deaths and 1,000 injuries each year. In Vietnam, lightning kills around 100 people per year.

Benjamin Franklin is considered one of the first scientists to study lightning. In 1752, his experiments confirmed the electrical nature of lightning. Over the following years, many experiments and studies were conducted, leading to a deeper understanding of thunderstorms.

Since the mid-20th century, research on thunderstorms has accelerated in industrially advanced countries in America and Europe due to the growing need for practical applications. Extensive data on thunderstorms has been collected for years, allowing scientists to study their development patterns and classify areas based on thunderstorm activity, which supports thunderstorm forecasting. Lightning density and other parameters of lightning activity have been examined and evaluated in numerous research projects, leading to the proposal of lightning prevention measures. These include lightning protection for important industrial clusters, power lines, airports, ports, nuclear power plants, fuel depots, and rocket launch sites.

Vietnam is located within the Asian thunderstorm center, one of the three major thunderstorm regions globally, where lightning activity is intense. This activity not only hinders the industrialization and modernization of the country but also directly impacts socio-economic aspects. Over the past two decades, numerous structures such as warehouses, power lines, airports, industrial zones, scientific research equipment, and postal and telecommunications infrastructure have been severely damaged or destroyed by lightning, resulting in significant losses. Beyond economic damage, lightning also induces fear and loss of life.

Consequently, research into lightning protection, particularly lightning warning systems, has become increasingly urgent. Lightning warning is a critical element of lightning protection and plays a vital role in minimizing damage. However, effective lightning warning requires addressing several factors, including data sources, data processing methods, warning assessment techniques, and understanding the environment of the research area. In Vietnam, numerous studies on thunderstorms have been conducted over the past 20 years. This has included the installation of various equipment, such as lightning detectors, warning systems, and new-generation electric field sensors, all implemented for the first time in the country. As a result, many research papers and reports have been published both nationally and internationally. However, large-scale lightning warning research has only been piloted in specific regions such as Ha Noi (2002-2005), Quang Nam (2011-2013), Quang Ninh(2013), and Ba Ria Vung Tau (2019-2020), with most projects being led by the Institute of Geophysics. Efforts to test large-scale thunderstorm warnings in Ho Chi Minh City and nationwide are ongoing. Given the practical demands and existing research results, there is a pressing need for further, more comprehensive studies on lightning warnings. This forms the basis for my decision to choose this research topic: ***"Study on Evaluation of a Multi-source Data Lightning Warning Technique Applied to Specific Areas in Vietnam***"

The objective of this dissertation: To identify lightning warning methods suitable for the specific conditions in certain areas of Vietnam. These methods aim to enhance the timeliness and accuracy of early lightning warnings, thereby contributing to the reduction of lightning-related damage in those regions**.**

Study Contents of the Dissertation:

1. Overview of lightning warning systems and associated challenges.
2. Data collection and analysis methods for processing electric field intensity data in selected areas of Ha Noi, Ba Ria Vung Tau, Quang Nam, along with lightning location data, radar data, and satellite cloud images.
3. Research on the application and enhancement of lightning warning methods tailored to Vietnam's specific conditions.
4. Evaluation of lightning warning results in certain regions of Vietnam using the developed method.

Key Contributions of the Dissertation:

1. Developed a lightning warning method based on aggregated data sources (electric field intensity, lightning location, lightning warnings, satellite imagery, and radar) for specific areas with radii of 10 km and 8 km. This method was refined and adjusted based on data sources and environmental conditions in Vietnam.
2. Successfully applied the developed method to various regions in Vietnam, considering differing atmospheric conditions, thunderstorm activity, infrastructure, and geographical characteristics. The lightning warning accuracy rate for Gia Lam District, Ha Noi, was 88.0%, with an average lead time of 31.6 minutes. In Vung Tau City, the accuracy rate was 86.3%, with an average lead time of 23.0 minutes. Improved lightning warning methods applied to Quang Nam Province identified optimal lightning warning thresholds and electric field intensity amplitudes of 1000 V/m and 150 V/m, respectively. The average lead time for lightning warnings in Hoi An, Dai Loc, and Hiep Duc was 22.45 minutes, with a detection probability of 82.56%, and in Tam Ky, the average lead time was 18.0 minutes.

Structure of the Dissertation:

The dissertation consists of three chapters, in addition to the introduction and conclusion:

Chapter 1: A review of lightning research history, thunderstorm overviews, and relevant domestic and international studies on lightning warning systems.

Chapter 2: Data sources and processing methods used in lightning warning research, along with assessment methodologies based on different data sets.

Chapter 3: Research results on the effectiveness of lightning warning methods applied to specific areas in Gia Lam District (Ha Noi), Vung Tau City (Ba Ria Vung Tau), and regions of Quang Nam Province.

CHAPTER 1. OVERVIEW OF LIGHTNING WARNING AND RELATED ISSUES

1.1. Overview of lightning warning research in the world

The issue of research on warning or forecasting thunderstorm activity for specific areas has been and continues to be addressed by many researchers worldwide. The authors have developed several lightning warning methods, specifically as follows:

Lightning Warning Based on Electric Field Data: Research includes studies by Montanya et al. (2004, 2008), Beasley et al. (2008), Murphy et al. (2008, 2016), Aranguren et al. (2009), Ferro et al. (2011), López et al. (2012), Zeng et al. (2013), Junchi et al. (2015), Srivastava et al. (2015), Tao et al. (2016), Clullow et al. (2018), Wang et al. (2019), Meng et al. (2019), among others.

Lightning Warning Based on Radar or Satellite Data: This research has been conducted by Gremillion et al. (1999), Bonelli et al. (2008), Schneider et al. (2008), Mosier et al. (2011), Seroka et al. (2012), Karagiannidis et al. (2016), Zhou et al. (2020), Mecikalski et al. (2021), and Srivastava et al. (2022), among others.

Lightning Warning Based on Lightning Location Data and forecasting thunderstorm activity using numerical models, with contributions from Kohn et al. (2011), Holle et al. (2016), Lynn et al. (2012), Giannaros et al. (2015), Spiridonov et al. (2020), Rabbani et al. (2022), Paramanik et al. (2024), among others.

1.2. Overview of lightning warning research in Vietnam

In Vietnam, research on thunderstorms began in 1957 when the Department of Atmospheric Electricity was established with the support of the Polish government during the International Geophysics Year. Prior to 2000, research at the Institute of Geophysics and in the electricity industry primarily focused on lightning protection, the statistical characteristics of thunderstorm activity, lightning physics, and atmospheric electricity. In the meteorological and hydrological sectors, many studies have addressed thunderstorm warnings and forecasts, phenomena accompanied by lightning. These studies employed various methods and relied mainly on weather radar data, satellite cloud images, or synoptic observations.

The primary concerns remain thunderstorm warnings, forecasts, and monitoring (Lanh N.V., 2002; Thang N.V., 2005, 2006, 2007; Tien T.T., 2008; Son T.D., 2009; Thanh N.T.T., 2010; Quyet L.D., 2011; Quoc P.K., 2013; Hoa B.T.K., 2021; etc.), with limited direct connections to atmospheric electrical research equipment. Recently, some authors in the meteorological and hydrological sectors have utilized lightning location data, satellite data, radar data, and synoptic monitoring data to study thunderstorms and forecast thunderstorm activity over large areas. However, only a few studies have been published, and they have not yet addressed lightning warnings in specific areas, unlike research conducted globally (Trung L.B., et al., 2018; Thanh C., et al., 2018; Quyet L.D., et al., 2020; Quoc P.K., et al., 2021; Khiem M.V., et al., 2022).

After 2000, lightning warning research was piloted in several areas, including Ha Noi (2002-2005), Quang Nam (2011-2013), Quang Ninh

(2013), and Ba Ria Vung Tau (2019-2020). These studies were conducted by a research group from the Institute of Geophysics, which tested large-scale lightning warnings in Ho Chi Minh City and throughout Vietnam in collaboration with the meteorological and hydrological sector.

CHAPTER 2. DATA AND LIGHTNING WARNING METHODS

2.1. Data

The data used in the lightning warning study in Vietnam comes from a synthetic data source. The primary data sources include electric field data, lightning warning data (Table 2.1), and additional data sources such as satellite and radar data to assess the convective cloud area in the study area. Lightning location data is also utilized for comparison, analysis, and evaluation. These data sources are obtained from the Japan Meteorological Agency (JMA), the Aero-Meteorological Observatory (AMO), and the database of the Institute of Geophysics.

Table 2.1. Electric field and lightning warning station in Vietnam

No	Station	Longitude	Latitude	Instrument	Observation time
1	Phu Thuy	105.9600	21.0300	EMF-100	2017-2019
2	Hiep Duc	108.1047	15.5795	EMF-100	2016-2017
3	Hoi An	108.3346	15.8764	EMF-100	2016-2017
4	Dai Loc	108.1102	15.8814	EMF-100	2016-2017
5	Tam Ky	108.4989	15.5698	Strike Guard	2015-2016
6	Vung Tau	107.0896	10.3327	EMF-100C	2019

2.2. Lightning warning methods

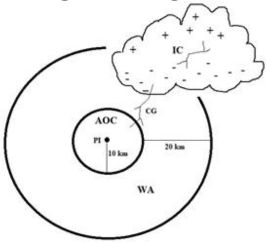

Figure 2.1. Lightning warning method based on electric field measurement equipment at a point on the surface and other data sources.

Lightning warning assessment methods were developed for the Gia Lam area in Ha Noi, Vung Tau City, and some regions in Quang Nam province, based on the works of Aranguren (2009), Junchi (2015), Zeng (2009), Karagiannidis (2016), and other data sources collected in Vietnam.

The lightning warning methods utilize electric field data, lightning location data, satellite data, and radar data. Specifically, a two-zone method is employed, using warning area (WA) information to alert the area requiring warning (AOC) (see Figure 2.1). This study focuses solely on lightning warnings related to cloud-ground discharges. The threshold for warning electric fields is determined through global studies and analyses of electric fields in favorable weather conditions and measurement environments. To assess the presence of convective cloud areas (limited to about 50 km around the EFM-100 station) that may develop or move into the study area, radar data is utilized for cloud areas with reflectivity greater than 35 dBz. Satellite data is also employed, specifically a combination of infrared channel data TIR6 (6.2 μm) and TIR2 (11.2 μm). The TIR2 channel represents the freezing level at the cloud top and the cloud growth rate, while the difference between TIR6 and TIR2 indicates cloud thickness. Lightning location data in this study is used to evaluate the lightning warning capabilities for the designated areas.

An improved lightning warning method is based on electric field data, lightning location data, satellite data, and radar data. This method enhances the warning process by reducing the warning radius and employing two indicators for lightning warnings: the Electric Field Amplitude Index (EFAI) and the Electric Field Difference Index (EFDI). The EFAI measures the frequency at which the absolute value of the electric field exceeds a specified threshold over a defined period, indicating a certain level of activity. This value is derived from a series of magnitude thresholds and electric field values that exceed this threshold to identify the optimal EFAI value. The second indicator, the electric field strength difference, is captured by the EFDI. The relationship for the electric field difference can be expressed using equation (2.1):

$$dE(x,y,z)/dt = (\text{E}\_t2\ (x,y,z)) - \text{E}\_t1\ (x,y,z)))/\Delta\text{t} \quad (2.1)$$

Here, t1 and t2 are any consecutive consecutive times. When the sampling frequency of the electric field device is 1 second, the electric field difference is then represented as:

$$\Delta E(x,y,z) = \text{E}_{t2}(x,y,z)) - \text{E}_{t1}(x,y,z)) \quad (2.2)$$

The method also needs to define some parameters: Probability Of Detection (POD), False Alarm Rate (FAR) and Critical Success Index (CSI) as follows: POD = X/(X+Y) (2.3)

FAR = Z/(X+Z) (2.4)

CSI = X/(X+Y+Z) (2.5)

In which X is the total number (Observervation: Yes; Warning: Yes); Y is the total number (Observervation: Yes; Warning: No); Z is the total number (Observervation: No; Warning: Yes).

Using the electric field measurement dataset, we will determine the EFAI and EFDI indices based on specific thresholds and the number of occurrences during the time periods leading up to a warning. From this analysis, we can identify the optimal thresholds according to the POD, FAR, and CSI indices. By incorporating additional radar data from the study area and either utilizing the RFI index or substituting it with the index derived from satellite data (SFI), we can provide lightning warning information for the designated lightning warning area.

CHAPTER 3. THE RESULTS OF EVALUATION OF A MULTI-SOURCE DATA LIGHTNING WARNING TECHNIQUE APPLIED TO SPECIFIC AREAS IN VIETNAM

3.1. Lightning warning results and evaluation of lightning warning applied to Gia Lam district, Ha Noi

Figure 3.2 shows the frequency of lightning discharges over time during the day, which serves as the basis for determining the lightning warning threshold (1 kV/m) and for dividing the time into day and afternoon segments to study and evaluate lightning warnings for the Gia

Lam area. Figures 3.3 and 3.5 present two specific examples from 97 days of measurements included in the lightning warning study. On August 22, 2019, using electric field data, satellite data, and lightning location data, the lightning warning time was determined to be 8 minutes. On September 9, 2019, utilizing electric field data, weather radar data, and lightning location data, the lightning warning time was established to be 47 minutes.

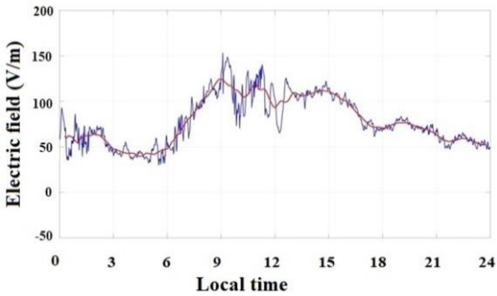

Figure 3.1. Variation of the average daily electric field intensity in fine weather conditions at Phuthuy station

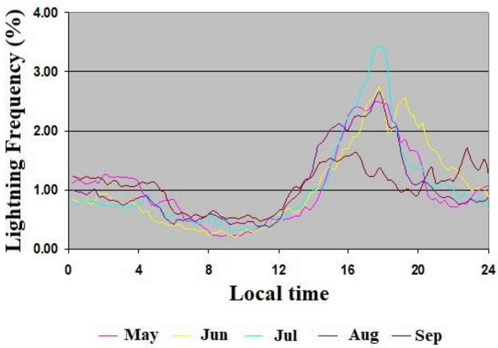

Figure 3.2. Lightning frequency in Ha Noi area

Following this methodology, lightning warning research was conducted for the Gia Lam area in Ha Noi using all available measurement data. The dataset includes 97 days of electric field intensity measurements, lightning location data, and Himawari satellite or weather radar data. Furthermore, I divided the measurement data into two categories: one for the entire day and another for the period after noon. The calculation results and evaluations of the warning results are presented in Figures 3.7 and 3.8. Figure 3.8 illustrates the results of determining the Probability of Detection (POD), Critical Success Index (CSI), and False Alarm Ratio (FAR). The

Probability of Detection (POD) relates to the number of successful warnings, the number of correct warnings that occurred in the Area of Concern (AOC), and instances where no warning was issued, yet lightning still occurred within the AOC.

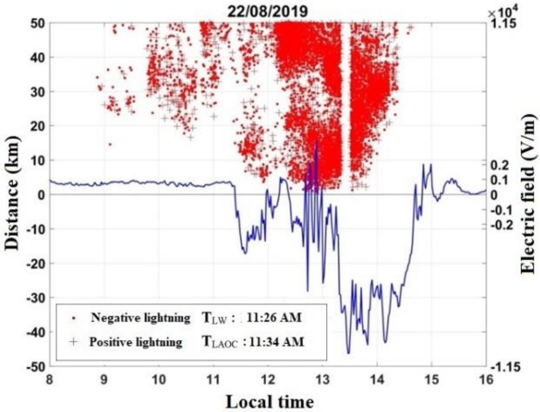

Figure 3.3. Variation of electric field intensity in weather conditions where lightning activity occurred near Phuthuy Station on Aug 22, 2019

The overall result for the entire data set shows a Probability of Detection (POD) value of 86.99%, while the POD value for the time after noon is 88.0%. The POD value after noon is higher than the daily average because thunderstorms occurring later in the day are often stronger than those in the morning, leading to greater detection capabilities of the thunderstorm research equipment. From the chart and the correct warning rate, we can also determine the Failure to Warn (FTW) rate: FTW = 13.1% for daily cases and FTW = 12.0% for cases after noon. This indicates that in the Gialam area of Ha Noi, with the current equipment, for every 100 lightning warnings issued, there are approximately 87 correct warnings and about 13 incorrect ones. The False Alarm Ratio (FAR), which measures the rate of false warnings issued when lightning does not occur in the warned area (AOC), is influenced by various factors. Causes of false warnings include cases where thunderstorms either only move to the warned area or develop within it without entering the warned area, as well as errors in lightning location equipment that lead to incorrect alerts. Additionally, abnormal changes in the atmospheric environment, such as an increase in condensation nuclei causing electric field intensity to exceed the threshold, can also contribute to false alarms. The FAR for the entire day is 16.41%, while the FAR after noon is 18.52%. The overall daily FAR is 2.11% lower than the afternoon FAR, as the total number of correct alarms for the entire day in Gialam district is significantly higher (about 1.5 times) than those issued in the afternoon. Therefore, the false alarm rate for the whole day is lower than that for the afternoon.

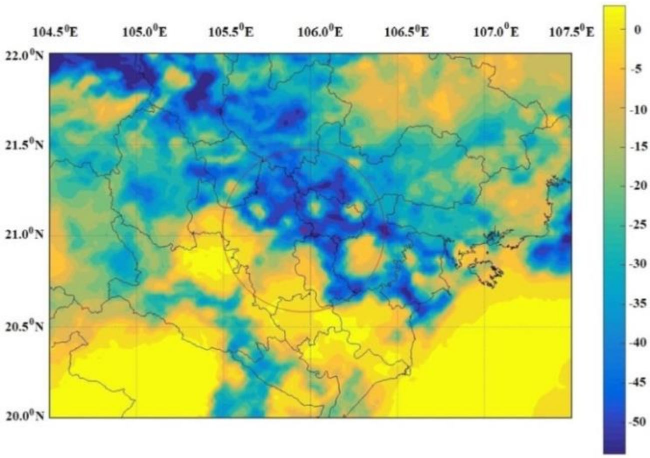

Figure 3.4. Temperature difference between infrared channels TIR6 (6.2µm) and TIR2 (11.2µm), K, at 11:20 on Aug 22, 2019

Figure 3.8 illustrates the variation in lightning warning times (LT) based on 107 instances recorded over 97 days from 2017 to 2019. The timing of lightning warnings can be either earlier or later, which is significant depending on the specific context. This variation ranges from a few minutes to less than 120 minutes (see Figure 3.8), with an average value of 31.6 minutes. This average is consistent with findings from several previous studies, where one study reported an average lightning warning time of LT = 20.0 minutes with a Probability of Detection (POD) of 80.0%. In contrast, my study utilized a broader range of data sources including electric field strength, lightning location, weather radar, and satellite data to enhance the accuracy of lightning warnings, achieving a POD of 86.99%.

Consequently, the average lightning warning time was also greater for the Gia Lam area in Ha Noi.

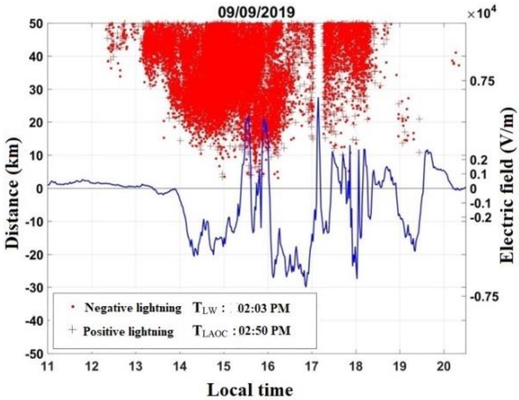

Figure 3.5. Variation of electric field intensity in weather conditions where lightning activity occurred near Phuthuy Station on Sep 9, 2019

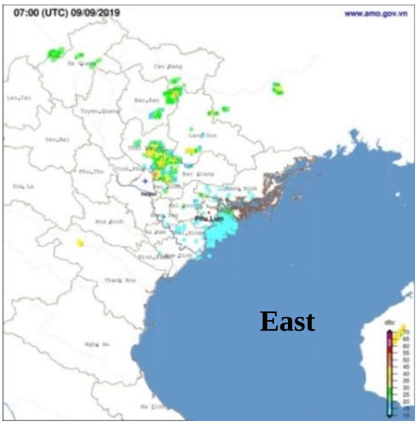

Figure 3.6. Radar image of Phulien station at 2:00 p.m. on September 9, 2019

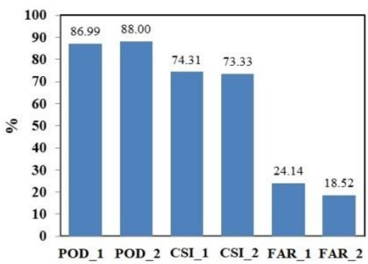

Figure 3.7. Comparison chart of parameters for evaluating lightning warning results in Gia Lam area, Ha Noi (1: full day and 2: after noon)

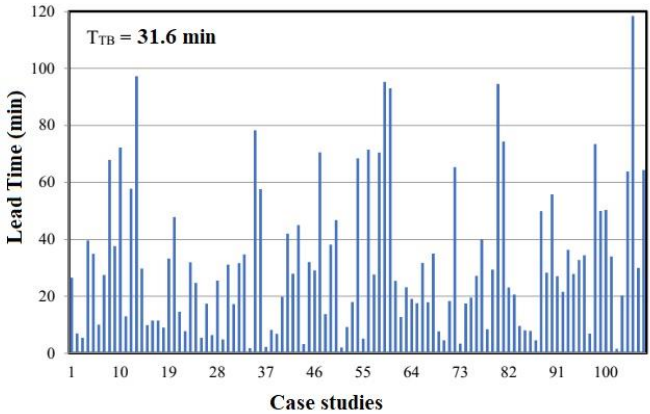

Figure 3.8. Variation of lead time and case studies of lightning warning for Gia Lam area, Ha Noi

3.2. The results of the evaluation of a multi-source data lightning warning technique applied to Vung Tau City

The lightning warning method for Vung Tau City is developed similarly to that for the Gia Lam area in Ha Noi. However, in this method, it is crucial to consider the influence of the coastal environment. Figure 3.9 illustrates the average daily changes in the electric field under clear weather conditions; the average value is higher than that of areas affected by a continental climate, such as Gia Lam. Consequently, the lightning warning threshold is set at 1.5 kV/m. Figures 3.10, 3.11, and 3.12 present a specific case study on lightning warnings in the Vung Tau area. Based on the synthesized data, the lightning warning time is determined to be 59 minutes.

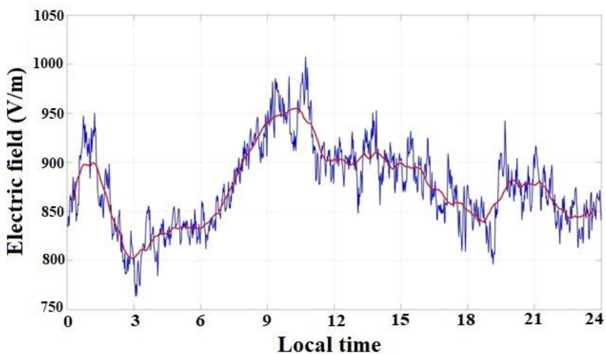

Figure 3.9. Variation of the average daily electric field intensity in fine weather conditions at Vungtau station

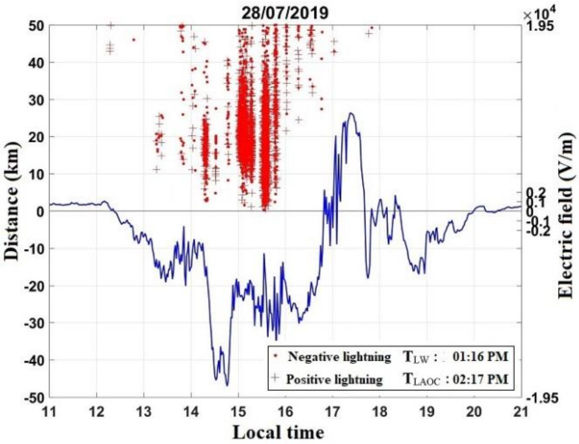

Figure 3.10. Variation of electric field intensity in weather conditions where lightning activity occurred near Vungtau station on July 28, 2019

Based on a dataset of 106 days, which includes electric field intensity disturbances measured at Rescue Station No. 1 in Vung Tau City during 2019, along with additional related data sources such as lightning location data, Himawari satellite cloud images in the infrared channel, and Nhabe weather radar data, I conducted research to evaluate experimental lightning warnings for the Vung Tau City area. The calculation and evaluation results are presented in Figures 3.13 and 3.14. Figure 3.13 illustrates the determination of the Probability of Detection (POD), Critical Success Index (CSI), and False Alarm Ratio (FAR). The POD is associated with the number of successful warnings, the number of correct warnings that occurred in the Area of Concern (AOC), and instances where no warning was issued, yet lightning still occurred in the AOC. The overall POD value for the dataset is 86.3%. From this chart, I also calculated the Failure to Warn (FTW) rate, which is 13.7%. This indicates that, in the Vung Tau City area, using the current equipment and the warning method proposed by this study, for every 100 lightning warnings issued, approximately 86 warnings are successful, while about 14 instances of lightning occur without a warning. The FAR relates to instances where warning information is issued, but no lightning occurs in the AOC; the FAR is 23.7%. This means that, on average, out of

100 warnings, there are 76 instances of actual lightning occurrences and 24 warnings where no lightning occurred.

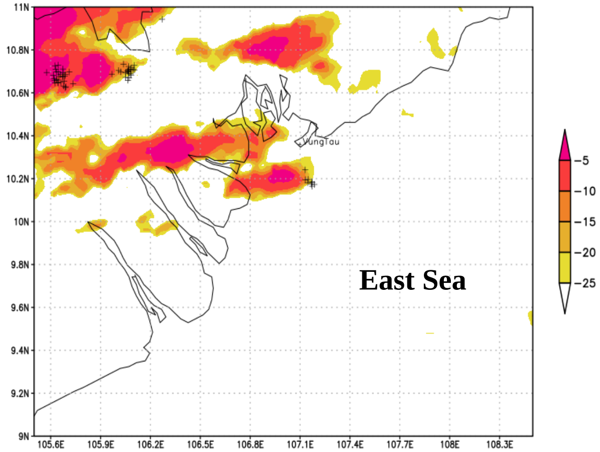

Figure 3.11. Temperature difference between infrared channels TIR6 (6.2μm) and TIR2 (11.2μm), K, at 13:20 and lightning in the previous 10 min, on July 28, 2019

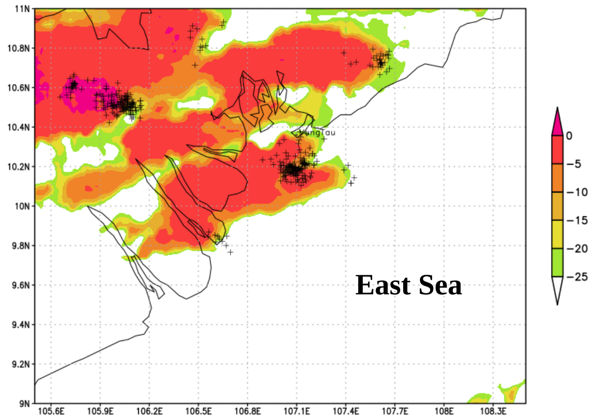

Figure 3.12. Temperature difference between infrared channels TIR6 (6.2μm) and TIR2 (11.2μm), K, at 14:20 and lightning in the previous 10 min, on July 28, 2019

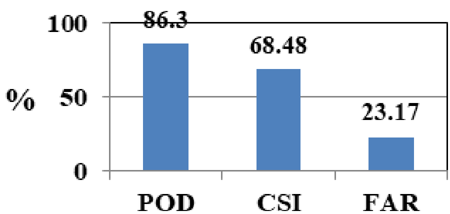

Figure 3.13. Some parameters for evaluating lightning warnings in Vung Tau City

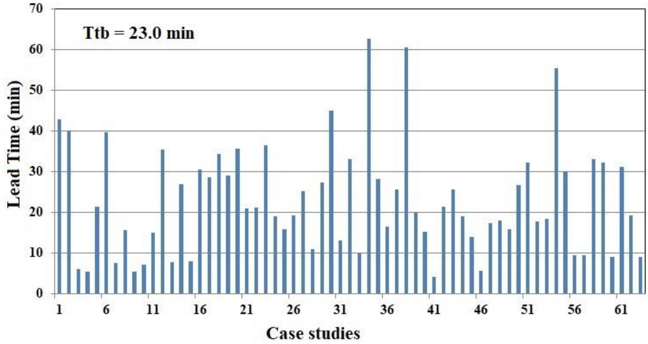

Figure 3.14. Variation of lead time and case studies of lightning warning for the Vung Tau area.

Figure 3.14 depicts the variation in Lightning Warning Time (LT) based on the 63 lightning warnings derived from the electric field intensity data collected in 2019. The warning times vary depending on the specific circumstances, ranging from a few minutes to over 60 minutes, with an average of 23.0 minutes. This average aligns with findings from previous studies, such as Karagiannidis et al. (2016), who reported an average warning time of 15.0 minutes and a POD of 81.0%. However, their study relied solely on satellite and lightning location data, while my research utilized a combination of data sources, including electric field measurements, lightning location, weather radar, and satellite data. Although the advance warning time (LT) is dependent on the study area, the improved lightning warning accuracy (POD = 86.3%) and the average advance warning time in Vungtau City may be attributed to this multi-source data approach.

3.3. The results of improving lightning warning technique based on a combination of multi-source data applied to some areas in Quang Nam province

The average electric field on a clear day at the Hoi An, Hiep Duc, and Dai Loc stations is less affected by the atmospheric environment, as shown in Figures 3.15, 3.16, and 3.17. However, to further evaluate the lightning warning method, I utilized the improved lightning warning method, which incorporates electric field data collected at Hoi An, Hiep Duc, and Dai Loc, along with satellite data and lightning location data.

Figures 3.18, 3.19, and 3.20 display statistical indicators for evaluating the warning results according to the EFAI method (threshold method) at various thresholds. Based on the probability of detection, false alarm rate (FAR), and critical success index (CSI), the optimal threshold for lightning warnings according to the EFAI method is determined to be 1 kV/m.

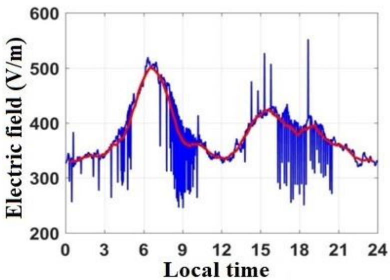

Figure 3.15. Electric field in fine weather at Hoi An

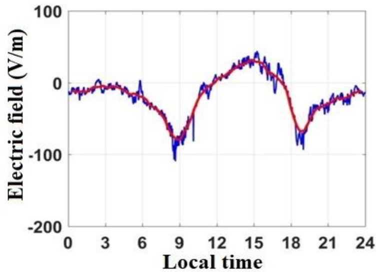

Figure 3.16. Electric field in fine weather at Hiep Duc

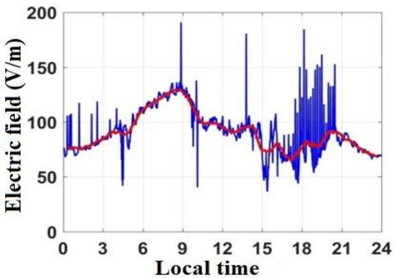

Figure 3.17. Electric field in fine weather at Dai Loc

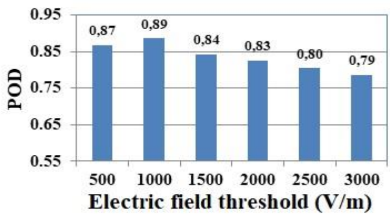

Figure 3.18. POD determined by EFAI method

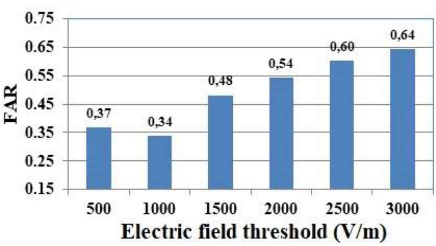

Figure 3.19. FAR determined by EFAI method

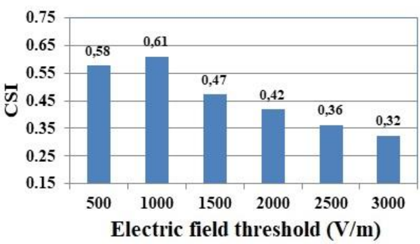

Figure 3.20. CSI determined by EFAI method

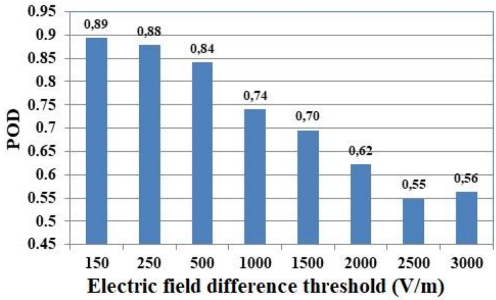

Figure 3.21. POD determined by EFDI method

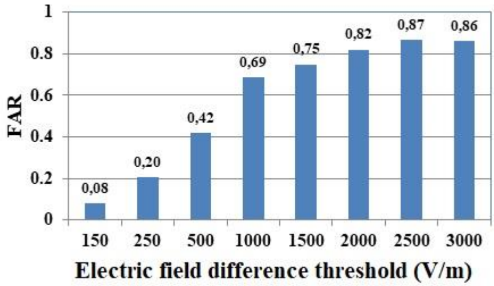

Figure 3.22. FAR determined by EFDI method

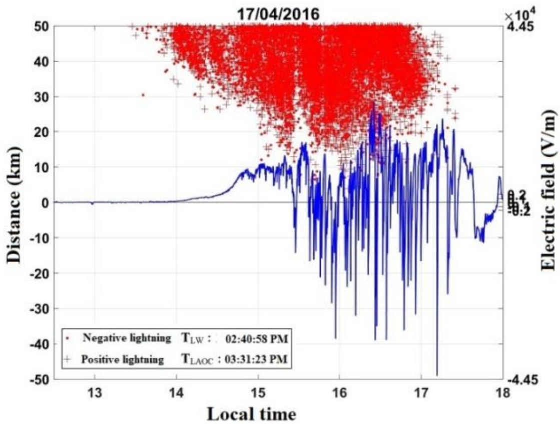

Figure 3.23. Variation of electric field intensity in weather conditions where lightning activity occurred near Hiepduc station on April 17, 2016

Figures 3.21, 3.22, and 3.23 present the results of determining the optimal electric field difference threshold using the EFDI method. The threshold corresponding to the highest Probability of Detection (POD) is 0.89, at a value of 150 V/m. These thresholds were applied to warn of lightning based on independent data from 2017, as well as some test cases from 2016. Figures 3.23 and 3.24 illustrate a specific case from April 17, 2016, where lightning warnings were issued using the improved method, incorporating electric field data, satellite data, and lightning positioning. The warnings were successful, with a lead time of 51.42 minutes.

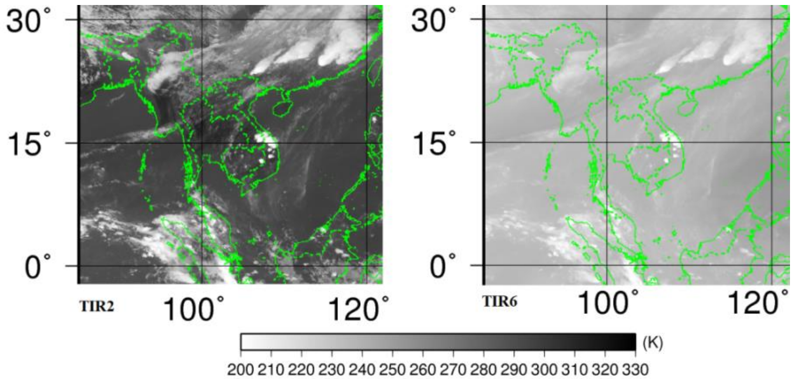

Figure 3.24. Temperature infrared channels TIR6 (6.2µm) and TIR2 (11.2µm) at 14:40 on April 17, 2016

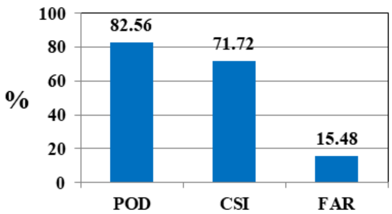

Figure 3.25. Comparison chart of parameters for evaluating lightning warning results in Dai Loc, Hiep Duc, and Hoi An areas of Quang Nam province.

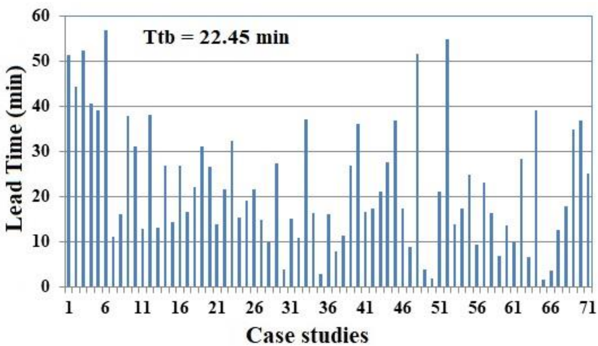

Figure 3.26. Variation of lead time and case studies of lightning warning for the Quang Nam area.

The entire dataset of electric field data collected in 2017, along with three research case studies at Hoi An station, Hiep Duc station, and Dai Doc station in Quang Nam province, was combined with satellite data, lightning location data, and a pilot study of lightning warnings for 99 cases. This data is independent of the established method.

The results indicate the following: POD = 82.56%, FAR = 15.48%, CSI = 71.72% (see Figure 3.25). A total of 71 correct warning cases were identified, and the results regarding the lead time for lightning warnings are presented in Figure 3.26. Most lightning warnings were issued more than 10 minutes in advance, with a maximum lead time of nearly 60 minutes and a minimum of just a few minutes; the average lead time was 22.45 minutes.

The research findings demonstrate that the correct warning rate exceeds 80%, with a success score above 70% and a false warning rate below 20%. The average lightning warning time is over 20 minutes. These values are consistent with numerous studies worldwide and the lightning warning research results in Vung Tau City. However, in Vung Tau City, the warning radius is larger (10 km), resulting in higher warning times and correct warning rates compared to some areas in Quang Nam province.

The lightning warning evaluation results in Quang Nam allow for the application of the lightning warning method in these areas, following the established method with optimal thresholds (EFAI and EFDI).the entire electric field data set collected in 2017 and the 3 research case studies at Hoi An station, Hiep Duc station, and Dai Loc station, Quang Nam province. Combined with satellite data, lightning location data, and a pilot study of lightning warnings for 99 cases, the data is independent of the established method. The results show: POD = 82.56%, FAR = 15.48%, CSI = 71.72% (Figure 3.25). There are 71 correct warning cases that were identified; the results of the lightning warning time in advance are presented in Figure 3.26. Most of the lightning warning times in advance are greater than 10 minutes; the maximum value is nearly 60 minutes; the minimum is only a few minutes; and the average value is 22.45 minutes. The research results show that the correct warning rate is over 80%, with a success score of over 70% and a false warning rate of under 20%, and the average lightning warning time is over 20 minutes. These values are similar to many research results in the world and the lightning warning research results in Vung Tau City. However, in Vung Tau City, the warning radius is larger (10 km), so the warning time and correct warning rate are higher than in some areas in Quang Nam province. The lightning warning evaluation results in Quang Nam allow us to use the lightning warning method for these areas, according to the established method, with optimal thresholds (EFAI and EFDI).

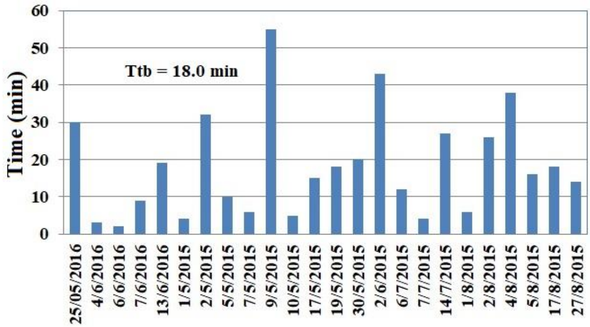

Figure 3.27. Lightning warning results based on aggregated data sources in Tam Ky

Another lightning warning method utilizes data from lightning warning devices, satellite data, and lightning positioning data to study the warning area in Tam Ky. The warning radius of 8 km surrounding the warning station is shown in Figure 3.27. It is divided into attention zones (16 to 32 km), warning zones (8 to 16 km), and alarm zones (0 to 8 km). Based on the Strike Guard lightning warning device data collected in the Tam Ky area of Quang Nam in 2015 and 2016 (spanning 91 days), and using additional data from Himawari satellites and GLD360 lightning positioning, it was determined that thunderstorm clouds shifted on 24 days out of a total of 96 days with data, as described in Chapter 2. The lightning warning time for the 8 km radius around the warning station varied from a few minutes to more than 50 minutes, as shown in Figure 3.66. The average lightning warning time for the 24 studied cases is 18 minutes. This is a significant figure for lightning protection efforts in the Tam Ky area.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

In the dissertation, the author conducted a study on lightning warning systems for several areas in Ha Noi, Ba Ria Vung Tau, and Quang Nam, utilizing synthesized data sources to evaluate the capability of these warnings. Based on the findings, the following conclusions can be drawn:

1. The dissertation developed a lightning warning method based on electric field data, lightning location data, satellite information, and radar. This method provides lightning warnings for areas within a radius of 10 km and 8 km around electric field measuring stations and lightning warning stations. The lightning warning electric field threshold was optimally determined from actual survey data, while the convective cloud area was identified using radar or satellite data. The developed method has been successfully implemented, and its lightning warning capability has been evaluated in various regions of Vietnam based on available data sources and the research environment.
2. The results of the lightning warning research in the Gia Lam area of Ha Noi, using the complete dataset collected in 2017, 2018, and 2019, were applied to two timeframes: after noon and all day. The probability of detection (POD) was found to be 88.00% and 86.99%, respectively; the critical success index (CSI) was 73.33% and 74.31%, respectively; and the false alarm rates (FAR) for the two cases were 18.52% and 16.41%. The correct lightning warning rate in the Gia Lam area for the entire day was lower than that for after noon, as thunderstorms and lightning activities frequently and intensively occur in the area during the afternoon. The average lightning warning time for Gia Lam was 31.6 minutes, which is higher (better) and aligns with values reported in some global studies.
3. Research results for lightning warning in Vung Tau City, Ba Ria Vung Tau Province, indicated that the entire collected dataset yielded a POD

of 86.3%, a CSI of 68.48%, and an FAR of 23.17%. The average lightning warning time for Vung Tau City was 23.0 minutes, a significant duration for lightning protection in coastal areas and for the overall safety of the city.

4. The results from the lightning warning research, which employed the improved lightning warning method and synthesized data sources, established electric field thresholds (EFAI = 1000 V/m and EFDI = 150 V/m) for lightning warnings at optimal levels in specific areas of Quang Nam. The average lightning warning time for Hoi An, Hiep Duc, and Dai Loc was found to be 22.45 minutes, with a detection probability of 82.56%. In the Tam Ky area, the warning time was 18.0 minutes. These values are both scientifically and practically significant for lightning prevention efforts in the region.

RECOMMENDATIONS

1. It is necessary to expand the research to other areas in Ha Noi, specifically the districts of Dong Anh, Phu Xuyen, Chuong My, Thach That, and the inner districts of Ha Noi, where the survey data sources are similar to those in Gia Lam.
2. To reduce the areas that need warning and improve the quality of lightning warning, it is necessary to study the combination of electric field measuring stations in the same research area. When it is necessary to minimize the risks of thunderstorms, it is necessary to study the construction of electric field measuring stations, lightning detection, and locating equipment in areas affected by a lot of thunderstorm activities.
3. It is necessary to study the use of artificial intelligence (AI) technology, applying the WRF numerical model with PR92, LPI, and WRF-ELEC parameterization diagrams to forecast and warn of thunderstorms in the areas that need to be studied in Vietnam according to appropriate spatial and temporal scales, contributing to minimizing the damage caused by thunderstorms there.

LIST OF THE PUBLICATIONS RELATED TO THE DISSERTATION

1. **Hoang Hai Son**, Nguyen Xuan Anh, Pham Xuan Thanh, Pham Le Khuong, Nguyen Van Hiep. *Research to improve lightning warning methods based on a combination of multiple data sources applied to some areas in Quang Nam province*. Vietnam Journal of Hydrometeo rology, 2024, 766, 29-42, doi:10.36335/VNJHM.2024.
2. **Hoang Hai Son**, Nguyen Xuan Anh, Pham Xuan Thanh, Pham Le Khuong, Hiep Van Nguyen. *Evaluation of lightning warning technique with multi-source data for Vung Tau coastal area*. Vietnam Journal of Marine Science and Technology, 2023, Vol 23, No.2, pp 209-222, https://doi.org/10.15625/ 1859-3097/18413.
3. **Hoang Hai Son**, Nguyen Xuan Anh, Pham Xuan Thanh, Nguyen Van Hiep. *A research on lightning warning by integated data: a case study for Gialam area, Ha Noi city*. Vietnam Journal of Hydrometeorology, 2020, 720, 32-48, doi:10.36 335/VNJHM.2020.
4. Hiep Van Nguyen, Pham Xuan Thanh, Nguyen Duc Nam, Nguyen Xuan Anh, Pham Le Khuong, **Hoang Hai Son**, Nguyen Tien Manh, and Pham Chi Cong. *Observation and Simulation of Wind Speed and Wind Power Density over Bac Lieu Region*. Advances in Meteorology, Volume 2021, Article ID 8823940, 17 pages, https://doi.org/10.1155/ 2021/8823940.
5. Nguyen Van Hiep, Nguyen Xuan Anh, Nguyen Duc Nam, Dang Hong Nhu, Nguyen Tien Manh, Pham Le Khuong, Pham Xuan Thanh, **Hoang Hai Son**. *Simulation of heavy rainfall event during 30/10-01/11/2008 over Ha Noi by WRF model*. Conference proceeding: basic research in Earth and Environmental Sciences, 2019, pp 289-292, DOI: 10.15625/vap.2019.000 136.