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Evaluation of lightning warning technique with multi-source data for Vung Tau coastal area

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ABSTRACT

In this paper, the authors used multi-source data, including the electric field data observed by EFM-100C at Rescue Station No. 1 on the "Bai Sau" beach in Vung Tau coastal area for 166 days from May to October 2019; Himawari satellite data and Nha Be weather radar data and the GLD-360 lightning position data to evaluate the lightning warning method. Radar and satellite data were used to determine deep convective clouds. The GLD-360 lightning position data were used to examine the consistency of lightning location with the deep convective clouds. The "two areas" method was applied. The Area of Concern (AOC) has a radius of 10 km from the electric field measurement station. The Warning Area (WA) is 20 km extending from the outermost AOC area. Due to the influence of sea-salt aerosol on the background electric field intensity, the electric field threshold selected for a warning is larger than the absolute value (1.5 kV/m). The results showed that the probability of detection (POD), failure to warn (FTW), and false alarm ratio (FAR) were 86.3%, 13.07%, and 23.17%, respectively. The average time of lightning warning for the Vung Tau coastal area is 23 minutes in advance. The warning time is equivalent to that in some studies around the world. The value is suitable for practical application in lightning prevention on the beach and in the Vung Tau coastal area.

Keywords: Vung Tau coastal area; sea-salt aerosol; lightning warning; cloud electric field; satellite data; weather radar.

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INTRODUCTION

Vung Tau is a city in Ba Ria-Vung Tau province in the Southeast region of Vietnam. Vung Tau City is a center of economy, finance, culture, tourism, transportation, and education. This city has beautiful beaches and infrastructure. The city is a famous tourist destination and a logistics area of Vietnam's oil and gas industry. Vung Tau is also an area that is very vulnerable to thunderstorm activities. Life losses and property damage due to lightning strikes in Vung Tau. From 2016 to 2018, there was a series of lightning strikes in the Vung Tau beach area, killing three people and injuring one. The damage to electronic equipment and infrastructure caused by thunderstorms in Vung Tau is significant.

To minimize the damage caused by thunderstorm activities, research on thunderstorm warnings and forecasting in the world and Vietnam has been conducted. With different approaches, the studies in the world can be divided into two groups: The first group is based on lightning position data to perform lightning forecasting and warning [1–3]. The second group uses multi-source data to forecasting lightning or warning [4–17]. The second group selects multi-source data such as electric field intensity, lightning position data, weather radar data, satellite cloud image, synoptic observation data, and radiosonde sounding data are selected depending on purposes and locations.

Accurate forecasting or warning of lightning occurrence is still a big challenge for scientists. The accuracy of thunderstorm forecasting or warning depends on many factors, such as the error of measurement device, the study area, and the data processing method. Forecasting or warning lead time (*LT*) varies from a few minutes to 60 minutes. The shorter lead time is valuable for controlling the continuous operation of machinery systems. The longer lead time is valuable for outdoor activities such as manufacturing, transportation, entertainment, and sports. To evaluate the results of thunderstorm forecasting or warning, researchers often use statistical indicators such as *POD* (probability of detection), *FTW* (failure to warn), and *FAR* (false alarm ratio), etc. Previous studies showed that a shorter *LT* of a forecast usually results in larger *POD*, e.g., *LT* = 20.8 min, *POD* = 82.7%, [11]; *LT* = 30 min, *POD* = 46%, [1]; *LT* = 2 min, *POD* = 90%, [2].

Many researchers have conducted thunderstorm forecasting and warning in Vietnam. Most authors focus on thunderstorm forecasting, monitoring, and warning, or thunderstorm-induced heavy rain forecasting and warning [18–23]. The data in these studies are mainly synoptic observation data; radar data, satellite data, radiosonde sounding data, and atmospheric electricity observation data have not been used. Some other recent studies [24, 25] have used lightning position and weather radar data. However, these two studies are only associated with heavy rain warnings for the Northwest region and thunderstorm warnings for Vietnam. The study of the authors [26] used data sources, including electric field data, lightning position data, radar data and satellite data for experimental warning in Gia Lam-Hanoi, with a *POD* of 88% and an average lightning warning time of 31.6 min, providing a new result with practical significance; however, the study area is an area with very diverse data sets and many data sources for verification. In the study [26], the area is unaffected by the sea salt aerosol that increases the background electric field.

Based on analyzing previous studies, especially the studies [27–30], the research on lightning warning methods for Vung Tau coastal area has practical significance, considers local influences and should be carried out. Figure 1 depicts the map of the study area and the EFM-100C station. The following parts of this paper include Part 2 - data and method; Part 3 - some specific research results and evaluation; and Part 4 - conclusion.

DATA AND METHOD

Data

The data set used in this study includes electric field data, lightning position data,

satellite data, and weather radar data. Electric field intensity was measured at Rescue Station No. 1 in Vung Tau city (EFM-100C, station location: 10.3327°N; 107.0896°E, Figure 1). Lightning position data is the GLD-360 data set, which is the product of a collaborative project between the Finnish Meteorological Institute and the Vietnam Meteorological and Hydrological Administration [24, 26]. The Japan Meteorological Agency (JMA) provided Himawari satellite cloud images and infrared channels. Nha Be radar data were collected on the website of the Aero Meteorological Observatory.

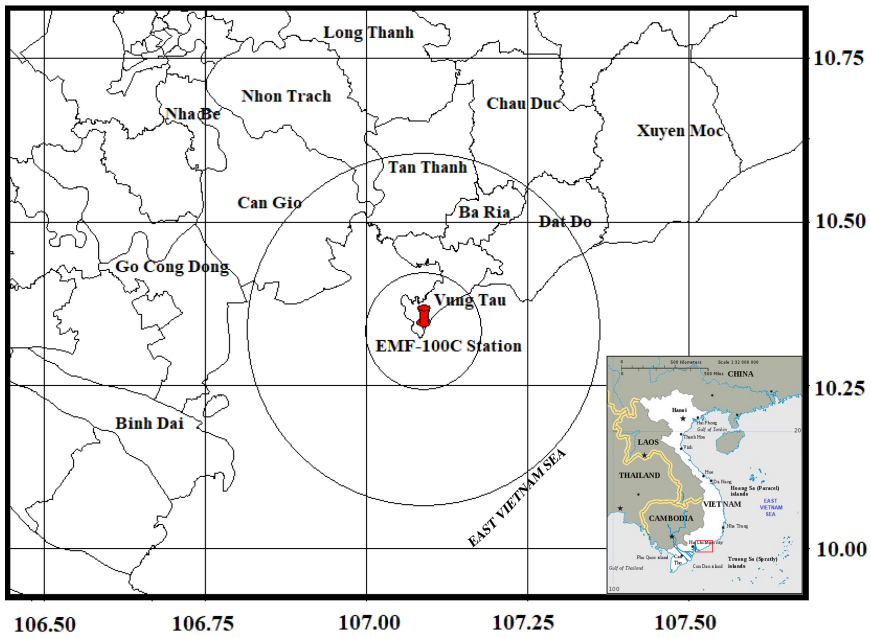

Figure 1. The map of the study area and the EFM-100C station in Vung Tau city

Figure 2. Outdoor sensor of EFM-100C at Rescue Station No. 1 in Vung Tau city

The electric field intensity measurement system EFM-100C at Rescue Station No. 1 in Vung Tau city includes the main components: an outdoor sensor (Figure 2), a power module, and adata transmission module. The data from the sensor are transmitted directly to the computer through these modules. EFM-100C measurement range is from -20 kV/m to +20 kV/m, with an accuracy of 0.01 kV/m.

Method

The method of quality evaluation of lightning warning for the Vung Tau coastal area in this study is “two areas” (Figure 3), similar to the method used by the authors in the project [26]. This method has been used in many other studies worldwide [2, 6, 12]. The basic parameters of this method include Point of Interest (*PI*) corresponding to the location of the electric field intensity measurement device at Rescue Station No. 1 in Vung Tau city; Area of Concern (*AOC*) corresponding to a circular area with a radius of 10 km, with the location of EFM-100C at Rescue Station No. 1 as the

center of the circle; Warning Area (*WA*) corresponding to an annular area with a radius of 10 km to 30 km, surrounding the *AOC*; Cloud-Ground (*CG*) - the cloud-ground discharge of thunderstorm (may be positive or negative), Intra Cloud (*IC*) - the intracloud discharge of thunderstorm. The method "two areas" uses the information in the *WA* to give warnings for the *AOC*. In this study, we are only interested in *CG* for lightning warnings. To confirm the existence of convective clouds (about 50 km around the EFM-100C at Rescue Station No. 1) that may develop or move to the study area, we use the data of infrared channels TIR6 (6.2 μm), TIR2 (11.2 μm) in combination. The TIR2 channel provides information regarding the freezing level at the cloud top and cloud development. The TIR6-TIR2 difference gives information about the deep convective region [31]. The deep convective region can also be related to the region on the radar image with radar echo greater than 35 dBz [19, 20]. Lightning position data were used in this study to evaluate the lightning warning for the study area.

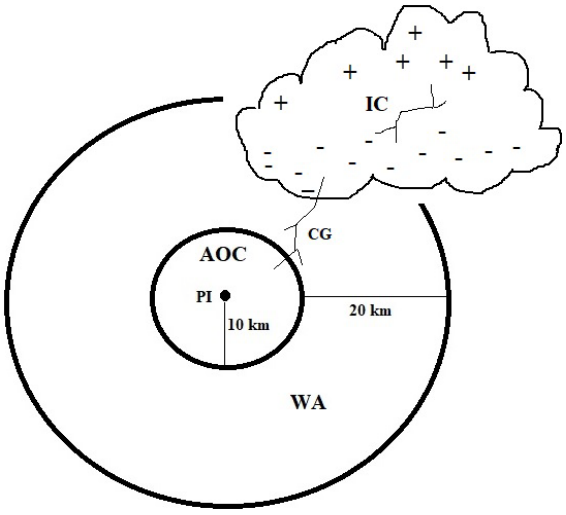

Figure 3. Lightning warning method based on electric field intensity measurement device at a point on the surface

Statistical indicators used to evaluate lightning warning include Probability of Detection - *POD* (warning in case of lightning); Failure to Warn - *FTW* (lightning, but no warning); False Alarm Ratio - *FAR* (no lightning, but warning):

$$POD = \frac{SUC}{CGAOC} \quad (1)$$

$$FTW = 1 - POD \quad (2)$$

$$FAR = \frac{FA}{FA + SUC} \quad (3)$$

where: SUC (Successful) is the number of successful warnings; *CGAOC* (Cloud-Ground in *AOC*) is the number of warnings with at least one cloud-ground discharge in the *AOC*; *FA* is a false alarm, i.e., a lightning warning is triggered; meanwhile, no cloud-ground discharge occurs in the *AOC*. In addition, *LT* is lead time, i.e., the period from the start of the warning to the occurrence of the first cloud-ground discharge in the *AOC*.

Effect of seawater on electric field intensity

The diurnal variation of the atmospheric electric field is an essential parameter in the research field of atmospheric electricity around the globe. Aerosols, cosmic radiation, and radioactivity influence the atmospheric electric field. In urban areas, these aerosols mainly consist of dust particles [32]. In the coastal zone, sea-salt particles are the most significant aerosol component in the atmosphere. These aerosols mainly consist of sea-salt particles [33]. In fine weather conditions and a relatively clean atmosphere, the electric field at the surface is about 130 V/m. However, when the thunderstorm develops or moves to a point, the electric field intensity at the point below the thunderstorm will be disturbed and reach 1 kV/m higher than the absolute value [4]. Therefore, scientists have used this threshold to warn of lightning. Aerosols affect the background electric field, so the electric field threshold for lightning warnings should suit the local environment. In this study, in the electric field observatory at Rescue Station No. 1 near the sea, the sea-salt aerosols increase the background electric field, so the average electric field in satisfactory weather conditions

is about 0.5 kV/m greater than the standard value. Therefore, the electric field threshold selected for warning in this study is 1.5 kV/m larger than the absolute value. Deep convective clouds are identified by satellite or radar data through several criteria described above. The evaluation of lightning warning results follows the formulas (1), (2), and (3).

RESULTS

Lightning warning results on May 03, 2019

Figure 4 depicts the variation of electric field intensity and lightning activity within 50 km around Rescue Station No. 1, from 2:00 to 11:00, on May 3, 2019. From about 2:00 to almost 5:00, lightning activity occurred within an area from 20 km to 50 km (outside the AOC). The electric field intensity measured at Rescue Station No. 1 did not vary considerably, not exceeding the threshold of ±1.5 kV/m. At about 5:00, when lightning activity tended to shift towards Vung Tau City, the electric field intensity gradually turned negative, exceeding the threshold (less than -1.5 kV/m) at 5:07 (starting time of lightning warning: T_{LW}). Lightning activity still occurred within the area 18 km to 50 km from Rescue Station No. 1. Himawari satellite data, TIR2 channel, and temperature difference between the TIR6 channel and TIR2 channel were examined (Figure 5). Within 50 km around Rescue Station No. 1, there were many areas with slight temperature differences (close to 0), indicated thicker clouds than those to the areas with significant temperature differences.

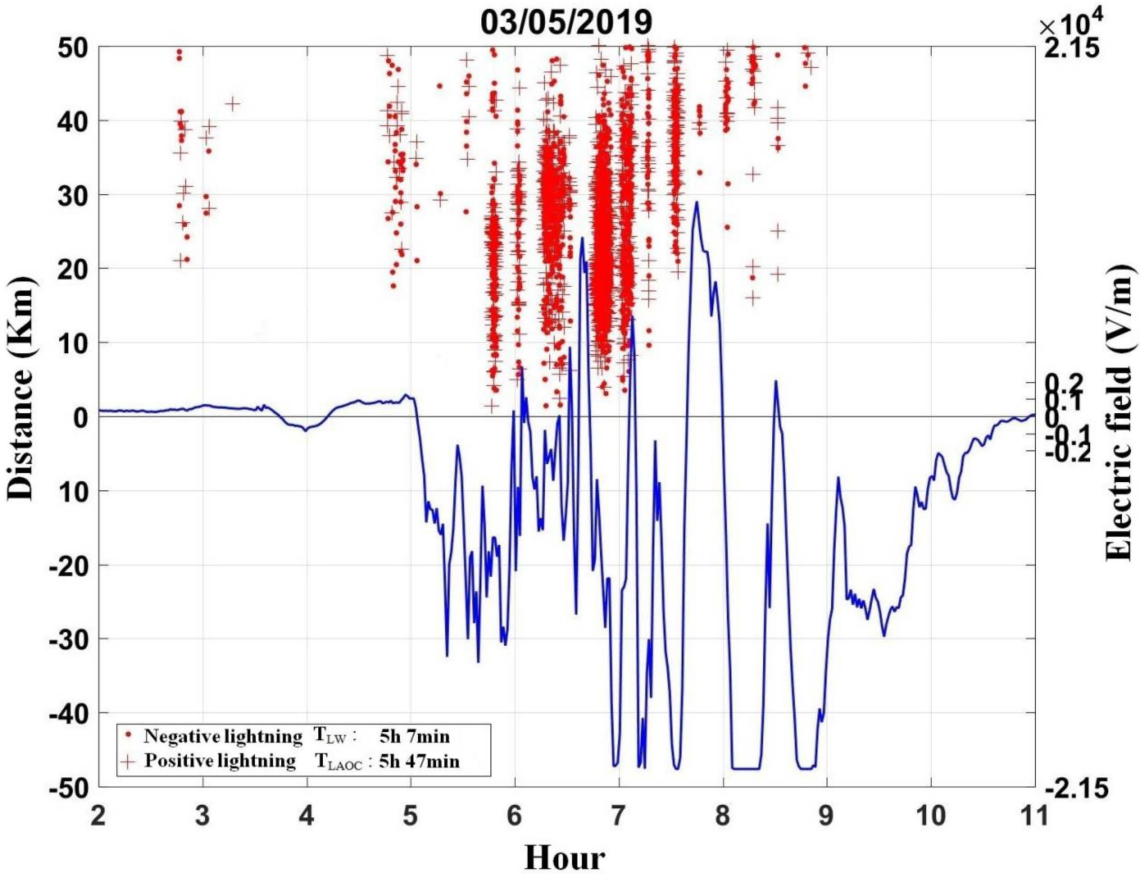

Figure 4. Variation of electric field intensity in weather conditions where lightning activity occurred near Rescue Station No. 1, on May 3, 2019

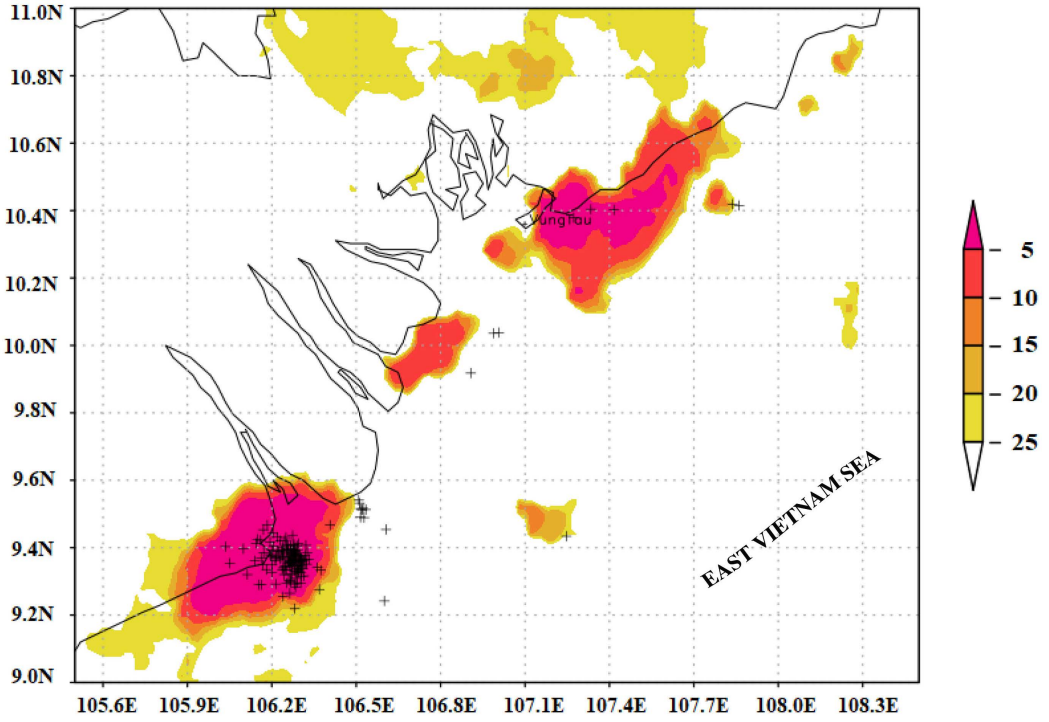

Figure 5. Temperature difference between infrared channels TIR6 (6.2 μm) and TIR2 (11.2 μm), K, at 5:10 and lightning in the previous 10 min, on May 3, 2019

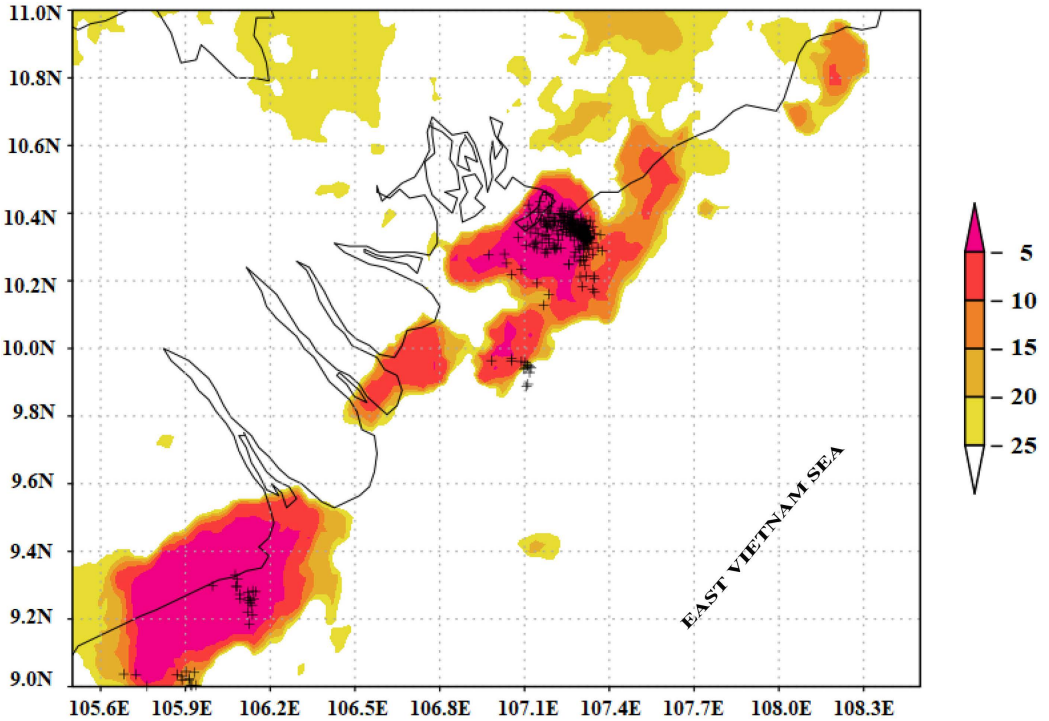

Figure 6. Temperature difference between infrared channels TIR6 (6.2μm) and TIR2 (11.2μm), K, at 5:50 and lightning in the previous 10 min, on May 3, 2019

Moreover, in this region, the temperature of the TIR2 channel in many areas was less than 220 K, and the convective clouds tended to develop. Thereby, we confirmed the existence of convective clouds in the study area. Information on lightning warnings in the Vung Tau coastal area corresponding to the AOC was determined. At 5:47 (determining the first lightning strike in the *AOC*: T_{LAOC}), the first occurred in the AOC, so the warning information is correct, *LT* = 40 min. Figure 6 shows the match between lightning activity in the WA and convective clouds determined by satellite. After the first lightning strike, lightning activity occurred on a large scale in the Vung Tau coastal area, especially between 6:00 and 7:00. After 7:30, lightning activity gradually decreased in the study area and no longer occurred in the *AOC*; at 10:30, the electric field intensity returned to the normal state.

Lightning warning results on July 28, 2019

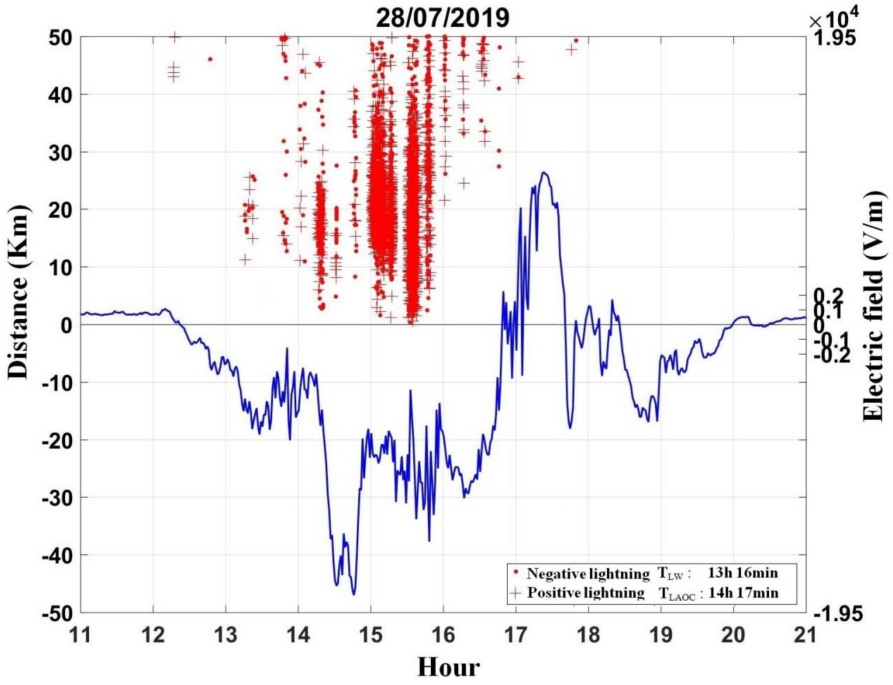

Figure 7. Variation of electric field intensity in weather conditions where lightning activity occurred near Rescue Station No. 1, on July 28, 2019

Figure 7 depicts the variation of electric field intensity and lightning activity within 50 km around Rescue Station No. 1, from 11:00 to 21:00, on July 28, 2019. From about 11:00 to nearly 12:20, there was no lightning activity within 50 km around the station; after this, lightning activity occurred from 40 km to 50 km outside the *AOC*. The electric field intensity measured at Rescue Station No. 1 tended to decrease, exceeding the threshold (less than -1.5 kV/m) at 13:16 (starting time of lightning warning: T_{LW}); lightning activity still occurred in the area more than 10 km from Rescue Station No. 1. Himawari satellite data (Fig. 8) were used to examine the existence of convective clouds within 50 km around Rescue Station No. 1. Thereby, we confirmed the existence of convective clouds in the study area. Information on lightning warnings in the Vung Tau coastal area corresponding to the *AOC* was determined. At 14:17 (T_{LAOC}), the first lightning strike appeared in the *AOC*, so the warning information is correct, *LT* = 61 min. Figure 9 shows the match between lightning activity in the *WA* and convective clouds identified by satellite. After the first lightning strike in the AOC, the lightning activity shifted towards Rescue Station No. 1,

especially from 15:00 to 16:00. After that, the lightning activity gradually decreased in the study area; after 20:00, the electric field returned to its normal state.

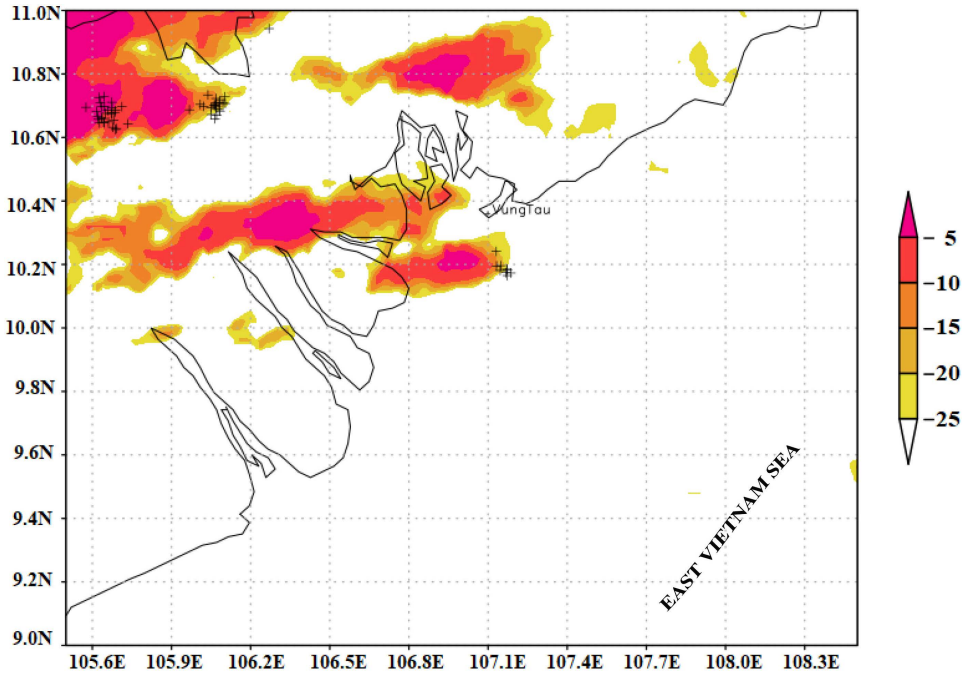

Figure 8. Temperature difference between infrared channels TIR6 (6.2μm) and TIR2 (11.2μm), K, at 13:20 and lightning in the previous 10 min, on July 28, 2019

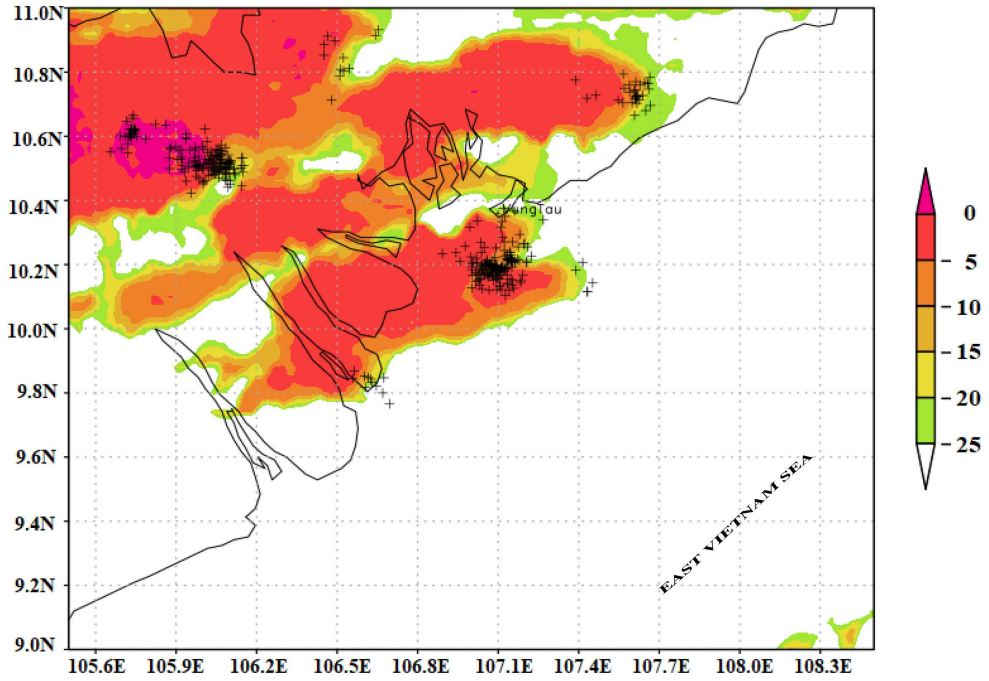

Figure 9. Temperature difference between infrared channels TIR6 (6.2μm) and TIR2 (11.2μm), K, at 14:20 and lightning in the previous 10 min, on July 28, 2019

Lightning warning results on August 20, 2019

Figure 10 depicts the variation of electric field intensity and lightning activity within 50 km around Rescue Station No. 1, from 14:00 to 24:00, on August 20, 2019. There were three different thunderstorms in Vung Tau coastal area on that day. In the first thunderstorm, the electric field intensity exceeded the threshold was 16:11 (starting time of lightning warning: T_{LW1}). Figure 11, Nha Be weather radar image at 16:10, also indicates the existence of convective clouds (echo > 35 dBz) near the station area. Information on lightning warnings in the Vung Tau coastal area corresponding to the *AOC* was determined. At 16:16 (T_{LAOC1}), the first lightning strike occurred in the *AOC*, so the warning information is correct, *LT* = 6 min. From about 17:00 to 18:00, lightning activity did not occur in the *AOC* and in the *WA*. After 18:00, the second thunderstorm appeared, and lightning activity gradually shifted towards Vung Tau coastal area; the electric field intensity exceeded the threshold at 18:06 (starting time of lightning warning: T_{LW2}). Nha Be weather radar data at 18:10 (Figure 12) also show that the cloud band with high echo (> 35 dBz) appeared near Vung Tau coastal area, so the information on the lightning warning was confirmed. At 18:27 (T_{LAOC2}), the first lightning strike occurred in the *AOC*, so the warning information is correct, *LT* = 21 min. Similarly, the third thunderstorm was determined, occurring from approximately 22:00 to 24:00, T_{LW3} = 22:58, T_{LAOC2} = 23:24. Thus, the lead time for the third thunderstorm is 26 min.

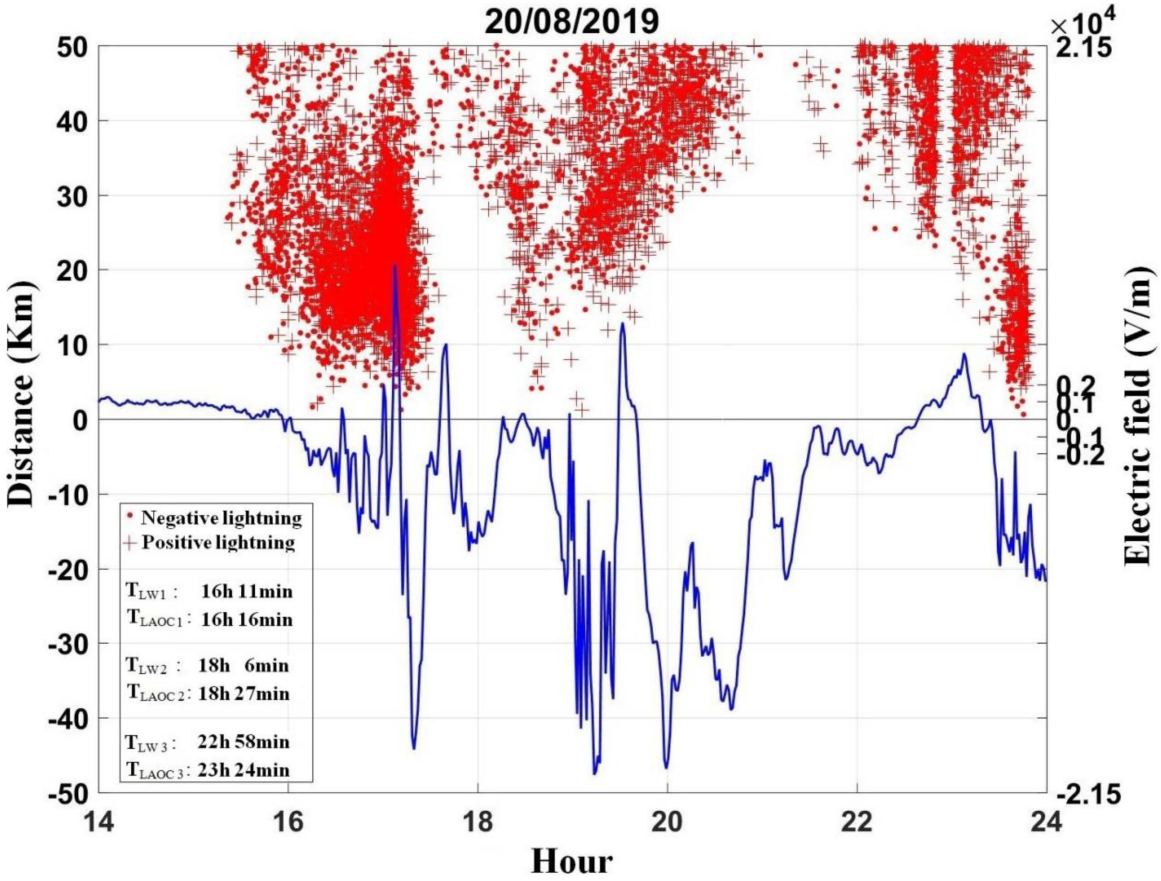

Figure 10. Variation of electric field intensity in weather conditions where lightning activity occurred near Rescue Station No. 1, on August 20, 2019

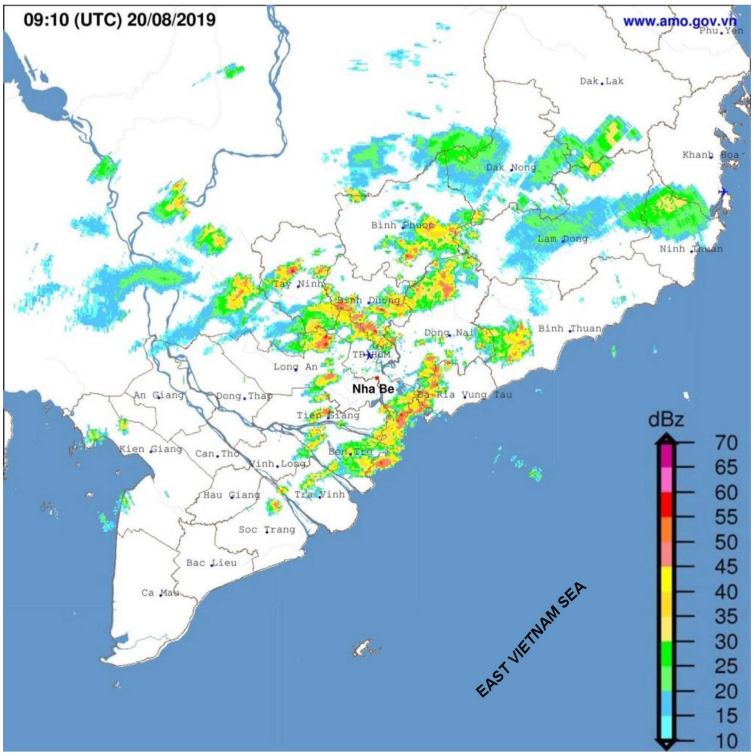

Figure 11. Nha Be weather radar image at 16:10 on August 20, 2019

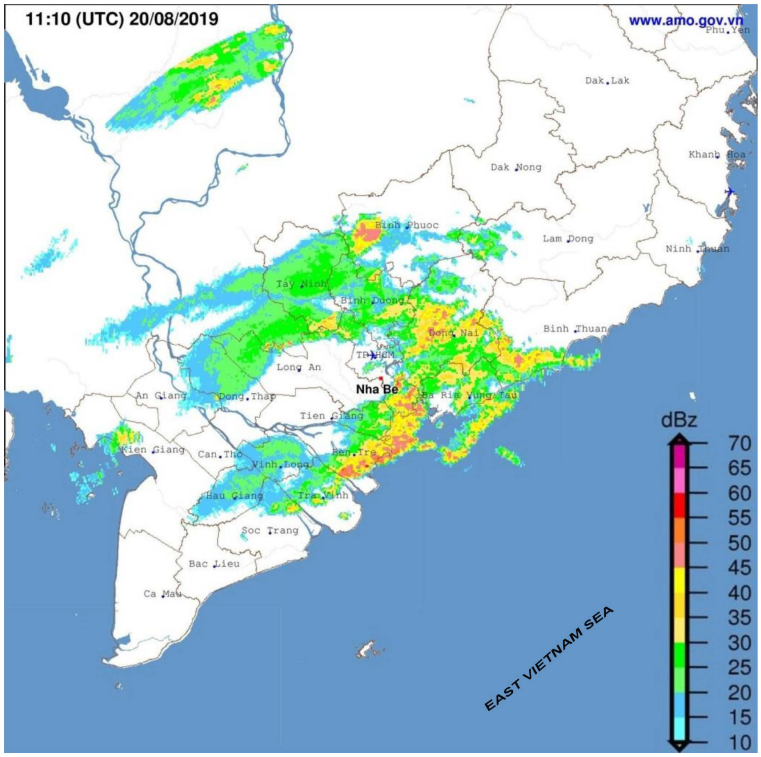

Figure 12. Nha Be weather radar image at 18:10 on August 20, 2019

Evaluation of lightning warning results for Vung Tau coastal area

Based on a data set of 106 days, from May to October, with disturbance of electric field intensity measured at Rescue Station No. 1 in Vung Tau City in 2019, as well as other relevant data sources such as lightning position data, Himawari satellite cloud image of infrared channel or Nha Be weather radar data, we have conducted research and evaluation of experimental lightning warning for the Vung Tau city coastal area. The calculation results and evaluation of warning results are presented in Figure 13 and Figure 14. Figure 13 shows the results of determining *POD*, *FTW*, and *FAR*. *POD* is related to the number of successful warnings, correct warnings about discharge in the *AOC*, and the number of times when no warning information was given but lightning still occurred in the *AOC*; the result for the entire data set is *POD* = 86.3%. We also determined *FTW* = 13.7% from the figures and the *POD*. This ratio indicates that in Vung Tau coastal area, with available devices and warning methods proposed by this study, among 100 cases of lightning warnings, there are 86 cases of correct warnings and 14 cases of no warning when lightning occurs. *FAR*, in which warning information is given but lightning does not occur in the *AOC*, is 23.7%. It means that on average, among 100 warnings, there are 76 cases of lightning occurrence and 24 cases of warning, but no lightning occurs.

Figure 14 describes the variation of lead time (*LT*) in the order of 63 lightning warnings determined from the data set of electric field intensity collected in 2019. The early or later lightning warning is significant, depending on the specific problem. This value varies from a few minutes to more than 60 minutes (Figure 14). The average value reached 23 minutes, which is consistent with many previous studies from many authors in the world [6, 8, 9, 11, 14, 34]. The authors determined the average lightning warning time [34], *LT* = 20.0 min, and *POD* = 80.0%. However, in the study [34], the authors only used electric field intensity and lightning position data. Meanwhile, our study used a combination of data sources (electrical field, lightning position, weather radar data, and satellite data). Although the lead time (*LT*) depends on the study area, the increase in the accuracy of lightning warnings (*POD* = 86.3%) and in average lightning warning time for the Vung Tau coastal area is likely due to the combination of multi-source data in this study.

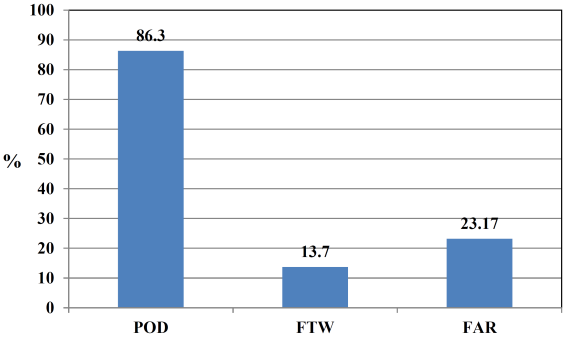

Figure 13. Comparison of parameters to evaluate lightning warning results in Vung Tau coastal area

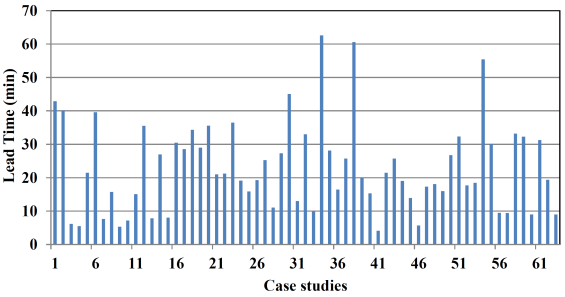

Figure 14. Variation of lead time (*LT*), in the order of lightning warnings for Vung Tau coastal area

CONCLUSION

Using multi-source data, including electric field intensity, satellite data, weather radar data, lightning position data during the period from May to October 2019, we have studied and evaluated the lightning warning method for Vung Tau coastal area. From the results presented above, some conclusions can be drawn as follows:

In specific cases on May 3, 2019; July 28, 2019; August 20, 2019 (3 different thunderstorms), the successful results of

lightning warning for the Vung Tau coastal area have been obtained, with the lead time (*LT*) before the first cloud-ground discharge in the study area: 40 minutes; 26 minutes; 33 minutes; 61 minutes; (6 minutes; 21 minutes; 26 minutes) respectively.

Overall, the collected data set, the probability of detection (*POD*), failure to warn (*FTW*), and false alarm ratio (*FAR*) were identified as 86.3%, 13.07%, 23.17%, respectively. The average lightning warning time for Vung Tau coastal area is 23 minutes, consistent with and more significant than some values determined in some studies around the world. This value has practical significance in lightning prevention on the beach and the Vung Tau coastal area.

The observation and study of electric field intensity in marine or coastal areas will contribute to studying the influence of sea-salt aerosols on the background electric field strength, providing help in selecting an appropriate lightning warning threshold and improving the effectiveness of lightning warnings in areas affected by the marine environment.

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REFERENCES

[1] Kohn, M., Galanti, E., Price, C., Lagouvardos, K., and Kotroni, V., 2011. Nowcasting thunderstorms in the Mediterranean region using lightning data. *Atmospheric Research*, *100*(4), 489–502. doi: 10.1016/j.atmosres.2010.08.010

[2] Holle, R. L., Demetriades, N. W., and Nag, A., 2016. Objective airport warnings over small areas using NLDN cloud and cloud-to-ground lightning data. *Weather and Forecasting*, *31*(4), 1061–1069. doi: 10.1175/WAF-D-15-0165.1

[3] Clulow, A. D., Strydom, S., Grant, B., Savage, M. J., and Everson, C. S., 2018. Integration of a ground-based lightning warning system into a mining operation in the Democratic Republic of the Congo. *Weather, Climate, and Society*, *10*(4), 899–912. https://doi.org/10.1175/WCAS-D-18-0004.1

[4] Montanya, J., Bergas, J., and Hermoso, B., 2004. Electric field measurements at ground level as a basis for lightning hazard warning. *Journal of Electrostatics*, *60*(2–4), 241–246. https://doi.org/10.1016/j.elstat.2004.01.009

[5] Montanya, J., Aranguren, D., Pineda, N., Sola, G., Romero, D., and March, V., 2008. Total lightning, electrostatic field and meteorological radar applied to lightning hazard warning. In *Proceedings of the 20th International Lightning Detection Conference*.

[6] Aranguren, D., Montanya, J., Sola, G., March, V., Romero, D., and Torres, H., 2009. On the lightning hazard warning using electrostatic field: Analysis of summer thunderstorms in Spain. *Journal of Electrostatics*, *67*(2–3), 507–512. https://doi.org/10.1016/j.elstat.2009.01.023

[7] Ferro, M. A. D. S., Yamasaki, J., Pimentel, D. R. M., Naccarato, K. P., and Saba, M. M. F., 2011. Lightning risk warnings based on atmospheric electric field measurements in Brazil. *Journal of Aerospace Technology and Management*, *3*, 301–310. https://doi.org/10.5028/jatm.2011.03032511

[8] Mosier, R. M., Schumacher, C., Orville, R. E., and Carey, L. D., 2011. Radar nowcasting of cloud-to-ground lightning over Houston, Texas. *Weather and Forecasting*, *26*(2), 199–212. doi: 10.1175/2010WAF2222431.1

[9] Lopez, J., Perez, E., Herrera, J., Aranguren, D., and Porras, L., 2012. Thunderstorm warning alarms methodology using electric field mills and lightning location networks in mountainous regions. In *2012*

International conference on lightning protection (ICLP) (pp. 1–6). IEEE. doi: 10.1109/ICLP.2012.6344397

[10] Seroka, G. N., Orville, R. E., and Schumacher, C., 2012. Radar nowcasting of total lightning over the Kennedy Space Center. *Weather and forecasting*, *27*(1), 189–204. https://doi.org/10.1175/WAF-D-11-00035.1

[11] Zeng, Q., Wang, Z., Guo, F., Feng, M., Zhou, S., Wang, H., and Xu, D., 2013. The application of lightning forecasting based on surface electrostatic field observations and radar data. *Journal of Electrostatics*, *71*(1), 6–13. https://doi.org/10.1016/j.elstat.2012.10.007

[12] Junchi, Z., Qingfeng, Z., Shah, A. B., Xue, J., and Ye, Z., 2015. A Lightning Warning Algorithm Using a EFMs Network and LPS. *Pakistan Journal of Meteorology*, *12*(23), 49–55.

[13] Srivastava, A., Mishra, M., and Kumar, M., 2015. Lightning alarm system using stochastic modelling. *Natural Hazards*, *75*, 1–11. https://doi.org/10.1007/s11069-014-1247-8

[14] Karagiannidis, A., Lagouvardos, K., and Kotroni, V., 2016. The use of lightning data and Meteosat infrared imagery for the nowcasting of lightning activity. *Atmospheric Research*, *168*, 57–69. https://doi.org/10.1016/j.atmosres.2015.08.011

[15] Tao, H., Gu, S., Wang, H., Feng, W., Guo, J., Wang, Y., and Zhang, L., 2016. Method of lightning warning based on atmospheric electric field and lightning location data. In *2016 33rd International Conference on Lightning Protection (ICLP)* (pp. 1–5). IEEE. doi: 10.1109/ICLP.2016.7791394

[16] Meng, Q., Yao, W., and Xu, L., 2019. Development of lightning nowcasting and warning technique and its application. *Advances in meteorology*, *2019*, 2405936. https://doi.org/10.1155/2019/2405936

[17] Wang, G., Kim, W. H., Kil, G. S., Park, D. W., and Kim, S. W., 2019. An intelligent lightning warning system based on electromagnetic field and neural network. *Energies*, *12*(7), 1275. https://doi.org/10.3390/en12071275

[18] Lanh, N. V., 2001. Studying the airmass thunderstorm forecast in the Northern Delta in the first half of summer. *Dissertation of Doctor Geography*, 148 p. (in Vietnamese).

[19] Thang, N. V., 2005. Use of the TRS-2730 radar for observation, monitoring, detecting and warning convective clouds that may cause thunderstorm, squalls, tornadoes, hails in Vietnam. *Scientific and Technical Hydro-Meteorological Journal*, *529*, 19–25. (in Vietnamese).

[20] Thang, N. V., and Binh, N. T. T., 2007. Use of the information of TRS-2730 radar and satellites for monitoring and detecting convective clouds that may cause squalls, tornadoes, hails in the North of Vietnam. *Scientific and Technical Hydro-Meteorological Journal*, *564*, 21–28. (in Vietnamese).

[21] Tien, T. T., and Dung, D. T. H., 2009. Studying the thunderstorm forecast technique applied for Noibai airport using forecast outputs of ETA. *VNU Journal of Science: Natural Sciences and Technology*, *25*, 125–123. (in Vietnamese).

[22] Thanh, C., Nguyen, V. T., and Thuc, T. D., 2018. Application of Titan Software for Recognition, Monitoring, Instantaneous Analysis of Thunderstorm for Ho Chi Minh City. *VNU Journal of Science: Earth and Environmental Sciences*, *34*, 18–25. (in Vietnamese).

[23] Cong, T. T., Quyen, L. N., Giam, N. M., and Quyet, L. D., 2020. The application of himawari satellite data in forecast and warning of rain and thunderstorm. *Vietnam Journal of Hydrometeorology*, *713*, 1–13. (in Vietnamese).

[24] Trung, L. B., Toan, H. M., and Phong, N. B., 2018. Research the usage of thunderbolt location data combined with images from radar in order to warn the coming rain in North-West area from August 1st to 6th, 2018. *Vietnam Journal of Hydrometeorology*, *685*, 48–54. (in Vietnamese).

[25] Quoc, P. K., Lam, T. L, and Huyen, D. T. A., 2021. An experiment on thunderstorm warning by combining weather radar and lightning data in Vietnam. *Vietnam Journal of Hydrometeorology*, *723*, 88–96. (in Vietnamese).

[26] Son, H. H., Anh, N. X., Thành, P. X., and Hiep, N. V., 2020. A research on lightning warning by integated data: a case study for Gialam area, Hanoi city. *Vietnam Journal of Hydrometeorology*, *720*, 32–48. (in Vietnamese).

[27] Anh, N. X., 2005. Investigation of thunderstorm, lightning activities in Vietnam and protective solution recommendation. *The national project report*. 252 p. (in Vietnamese).

[28] Anh, N. X., Huy, L. V., and Son, H. H., 2007. Some results in thunderstorm and lightning study in Vietnam using lighnting detection network. *Proceeding of the 5th conference Geophysics sciencetific*. *Science and Technics Publishing House*. pp. 11–20. (in Vietnamese).

[29] Anh, N. X., Huy, L. V., and Son, H. H., 2008. Research on thunderstorm activities and problem of lightning protection in Vietnam: Results and future work. *Proceeding of Geophysics sciencetific conference in 2008, The natural science and technology publisher*, pp. 289–306. (in Vietnamese).

[30] Anh, N. X., 2013. Study and proposed of the lightning preventive solution in Quangnam. *The mission report of the committee for local science and technology*. 188 p. (in Vietnamese).

[31] Lee, S., Han, H., Im, J., Jang, E., and Lee, M. I., 2017. Detection of deterministic and probabilistic convection initiation using Himawari-8 Advanced Himawari Imager data. *Atmospheric Measurement Techniques*, *10*(5), 1859–1874. https://doi.org/10.5194/amt-10-1859-2017

[32] Wright, M. D., Matthews, J. C., Silva, H. G., Bacak, A., Percival, C., and Shallcross, D. E., 2020. The relationship between aerosol concentration and atmospheric potential gradient in urban environments. *Science of The Total Environment, 716*, 134959. https://doi.org/10.1016/j.scitotenv.2019.134959

[33] Pant, V., Deshpande, C. G., and Kamra, A. K., 2008. Size distributions of aerosols over the Indian Ocean. *Indian Journal of Marine Sciences*, *37*(1), 104–108.

[34] Murphy, M. J., and Said, R. K., 2016. Preliminary analysis of lightning warnings in and near the rocky mountains using US national lightning detection network and electric field mill data. In *Preprints, 24th Int. Lightning Detection Conf. & 6th Int. Lightning Meteorology Conf., San Diego, California USA, Vaisala Inc*.