



Seasonal and Diurnal Variation of Lightning Over Java Region and Its Relationship with Aerosol

Ahmad Rizqy Shubri¹, Mutya Vonnisa^{1*}, Marzuki Marzuki¹

¹Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Andalas, Padang 25163, Indonesia.

Received: July 24, 2023

Revised: October 10, 2023

Accepted: November 25, 2023

Published: November 30, 2023

Corresponding Author:

Mutya Vonnisa

mutyavonnisa@sci.unand.ac.id

DOI: [10.29303/jppipa.v9i11.4784](https://doi.org/10.29303/jppipa.v9i11.4784)

© 2023 The Authors. This open access article is distributed under a (CC-BY License)



Abstract: This study discusses the influence of aerosols on lightning on Java Island using monthly and diurnal observation data from the Tropical Rainfall Measuring Mission (TRMM) for 16 years (1998 - 2013). Aerosol Optical Depth (AOD) was obtained from The Modern Era Retrospective Analysis for Research and Applications version 2 (MERRA-2). Aerosol and lightning data are grouped into rainy (December-January-February) and dry (June-July-August) seasons and diurnal data grouped per 3 hours. The intensity of lightning strikes in the western part of Java Island, such as Jakarta and Banten, is higher than the eastern region, in accordance with the aerosol distribution pattern. The influence of aerosols and lightning in the rainy and dry seasons is relatively stable. However, influence of aerosols on lightning diurnally changes significantly. The strongest correlation between aerosol and lightning was recorded in the afternoon ($r = 0.8$) and evening ($r = 0.9$). Although the influence of aerosols on radiation reaches a saturation point during the day, the movement of land and sea breezes plays a dominant role. At night, the influence of aerosols on surface temperature is weakened due to the absence of solar radiation, so aerosols help the electrification of clouds through the formation of ice crystals.

Keywords: Aerosol; Java island; Lightning

Introduction

Lightning is an atmospheric phenomenon that releases enormous energy (Zheng et al., 2016) that can eliminate human lives, damage property and help the formation of NO_x in the atmosphere (Uman, 2011; Yadava et al., 2020). Therefore, many studies discuss lightning activity, especially the factors that affect it (Dewan et al., 2018; Oulkar et al., 2019; Siingh et al., 2013). One of the parameters that can affect lightning is atmospheric aerosols (Thornton et al., 2017). Human activities are one of the sources of aerosols so that the type and concentration of aerosols are different in each region. Aerosols act as cloud formation nuclei (CCN) and ice nuclei (IN) in cloud microphysics. Besides, adding aerosols to clouds decreases cloud droplet size, and reduces the collision-combination efficiency of cloud droplets (Seinfeld et al., 2016). This will further impact the thermodynamics and structure of the cloud

(Zhao et al., 2022). Aerosols can also cool the Earth's surface through radiation effects.

The relationship between aerosols and lightning is very complex and varies from region to region. There are several studies that discuss this such as related to aerosol types (total aerosols, smoke and dust) (Dayeh et al., 2021; Shi et al., 2020), lightning variations (cloud to ground lightning and positive cloud to ground lightning) (Zhao et al., 2020, 2022) and aerosol concentrations (Shi et al., 2020). There is a limit of aerosol concentration levels where there is a transition in the influence of aerosols on lightning. The Aerosol Optical Depth (AOD) limit chosen varies as Shi et al. (Shi et al., 2020) chose $\text{AOD} < 1.0$, Dayeh et al. (2021) chose $\text{AOD} < 0.8$, Kaufman et al. (2005) chose $\text{AOD} < 0.6$, and Altaratz et al. (2017) chose $\text{AOD} < 0.4$.

The relationship between aerosols and lightning shows temporal variations. Chen et al. (2021) reported that convective clouds were more frequent under polluted conditions in the morning, but the situation reversed in the afternoon. This study revealed the

How to Cite:

Rizqy Shubri, A., Vonnisa, M., & Marzuki, M. (2023). Seasonal and Diurnal Variation of Lightning Over Java Region and Its Relationship with Aerosol. *Jurnal Penelitian Pendidikan IPA*, 9(11), 9516-9523. <https://doi.org/10.29303/jppipa.v9i11.4784>

diurnal variation of aerosol effects on convective clouds. However, the diurnal fluctuations of aerosol impact on lightning or convective activity have not been clearly discussed. Wang et al. (2023) reported that when AOD is less than 0.3, an increase in AOD will cause an increase in lightning flashes in the afternoon and evening. In the afternoon, high aerosol concentrations reduce solar radiation reaching the ground through direct and indirect radiative effects. At night, since there is no solar radiation, the influence of aerosols on surface temperature is weakened. Thus, the degree of aerosol inhibition on lightning activity is weakened. Temporal variations of the atmosphere, including aerosols and lightning, will be influenced by local and global factors so that these variations can differ from one region to another. Therefore, research related to this needs to be conducted in many locations worldwide.

In this study, we analyze the temporal variation of lightning, especially the seasonal and diurnal variation of lightning on Java Island, and its relationship with aerosols. Java is one of the most populous islands in Indonesia, with a 2010 population of approximately 151.59 million people (BPS, 2021). Therefore, most Java aerosols are anthropogenic from human activities (Kusumaningtyas et al., 2022). Global warming, which has occurred since the industrial revolution, also stimulates increased humidity and CAPE, increasing the

potential for cloud development, charge separation and lightning. Scientists predict that global warming will increase the intensity of lightning that will occur in the future (Tippett et al., 2015; Yair, 2018). Therefore, this research is critical to understanding the lightning development process in order to mitigate future lightning activity in the region. This research is a continuation of previous research (in press), which discussed the climatology of the relationship between lightning and aerosols in Java.

Method

This study used lightning strike intensity data from 1998 to 2013 from Tropical Rainfall Measuring Mission (TRMM) satellite observations. This data was chosen because of the high spatial resolution of the data ($0.1^\circ \times 0.1^\circ$) with a long observation period. Lightning data was only used until 2013 because TRMM observations were only available until that period. Aerosol data were obtained from The Modern Era Retrospective Analysis for Research and Applications version 2 (MERRA-2) reanalysis. MERRA-2 provides aerosol reanalysis data in the form of Aerosol Optical Depth (AOD) with a spatial resolution of $0.5^\circ \times 0.625^\circ$ and is derived from satellite observations and ground observation stations.

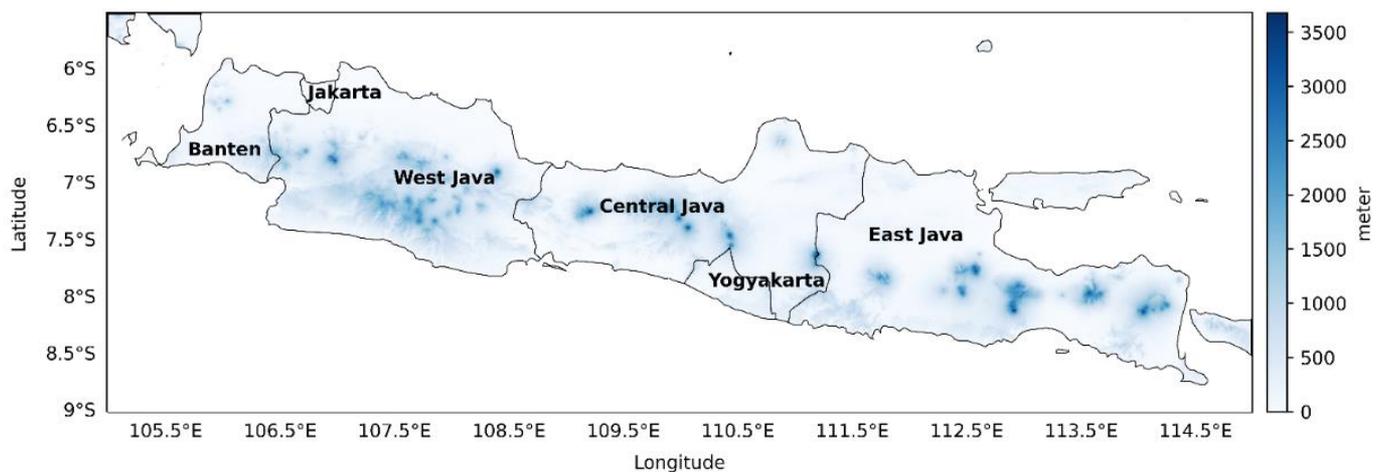


Figure 1. Topography map of Java Island

This research begins by grouping AOD and lightning intensity data to facilitate calculation and analysis. Monthly data is divided into December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON). While diurnal data is divided into 01:00-03:00 LST, 04:00-06:00 LST, 07:00-09:00, 10:00-12:00 LST, 13:00-15:00 LST, 16:00-18:00 LST, 19:00-21:00 LST, 22:00-24:00 LST. The division of months is based on the similarity of wind, rainfall, and cloud patterns

(Kusumawati et al., 2008; Marzuki et al., 2013). Furthermore, aerosol and lightning data display contour maps of lightning strike intensity and AOD for each month and hour category. Contour maps are displayed to determine the distribution of aerosols and lightning on Java Island. Then, AOD and lightning data are interpolated into a $0.5^\circ \times 0.625^\circ$ grid so that both data have the same grid. The relationship between aerosol and lightning is divided into morning (06:00-11:59 LST), afternoon (12:00-17:59 LST), night (18:00-23:59 LST), and

early morning (24:00-05:59 LST) as well as the rainy season (DJF) and dry season (JJA) to be further analyzed using linear regression.

Result and Discussion

Figure 2 shows the lightning distribution on Java Island for the DJF, MAM, JJA, and SON periods.

Lightning in DJF is more abundant than in other periods. The lowest aerosol concentration also occurs in this period (Figure 3). This period is the peak of the rainy season in Java, with more convective clouds (Aldrian et al., 2003; Ramadhan et al., 2022; Saidah et al., 2023). Thus, rain will shorten the dwell time of aerosols in the Earth's atmosphere.

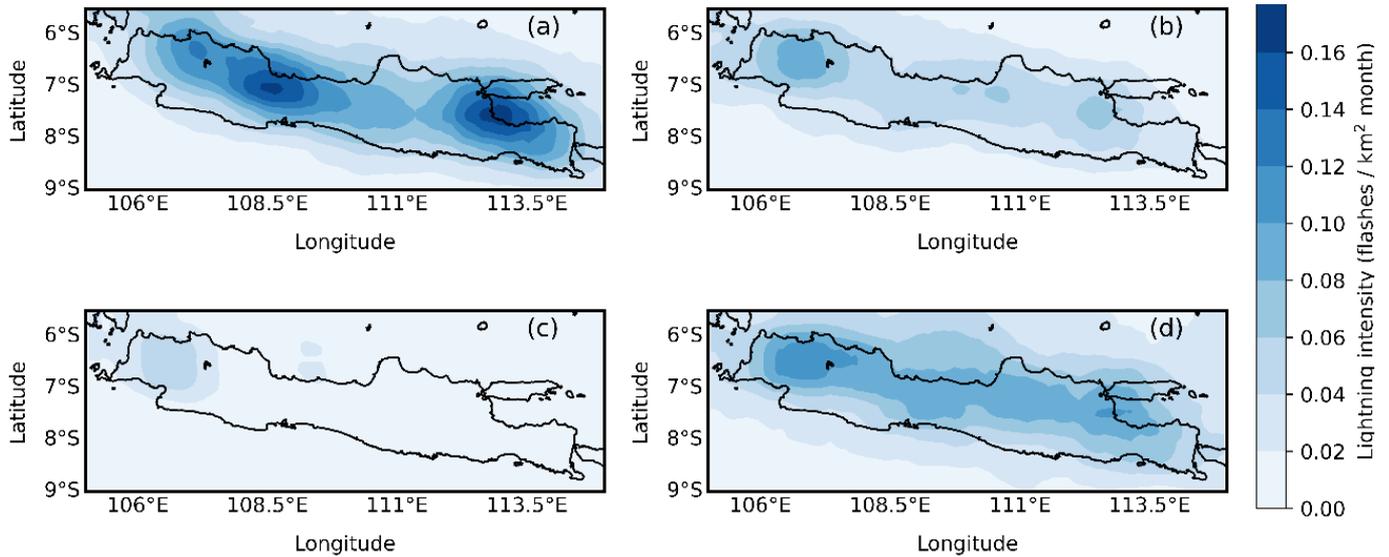


Figure 2. Spatial distribution of lightning averages during (a) DJF, (b) MAM, (c) JJA, (d) SON on Java Island

JJA is a dry month on the island of Java with fewer convective clouds than other months (Marzuki et al., 2013). During JJA, the wind blows from the south (Australia) to the north (Indonesia). The wind only carries a little water vapor, so convective clouds occur

little on the island of Java. The low convective clouds will further reduce the number of lightning occurrences (Figure 2c). Low convective clouds will also reduce rainfall so that the dwell time of aerosols in the atmosphere is longer (Figure 3c).

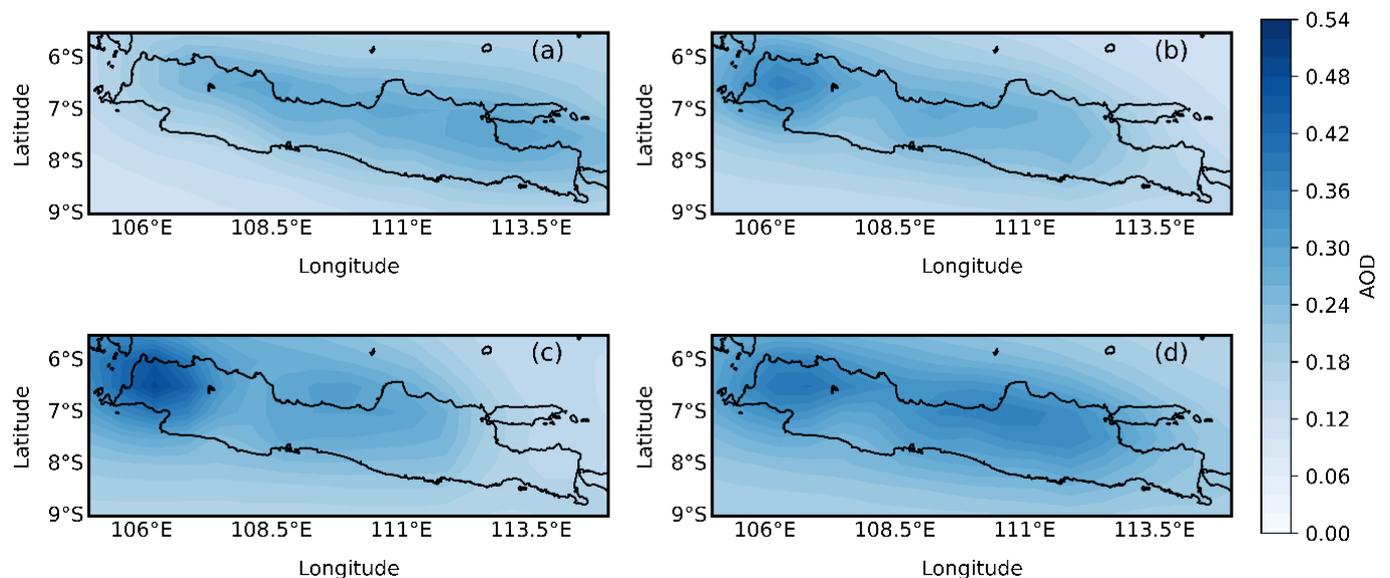


Figure 3. Spatial distribution of mean aerosol (a) DJF, (b) MAM, (c) JJA, (d) SON over Java Island

Aerosol dispersion has a high concentration in the western part of Java Island (Figure 2) due to urban pollution (Nisa et al., 2022). This is consistent with the distribution of lightning strike intensity on Java Island (Figure 3). The increase in lightning strike intensity during DJF (Figure 2a) is preceded by increased aerosols during SON (Figure 3d). This is also seen when the intensity of lightning strikes is quite low observed in

every region on Java Island during JJA (Figure 2c). Aerosol concentrations are lacking in the atmosphere during the rainy season (DJF) (Figure 3a). Aerosols stimulate cloud formation and provide an ideal environment for lightning development. The results obtained in Indonesia are also found in Uttrakand, northern India (Gautam et al., 2022).

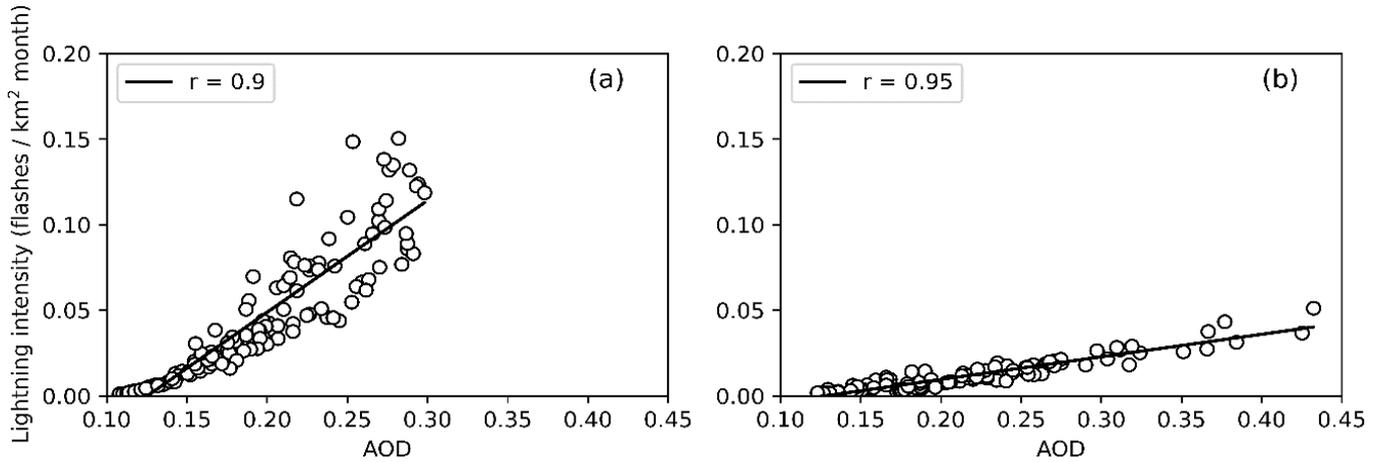


Figure 4. The relationship between lightning and aerosols a) DJF. b) JJA on Java Island

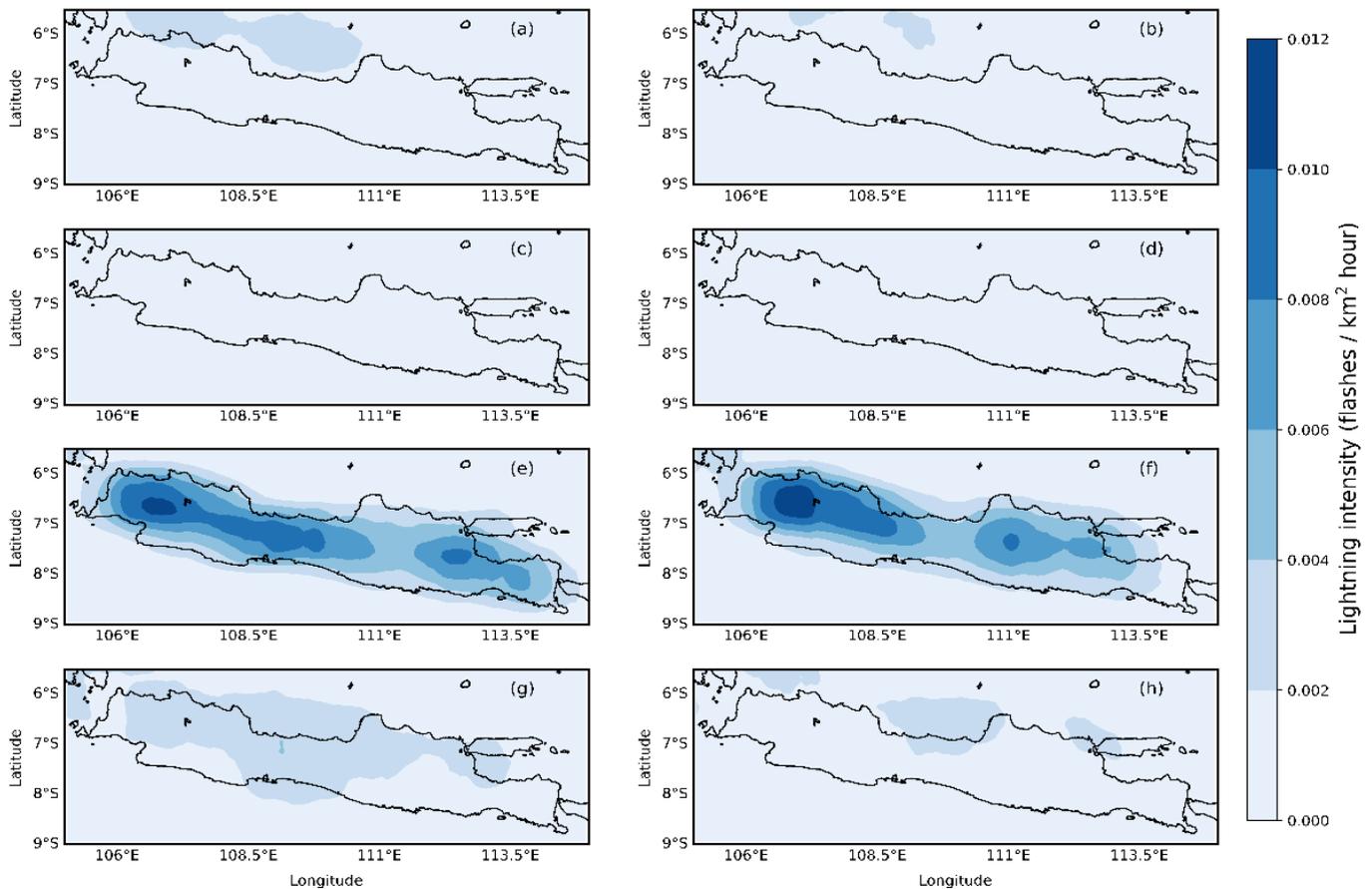


Figure 5. Lightning spatial distribution a) 01:00-03:00 LST. b) 04:00-06:00 LST. c) 07:00-09:00 LST. d) 10:00-12:00 LST. e) 13:00-15:00 LST. f) 16:00-18:00 LST. g) 19:00-21:00 LST. h) 22:00-24:00 LST on Java Island

The relationship between lightning and aerosols for the wet season (DJF) and the dry season (JJA) is given in Figure 4. The correlation coefficient between the wet ($r = 0.9$) and dry ($r = 0.95$) seasons is almost the same. However, the maximum value of each parameter is different. During DJF, lightning strikes are higher than JJA, but aerosols during DJF are lower than during JJA. The difference in convective clouds between the dry and wet seasons causes this difference. But in general, the increase in aerosol levels favors lightning activity in each season.

Figure 5 shows the spatial distribution of lightning strike intensity on Java Island for several time intervals. The intensity of lightning strikes peaks during the afternoon and evening between 13:00-15:00 & 16:00-18:00 LST. This is caused by strong surface heating during the day (Hidayat et al., 1999; Kusumawati et al.,

2008; Nitta et al., 1994). According to Qian et al. (2010) in the morning (01:00-13:00 LST), the wind moves from Java Island towards the sea. Therefore, lightning has decreased. However, during the afternoon and evening (13:00-01:00 LST), sea breezes, gathering from the north and south coasts to the island, head towards the mountainous areas near the south coast (at the peak of the rainy season in the afternoon and evening). The sea breeze carries a lot of water vapor, supporting convection activity (Satyawardhana et al., 2016).

Unlike lightning, aerosols do not show significant diurnal variations (Figure 6). Due to urban pollution, aerosol concentrations are highest in the west of Java Island (Jakarta, small parts of Banten and West Java). This pollution is related to the city's enormous population and rapid economic development (Nisa et al., 2022).

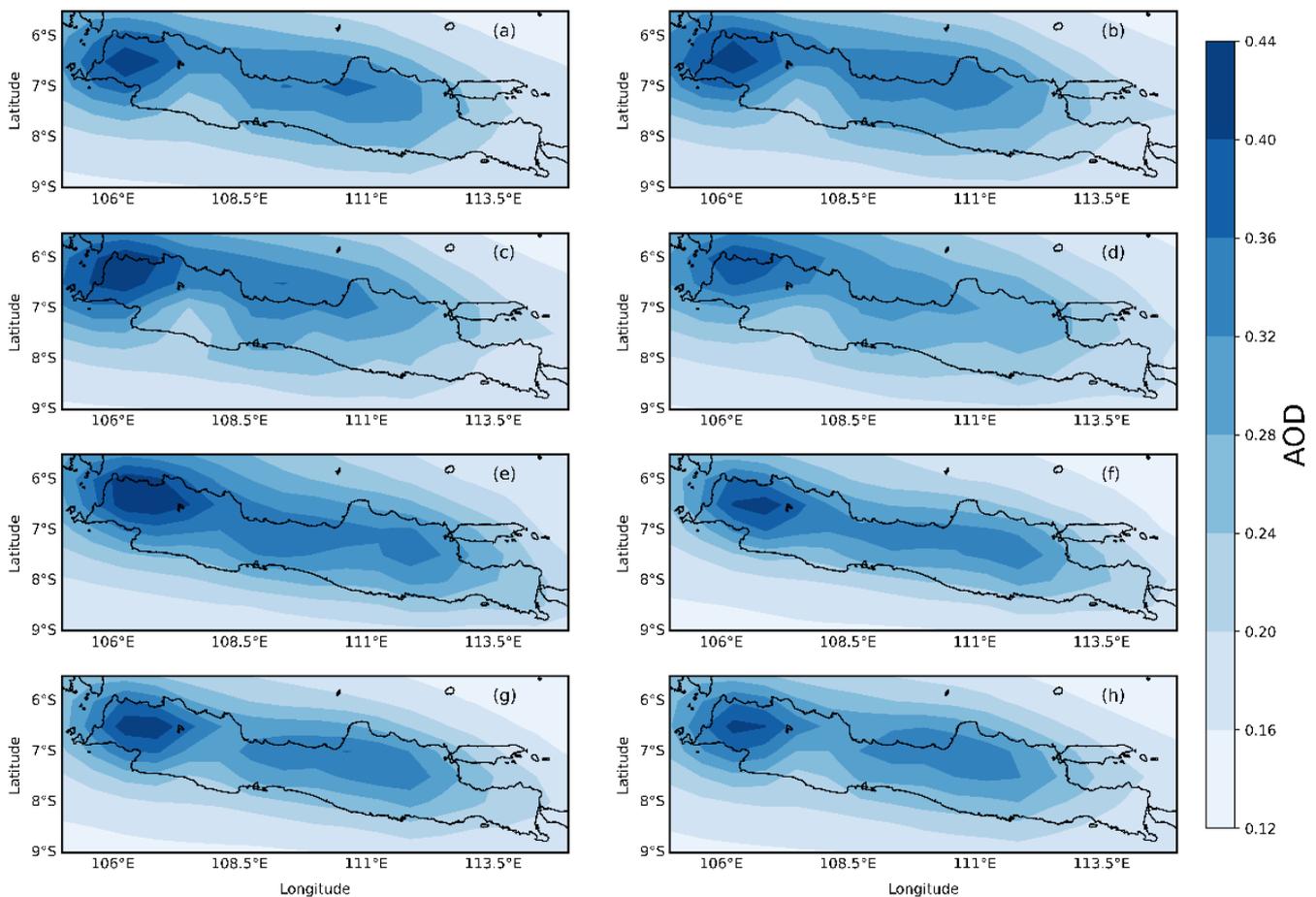


Figure 6. Spatial distribution of aerosol a) 01:00-03:00 LST. b) 04:00-06:00 LST. c) 07:00-09:00 LST. d) 10:00-12:00 LST. e) 13:00-15:00 LST. f) 16:00-18:00 LST. g) 19:00-21:00 LST. h) 22:00-24:00 LST on Java Island

Figure 7 shows the relationship between lightning and aerosols in the morning, afternoon, evening, and early morning on Java Island. The most robust relationship is observed in the afternoon & evening. This follows the diurnal pattern of lightning intensity on Java Island, where the peak occurs in the afternoon and

evening. During the day, the radiative effect of aerosols reaches saturation. Adding aerosols will also increase cloud thickness, cover, and albedo by acting as cloud condensation nuclei, thereby reducing solar radiation reaching the ground. This in turn increases atmospheric stability and inhibits the intensity of lightning strikes

(Wang et al., 2023). However, Java Island is located in the tropics, making the air mass interaction between land and load quite dominant (Ogino et al., 2016). In

addition, the movement of air masses that reaches their peak during the day also affects this (Qian et al., 2010).

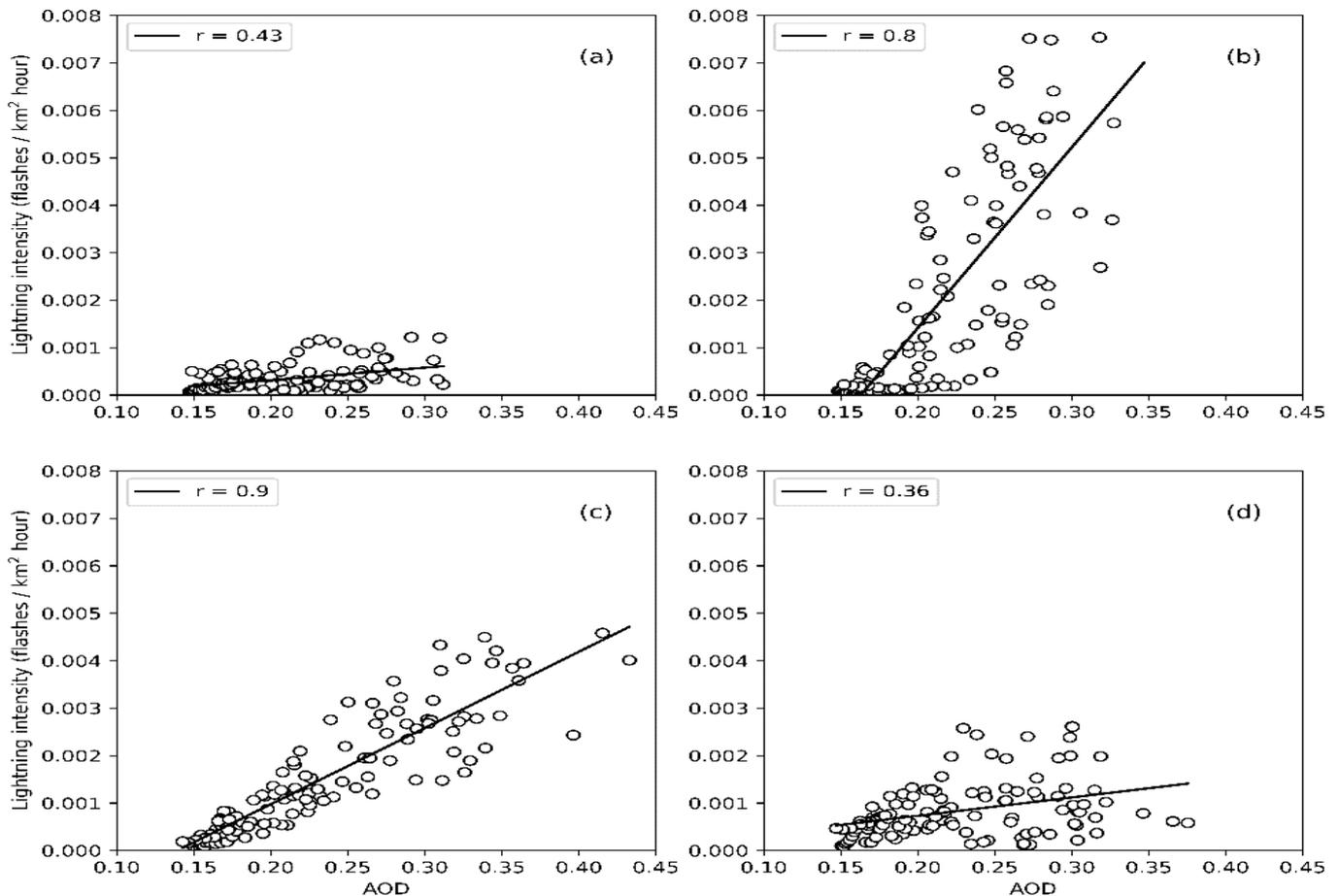


Figure 7. The relationship between lightning and aerosols a) morning (06:00-11:00 LST), b) afternoon (12:00-17:00 LST), c) night (18:00-23:00 LST), and d) early morning (24:00-05:00 LST), over Java Island

At night, the effect of aerosols on surface temperature weakens due to the absence of solar radiation. The increase in aerosol concentration does not inhibit the intensity of lightning strikes. The lower night air temperature makes aerosols more dominant as ice nuclei (IN) (Wang et al., 2023). Ice crystals in the cloud then play a role in the electrification process in the cloud (Wallace et al., 2014). The low correlation between lightning and aerosols in the morning and night is due to the movement of air masses from land to sea (Qian et al., 2010).

Conclusion

The results showed that the relationship between lightning intensity and aerosols on the island of Java has seasonal and diurnal variations. The influence of aerosols and lightning in rainy and dry seasons is relatively stable. However, the effect of aerosols on lightning diurnally changes significantly. The strongest

correlation between aerosol and lightning was recorded during the day ($r = 0.8$) and night ($r = 0.9$). During the day, although the influence of aerosols on radiation reaches the saturation point, land and sea breeze movements play a dominant role. At night, the impact of aerosols on surface temperature is weakened due to the absence of solar radiation, so aerosols help the electrification of clouds through the formation of ice crystals.

Acknowledgments

The authors are grateful to acknowledge the support from Universitas Andalas. We also thank the anonymous reviewers whose critical and constructive comments greatly helped us to prepare an improved and clearer version of this paper. Furthermore, thanks to NASA and EMCWF for TRMM-LIS, MERRA-2 and ERA5 data, respectively.

Author Contributions

Conceptualization, A.R.S., M.V and M.M.; methodology, A.R.S, M.V and M.M; software, A.R.S.; validation, M.M; formal

analysis, A.R.S and M.M.; investigation, A.R.S; resources, A.R.S; data curation, M.V. and M.M; writing—original draft preparation, A.R.S.; writing—review and editing, A.R.S, M.V and M.M; visualization, A.R.S.; supervision, M.V. and M.M; project administration, A.R.S and M.V; funding acquisition, M.V. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Universitas Andalas (T/41/UN16.19/PT.01.03/IS-RPT/2023).

Conflicts of Interest

The authors declare no conflict of interest.

References

- Aldrian, E., & Dwi Susanto, R. (2003). Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *International Journal of Climatology*, 23(12), 1435–1452. <https://doi.org/10.1002/joc.950>
- Altaratz, O., Kucienska, B., Kostinski, A., Raga, G. B., & Koren, I. (2017). Global association of aerosol with flash density of intense lightning. *Environmental Research Letters*, 12, 114037. <https://doi.org/10.1088/1748-9326/aa922b>
- BPS. (2021). *Hasil Sensus Penduduk 2020*. Retrieved from <https://sensus.bps.go.id/main/index/sp2020>
- Chen, T., Li, Z., A. Kahn, R., Zhao, C., Rosenfeld, D., Guo, J., Han, W., & Chen, D. (2021). Potential impact of aerosols on convective clouds revealed by Himawari-8 observations over different terrain types in eastern China. *Atmospheric Chemistry and Physics*, 21(8), 6199–6220. <https://doi.org/10.5194/acp-21-6199-2021>
- Dayeh, M. A., Farahat, A., Ismail-Aldayeh, H., & Abuelgasim, A. (2021). Effects of aerosols on lightning activity over the Arabian Peninsula. *Atmospheric Research*, 261, 105723. <https://doi.org/10.1016/j.atmosres.2021.105723>
- Dewan, A., Ongee, E. T., Rafiuddin, M., Rahman, M. M., & Mahmood, R. (2018). Lightning activity associated with precipitation and CAPE over Bangladesh. *International Journal of Climatology*, 38(4), 1649–1660. <https://doi.org/10.1002/joc.5286>
- Gautam, A. S., Joshi, A., Chandra, S., Dumka, U. C., Siingh, D., & Singh, R. P. (2022). Relationship between Lightning and Aerosol Optical Depth over the Uttarakhand Region in India: Thermodynamic Perspective. *Urban Science*, 6(4), 70. <https://doi.org/10.3390/urbansci6040070>
- Hidayat, S., & Ishii, M. (1999). Diurnal variation of lightning characteristics around Java Island. *Journal of Geophysical Research Atmospheres*, 104(D20), 24449–24454. <https://doi.org/10.1029/1999JD900769>
- Kaufman, Y. J., Koren, I., Remer, L. A., Rosenfeld, D., & Rudich, Y. (2005). The effect of smoke, dust, and pollution aerosol on shallow cloud development over the Atlantic Ocean. *Proceedings of the National Academy of Sciences*, 102(32), 11207–11212. <https://doi.org/10.1073/pnas.050519110>
- Kusumaningtyas, S. D. A., Tonokura, K., Aldrian, E., Giles, D. M., Holben, B. N., Gunawan, D., Lestari, P., & Iriana, W. (2022). Aerosols optical and radiative properties in Indonesia based on AERONET version 3. *Atmospheric Environment*, 282(2), 119174. <https://doi.org/10.1016/j.atmosenv.2022.119174>
- Kusumawati, Y., Effendy, S., & Aldrian, E. (2008). Variasi Spasial dan Temporal Hujan Konvektif di Pulau Jawa Berdasarkan Citra Satelit. *Agromet*, 22(1). <https://doi.org/10.29244/j.agromet.22.1.%25p>
- Marzuki, Hashiguchi, H., Yamamoto, M. K., Yamamoto, M., Mori, S., Yamanaka, M. D., Carbone, R. E., & Tuttle, J. D. (2013). Cloud episode propagation over the Indonesian Maritime Continent from 10 years of infrared brightness temperature observations. *Atmospheric Research*, 120–121, 268–286. <https://doi.org/10.1016/j.atmosres.2012.09.004>
- Nisa, A., Chel, M., Ooi, G., Juneng, L., Isra, M. A., Hernandi, R., & Tangang, F. (2022). Spatio-temporal analysis of aerosol optical depth using rotated empirical orthogonal function over the Maritime Continent from 2001 to 2020. *Atmospheric Environment*, 290, 119356. <https://doi.org/10.1016/j.atmosenv.2022.119356>
- Nitta, T., & Sakine, S. (1994). Diurnal variation of convective activity over the tropical western Pacific. *Journal of the Meteorological Society of Japan*, 72(5), 627–641. https://doi.org/10.2151/jmsj1965.72.5_627
- Ogino, S. Y., Yamanaka, M. D., Mori, S., & Matsumoto, J. (2016). How Much is the Precipitation Amount over the Tropical Coastal Region? *Journal of Climate*, 29(3), 1231–1236. <https://doi.org/10.1175/JCLI-D-15-0484.1>
- Oulkar, S., Siingh, D., Saha, U., & Kamra, A. K. (2019). Distribution of lightning in relation to topography and vegetation cover over the dry and moist regions in the Himalayas. *Journal of Earth System Science*, 128(7). <https://doi.org/10.1007/s12040-019-1203-9>
- Qian, J.-H., Robertson, A. W., & Moron, V. (2010). Interactions among ENSO, the Monsoon, and Diurnal Cycle in Rainfall Variability over Java,

- Indonesia. *Journal of the Atmospheric Sciences*, 67(11), 3509–3524. <https://doi.org/10.1175/2010JAS3348.1>
- Ramadhan, R., Marzuki, M., Yusnaini, H., Ningsih, A. P., Hashiguchi, H., Shimomai, T., Vonnisa, M., Ulfah, S., Suryanto, W., & Sholihun, S. (2022). Ground Validation of GPM IMERG-F Precipitation Products with the Point Rain Gauge Records on the Extreme Rainfall Over a Mountainous Area of Sumatra Island. *Jurnal Penelitian Pendidikan IPA*, 8(1), 163–170. <https://doi.org/10.29303/jppipa.v8i1.1155>
- Saidah, H., Hanifah, L., & Negara, I. D. G. J. (2023). Climate Change Impact on Drought Characteristics in North Lombok Regency. *Jurnal Penelitian Pendidikan IPA*, 9(5), 2332–2340. <https://doi.org/10.29303/jppipa.v9i5.2380>
- Satyawardhana, H., & Yulihastin, E. (2016). Interaksi El Nino, Monsun, dan Topografi Lokal Terhadap Anomali Hujan di Pulau Jawa. *Pusat Sains Dan Teknologi Atmosfer*, 60–74. Retrieved from https://www.researchgate.net/publication/309242925_Interaksi_El_Nino_Monsun_dan_Topografi_Lokal_Terdapat_Anomali_Hujan_di_Pulau_Jawa
- Seinfeld, J. H., & Pandis, S. N. (2016). *Atmospheric Chemistry and Physics from Air Pollution to Climate Change* (3rd ed.). John Wiley & Sons, Inc.
- Shi, Z., Wang, H., Tan, Y., Li, L., & Li, C. (2020). Influence of aerosols on lightning activities in central eastern parts of China. *Atmospheric Science Letters*, 21(2), 1–10. <https://doi.org/10.1002/asl.957>
- Siingh, D., Kumar, P. R., Kulkarni, M. N., Singh, R. P., & Singh, A. K. (2013). Lightning, convective rain and solar activity - Over the South/Southeast Asia. *Atmospheric Research*, 120–121, 99–111. <https://doi.org/10.1016/j.atmosres.2012.07.026>
- Thornton, J. A., Virts, K. S., Holzworth, R. H., & Mitchell, T. P. (2017). Lightning enhancement over major oceanic shipping lanes. *Geophysical Research Letters*, 44(17), 9102–9111. <https://doi.org/10.1002/2017GL074982>
- Tippett, M. K., Allen, J. T., Gensini, V. A., & Brooks, H. E. (2015). Climate and Hazardous Convective Weather. *Current Climate Change Reports*, 1(2), 60–73. <https://doi.org/10.1007/s40641-015-0006-6>
- Uman, M. A. (2011). *Lightning*. Dover Publication, Inc.
- Wallace, J. M., & Hobbs, P. V. (2014). Atmospheric science: an introductory survey. In *University of Washington* (2nd ed.).
- Wang, H., Tan, Y., Shi, Z., Yang, N., & Zheng, T. (2023). Diurnal differences in the effect of aerosols on cloud-to-ground lightning in the Sichuan Basin. *Atmospheric Chemistry and Physics*, 23(4), 2843–2857. <https://doi.org/10.5194/acp-23-2843-2023>
- Yadava, P. K., Soni, M., Verma, S., Kumar, H., Sharma, A., & Payra, S. (2020). The major lightning regions and associated casualties over India. *Natural Hazards*, 101(1), 217–229. <https://doi.org/10.1007/s11069-020-03870-8>
- Yair, Y. (2018). Lightning hazards to human societies in a changing climate. *Environmental Research Letters*, 13(12). <https://doi.org/10.1088/1748-9326/aaea86>
- Zhao, P., Li, Z., Xiao, H., Wu, F., Zheng, Y., Cribb, M. C., Jin, X., & Zhou, Y. (2020). Distinct aerosol effects on cloud-to-ground lightning in the plateau and basin regions of Sichuan, Southwest China. *Atmospheric Chemistry and Physics*, 20(21), 13379–13397. <https://doi.org/10.5194/acp-20-13379-2020>
- Zhao, P., Zhang, Y., Liu, C., Zhang, P., Xiao, H., & Zhou, Y. (2022). Potential Relationship Between Aerosols and Positive Cloud-to-Ground Lightning During the Warm Season in Sichuan, Southwest China. *Frontiers in Environmental Science*, 10, 1–11. <https://doi.org/10.3389/fenvs.2022.945100>
- Zheng, D., Zhang, Y., Meng, Q., Chen, L., & Dan, J. (2016). Climatological comparison of small- and large-current cloud-to-ground lightning flashes over Southern China. *Journal of Climate*, 29(8), 2831–2848. <https://doi.org/10.1175/JCLI-D-15-0386.1>