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Seasonal and Diurnal Variations of Lightning Activity Over West Sumatra and Its Correlation with Precipitation Type

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Abstract

Seasonal and diurnal variations of lightning activity over West Sumatra have been investigated using observations of Tropical Rainfall Measuring Mission–Lightning Imaging Sensor (TRMM–LIS) over a 16-year period. This study also used TRMM 3B43 and 2A25 data to observe the correlation between lightning activity with rainfall and precipitation type. Results show that lightning occurs more frequently over land than over ocean and coastal areas, in contrast to total rainfall, which is higher over ocean and coastal areas. The lightning pattern is similar to the convective rainfall (particularly deep convective) pattern, which indicates that the majority of lightning in West Sumatra is associated with deep convective rain. The lightning intensity in Indonesia during the convection period, namely, December–January–February and September–October–November, is higher than that during other periods. The diurnal cycle of lightning coincides with the diurnal cycle of cloud migration from the ocean to inland Sumatra, as reported in previous research. Lightning and deep convective precipitation are dominant during the day and evening (16.00–20.00 Local Standard Time [LST]), particularly over land. Stratiform precipitation occurs more frequently from afternoon to early morning (16.00–04.00 LST) over land and at 00.00–12.00 LST over the ocean.

Abstrak

Variasi Musiman dan Diurnal Petir di Sumatera Barat dan Korelasinya dengan Tipe Hujan. Variasi musiman dan diurnal petir di Sumatera Barat telah diteliti menggunakan data *Tropical Rainfall Measuring Mission–Lightning Imaging Sensor* (TRMM–LIS) selama 16 tahun. Penelitian ini juga menggunakan data TRMM 3B43 dan 2A25 untuk melihat hubungan antara petir dengan curah hujan dan tipe hujan. Hasil penelitian menunjukkan bahwa petir lebih sering terjadi di daratan daripada di lautan dan pantai berbeda dengan total curah hujan. Pola petir sama dengan pola curah hujan konkevtif khususnya hujan konvektif dalam (deep convective) yang menandakan bahwa mayoritas petir di Sumatera Barat diikuti oleh hujan konvektif dalam. Intensitas petir di Indonesia selama periode konveksi yaitu Desember-Januari-Februari dan September-Oktober-November lebih tinggi daripada periode lainnya.Pola diurnal petir di Sumatera Barat bertepatan dengan pola pergerakan awan dari lauatan ke daratan Sumatera, sebagaimana dilaporkan oleh penelitian sebelumnya. Petir dan hujan konvektif dalam dominan terjadi pada siang dan malam hari (16.00-20.00 WIB), khususnya di daratan. Hujan stratiform lebih sering terjadi pada sore hingga dini hari (16.00-04.00 WIB) di daratan dan 00.000-12.00 WIB di lautan.

Keywords: lightning; rainfall rate; rain type; West Sumatra; TRMM

Introduction

Lightning is an atmospheric phenomenon that can harm or kill humans [1,2], damage electrical grids and telecommunication networks, and disrupt airline flights [3]. In the tropics, the impact of lightning is extremely high because the lightning flash density, especially in the equatorial region, is higher than that in the middle latitude area. High temperature generates a high evaporation rate such that many convective clouds associated with lightning activity occur frequently in tropical regions [4].

Improved knowledge of local convective precipitation systems, particularly the relationship between lightning and rainfall, can enhance the estimation of convective rainfall in areas with poor radar coverage [5]. Therefore, many researchers have investigated the correlation between lightning and precipitation in different climatic conditions. For example, the relationship between convective precipitation and cloud-to-ground (CG) lightning in the Iberian Peninsula has been investigated using 1992–1994 data, which indicate that convective precipitation and CG lightning have a similar spatial distribution [7]. Most lightning occurrences are associated with convective rain [8]. The relationship between lightning and rainfall in the Indian Ocean, Maritime Continent, Western Pacific, and South Pacific Convergence Zone has been studied using 2007–2010 data of several instruments [9]. CG lightning, which is usually in the form of negative flashes, is mostly produced in the deep convective portion that also generates convective rain type. Some lightning flashes that occur in the stratiform portion are disproportionately positive.

Sumatra is located at the eastern edge of the Indian Ocean and plays an important role in global convection because of its unique position and topography. The precipitation system in Sumatra has strong inter-annual, seasonal [9], and intra-seasonal variations [10]. Moreover, the diurnal cycle of precipitation induced by land–sea breeze circulation is also prominent [11]. Similar to the precipitation system, the climatology of global lightning, including that in Sumatra, exhibits a diurnal pattern in which the lightning flash density is higher during the night than during the day [12]. The lightning also has strong intra-seasonal variation in terms of Madden–Julian oscillation [10]. Although research has been conducted on lightning activity in Sumatra, only one study has analyzed lightning characteristics in West Sumatra [13] and the study is only based on two-month observations. Therefore, we further analyzed the spatial and temporal distributions of lightning in West Sumatra using a longer data period. The relationship between lightning and rain type in West Sumatra has never been investigated; therefore, we will investigate this relationship qualitatively, particularly on a seasonal and diurnal variation basis.

Materials and Methods

This study used the lightning data from the Tropical Rainfall Measuring Mission–Lightning Imaging Sensor (TRMM–LIS) satellite for 16-year observation from January 1998 to December 2013. The data have 0.1^o spatial resolution with monthly and hourly temporal resolutions. The monthly rainfall of TRMM 3B43 and hourly rainfall of TRMM 3B42 with spatial resolution 0.25^o x 0.25^o from the aforementioned period were used to observe the seasonal and diurnal variations of total rainfall. In addition, TRMM 2A25 data were used to observe the seasonal and diurnal variations of rain-type occurrence over West Sumatra. The data were gridded into 0.1^o x 0.1^o latitude and longitude boxes. To observe the seasonal variation, the data were classified into DJF (December, January, February), MAM (March, April, May), JJA (June, July, August), and SON (September, October, November). The classification is based on the similarity of convective activity in each month [14]. Furthermore, the diurnal variation was investigated by grouping the TRMM 3B42, LIS, and 2A25 data into 3- and 4-hour intervals, respectively.

Results and Discussion

Climatology of Precipitation, Lightning, and Rain Type. Figure 1 shows the average of rainfall rate (a), lightning (b), stratiform rain-type percentage (c), and deep convective rain-type percentage (d) in West Sumatra from 16-year observation of TRMM satellite (1998–2013). In general, mean rainfall is higher over the ocean around Mentawai Island (coastal region) than on land. The ocean precipitation is dominated by stratiform rain (Figure 1c). The ocean environment appears more efficient in the production of stratiform precipitation through either the sustainability of convection by a warm, moist boundary layer with only a weak diurnal variation and/or by the near-moist adiabatic stratification of the free atmosphere. Factors such as wind shear and relative humidity of the large-scale environment can also affect the production of stratiform rain [15].

The lightning distribution (Figure 1b) has a similar spatial distribution pattern with deep convective rain type (Figure 1d), which is consistent with previous study [8]. The intensity of lightning in West Sumatra varies from one district to another district. In general, the further a district is from the sea, the higher the intensity of lightning is. The intensity of the lightning more than 40 flash/km^2/year was observed in Pasaman, 50 Kota, Sijunjung, Solok, South Solok, and Pesisir Selatan. These districts, except Pesisir Selatan, are far from the sea. Mentawai Island district and the sea around West Sumatra have low lightning intensity, i.e., less than 5 flash/km^2/year. The difference between lightning distribution over land and sea in West Sumatra can be due to two factors. First, the mainland has higher topography than the ocean and the convective clouds that produce lightning occur frequently at higher topography [16]. In West Sumatra, several plateaus are part of the Barisan mountain range. Second, lightning occurs more frequently over land than ocean because daily sunshine heats up the land surface faster than the ocean. The heated surface heats the air, and added hot air leads to stronger convection, thunderstorms, and lightning [17]. Interaction between air masses of different temperatures stimulates the storms and lightning [18].

Seasonal Variation of Precipitation, Lightning, and Rain Type. Figure 2 shows the seasonal variation of precipitation in West Sumatra for DJF, MAM, JJA, and SON. In general, high rainfall rate was observed

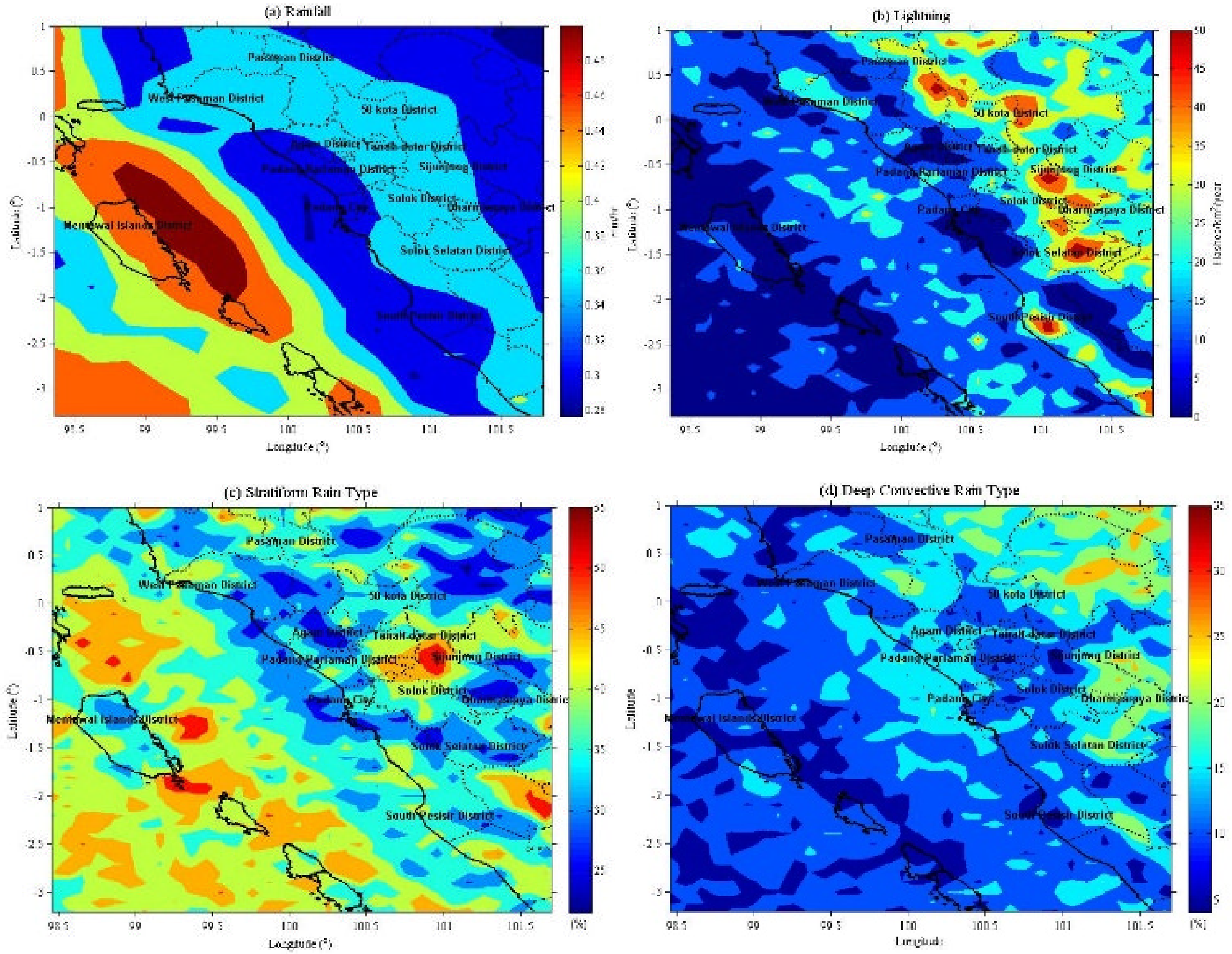

Figure 1. Climatology of Mean Rainfall Rate from TRMM 3B43: (a) Lightning from TRMM-LIS, (b) Stratiform, (c) Deep Convective Rain Type from TRMM 2A25, and (d) Over West Sumatra during 1998–2013. Some Districts in West Sumatra are also Indicated in the Figure

during all months. However, rainfall in West Sumatra is higher during DJF and MAM, consistent with some previous studies [19, 20]. Rainfall in West Sumatra has two peaks, i.e., from December to January and from April to May. Total rainfall for all months was higher around the coastal region than in the mainland, which is consistent with a previous study that found that 34% of the total rainfall in the tropics occurs in coastal areas within 300 km of the coastline [20]. The rainfall pattern is slightly different from the pattern of lightning (Figure 3) in which the lightning intensity during SON is higher than during MAM. On the other hand, rainfall over land during SON is much smaller than that during MAM. Thus, many rainfall events during the MAM period are probably not associated with lightning activity.

Figure 3 shows a seasonal variation of lightning in West Sumatra for DJF, MAM, JJA, and SON. In general, lightning was observed during all months. The intensity of the lightning during DJF and SON were higher than during the MAM and JJA periods. This pattern is consistent with the period of convection in Indonesia. The convection period usually occurs when the wind blowing eastward is dominant and it occurs during DJF. During SON, strong winds are only dominant in the western part of Indonesia so that convective clouds are only dominant in Sumatra and Kalimantan. JJA is a dry period in Indonesia with few convective clouds. During JJA, the wind blows from south (Australia) to north (Indonesia). As the wind passes through only a small part of the sea during JJA, the wind only brings a small amount of moisture, which is why few convective clouds occur in Indonesia [14].

Figure 4 shows the seasonal variation of stratiform rain type. The stratiform rain occurs more frequently over the ocean than on land. Lightning is primarily located in deep convective areas and occurs less frequently in stratiform areas [7]. This is the reason why small lightning density is observed over the ocean around West Sumatra (Figure 1).

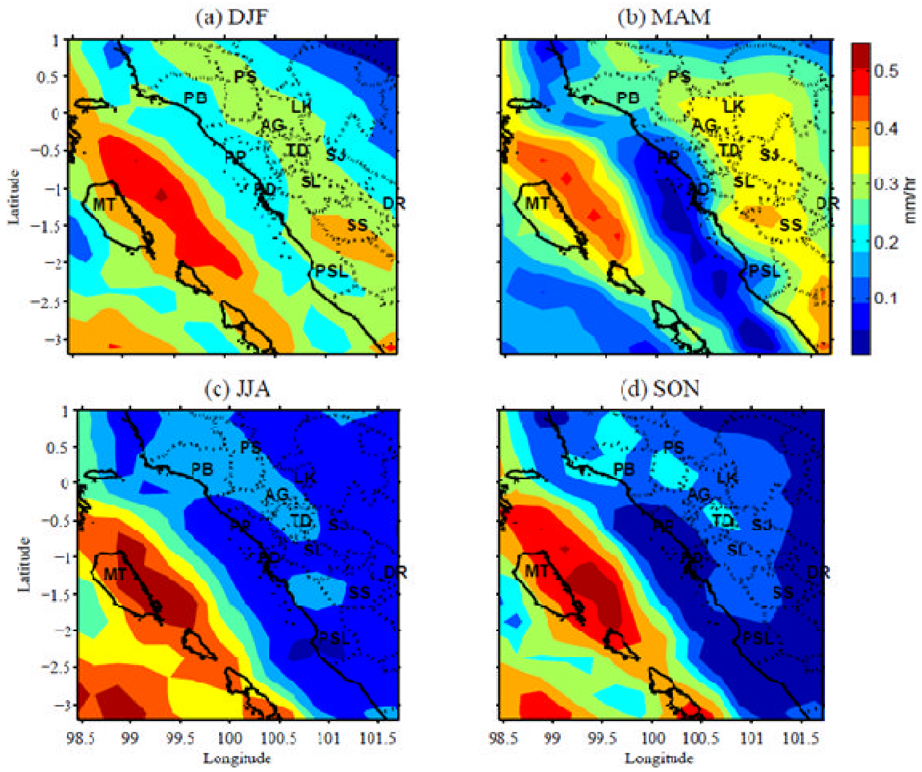

Figure 2. Seasonal Distribution of Mean Rainfall Rate Over West Sumatra during 1998–2013. Abbreviations Indicate the Districts in West Sumatra, i.e., MT is Mentawai, PSL is Pesisir Selatan, SS is South Solok, SL is Solok, PD is Padang, PP is Padang Pariaman, TD is Tanah Datar, SJ is Sijunjung, AG is Agam, LK is Lima Puluh Kota, PB is Pasaman Barat, and PS is Pasaman

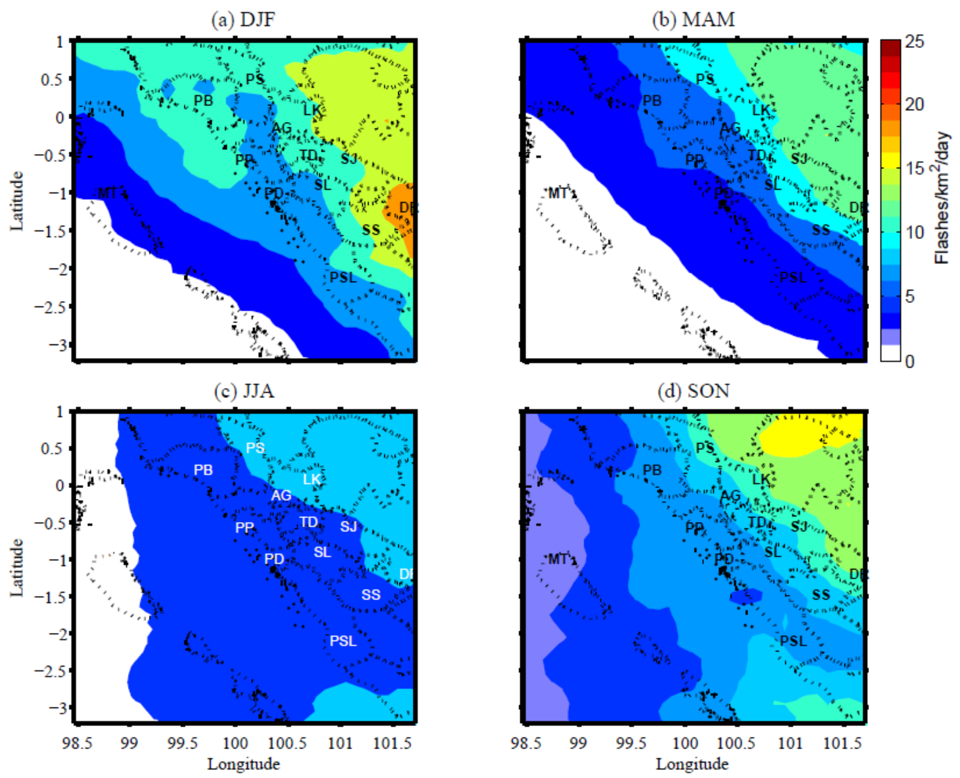

Figure 3. Seasonal Distribution of Lightning Activity in West Sumatra during 1998–2013. The Abbreviations are the same as those in Figure 2

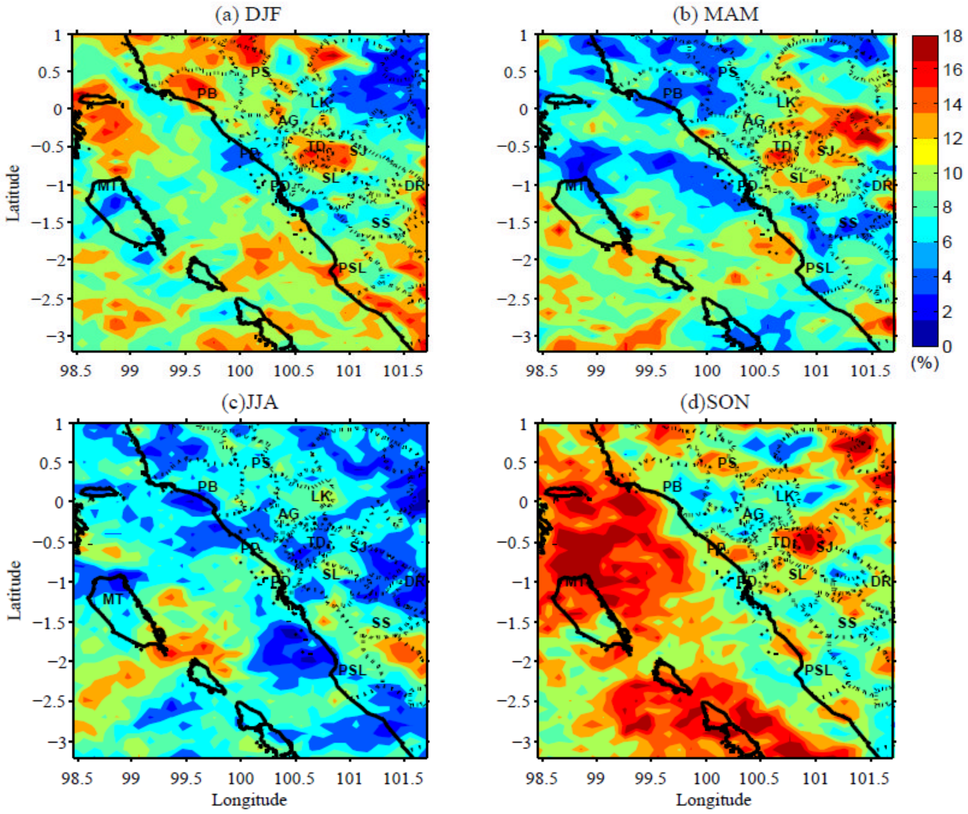

Figure 4. Seasonal Distribution of Stratiform Rain-type Occurrence Frequency in West Sumatra during 1998–2013. The Abbreviations are the same as those in Figure 2

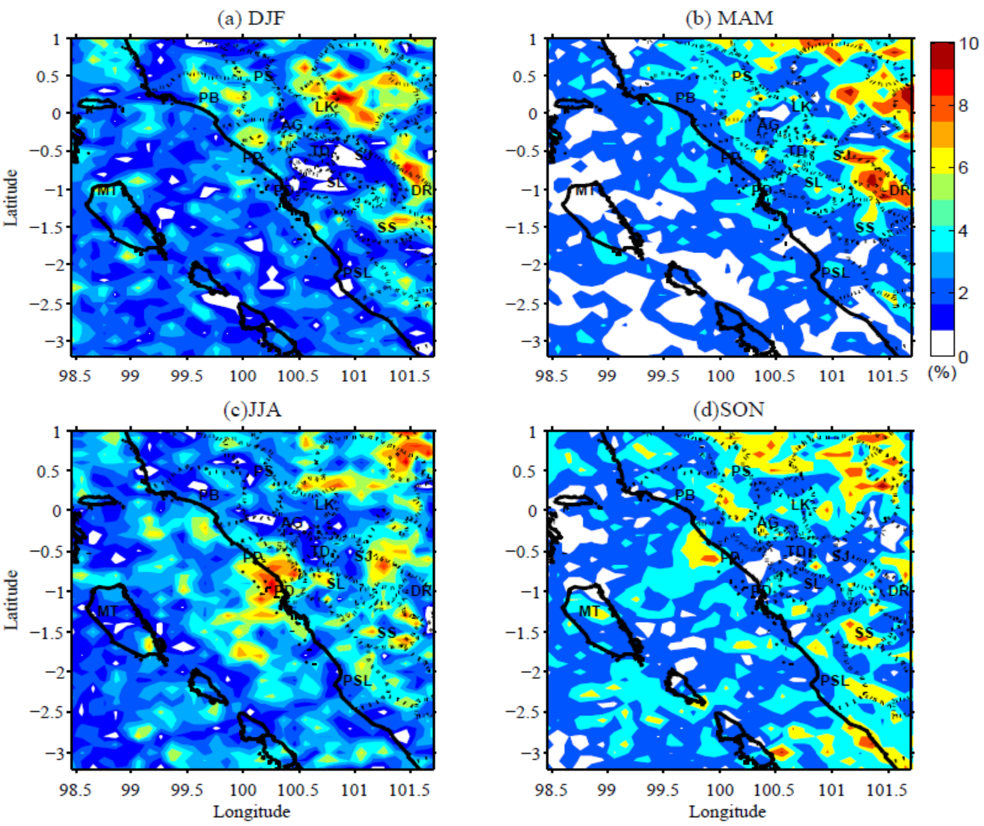

Figure 5. Seasonal Distribution of Convective Rain-type Occurrence Frequency in West Sumatra during 1998–2013. The Abbreviations are the same as those in Figure 2

The lightning activity has patterns similar to that of convective rain type where both lightning and convective rainfall occur more frequently on land than over the ocean during all months (Figure 5).

Figure 6 shows the diurnal variation of three hourly total rainfalls obtained from TRMM 3B42 data. The difference in the rainfall is prominent between oceanic and continental rainfall regimes. Over the ocean, the rainfall is generally higher than that on land, with peaks occurring from late evening to noon of the next day (22.00–12.00 LST), whereas the coastal region has peaks that occur from afternoon to late evening (16.00–23.00 LST). Maximum precipitation over land is observed during afternoon (16.00–19.00 LST). These results are common characteristics of tropical precipitation [17]. Rainfall anomalies begin to occur along the coastline from morning to noon, moving to the mainland, and disappearing at night in the coastal land. Other rainfall begins to occur along the coastline from noon to midnight, moving abroad, and disappearing in the afternoon on the beach [11].

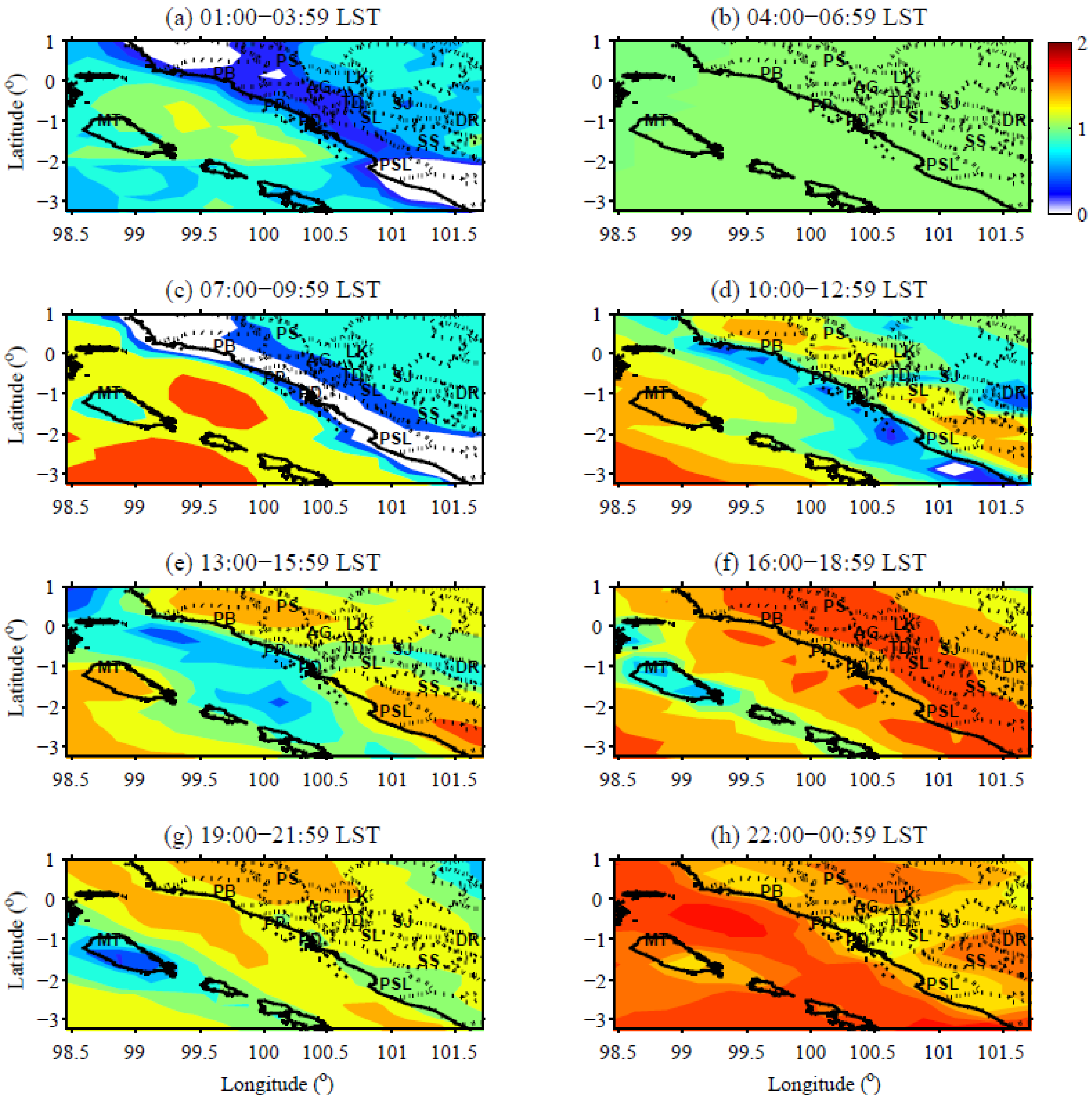

Figure 6. Diurnal Variations of Mean Rainfall Rate Over West Sumatra during 1998–2013. LST Indicates Local Standard Time (UTC + 7)

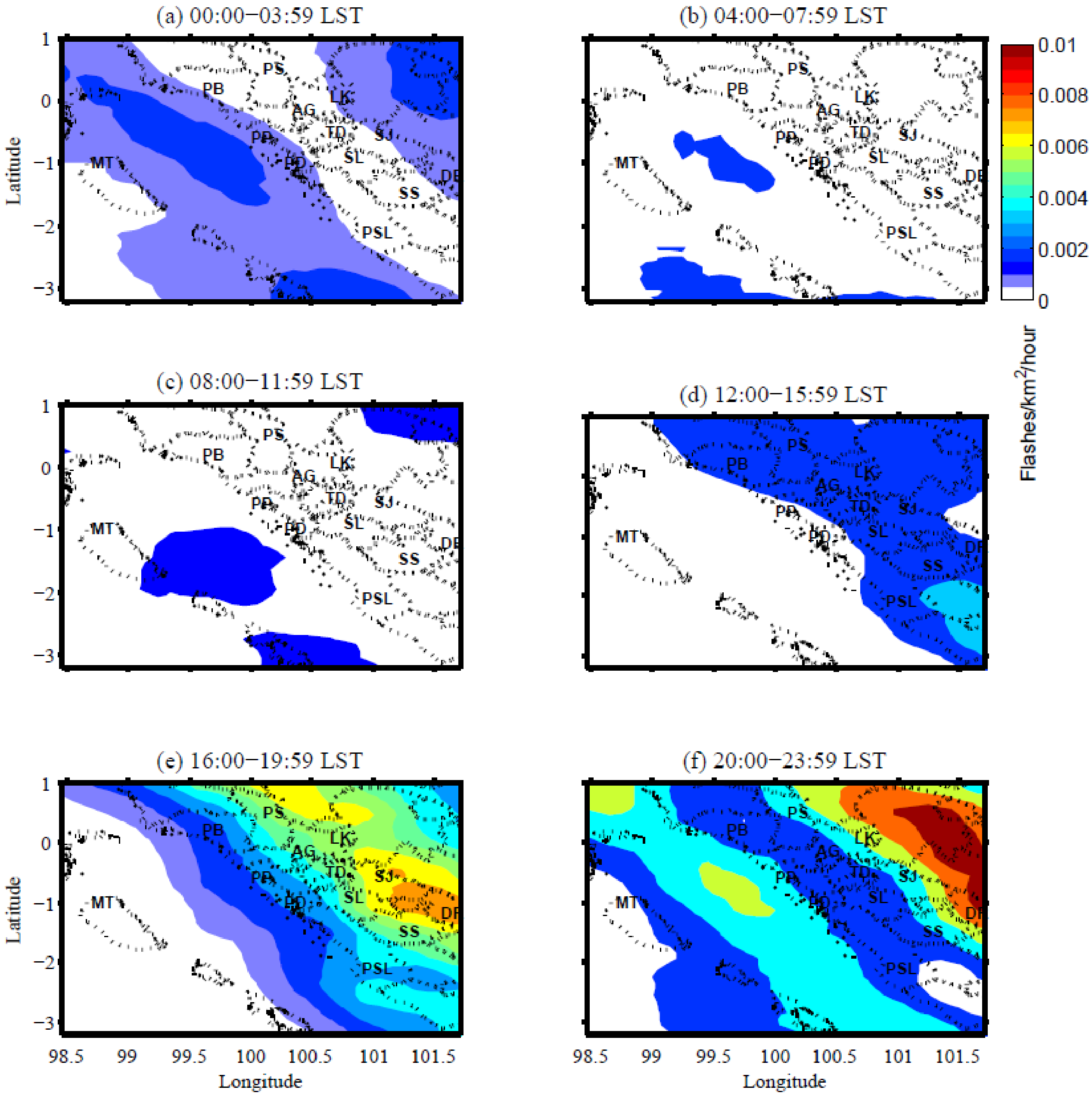

Figure 7. Diurnal Variations of Lightning in West Sumatra during 1998–2013. The Abbreviations are the same as those in Figure 6

Figure 7 shows the diurnal distribution of lightning in West Sumatra. The data were grouped into four-hour observation periods. During 00.00–04.00 LST, a high number of lightning occur around the coastal area. This condition coincides with the migration of clouds from the Sumatra mainland to the ocean and the arrival of sea breeze from the Indian Ocean [11]. At 04.00–08.00 LST, few clouds are present so that the lightning number is extremely small. Lightning again occurs over the ocean at 08.00–12.00 LST, coinciding with the increase of sunlight intensity. Clouds formed over the ocean move eastward to Sumatra and reach the mainland at 13.00 LST, with a peak at approximately 17.00–18.00 LST [10]. Therefore, the peak of lightning intensity is also observed during these periods. Convective clouds persist over Sumatra for several hours due to a blocking process on Bukit Barisan [11]. Therefore, the lightning intensity is also high for several hours in West Sumatra (Figure 7e–f). At night (Figure 7f), the clouds in mainland Sumatra begin to migrate to the sea along with the movement of winds from land to ocean. Therefore, the number of lightning on the coastal region and open ocean start to increase during the night. We can conclude that the diurnal cycle pattern of lightning in West Sumatra coincides with the diurnal cycle of cloud migration from sea to land, as reported in previous studies [11]. High lightning intensity in the mainland occurs in the afternoon and evening, coinciding with the maximum emergence of cloud convective in the mainland. These results are consistent with those of a previous study on lightning activity over Sumatra [13].

Figures 8 and 9 show the diurnal variation of stratiform and deep convective rain types, respectively. The percentage of stratiform rain occurrence frequency is much higher than that of deep convective rain. Stratiform precipitation occurs more frequently from the afternoon to early morning (16.00–04.00 LST), whereas deep convective precipitation occurs at daytime to early evening (12.00–20.00 LST). Thus, most precipitation in West Sumatra is from a well-organized convective system in which convective rain is frequently followed by stratiform rain.

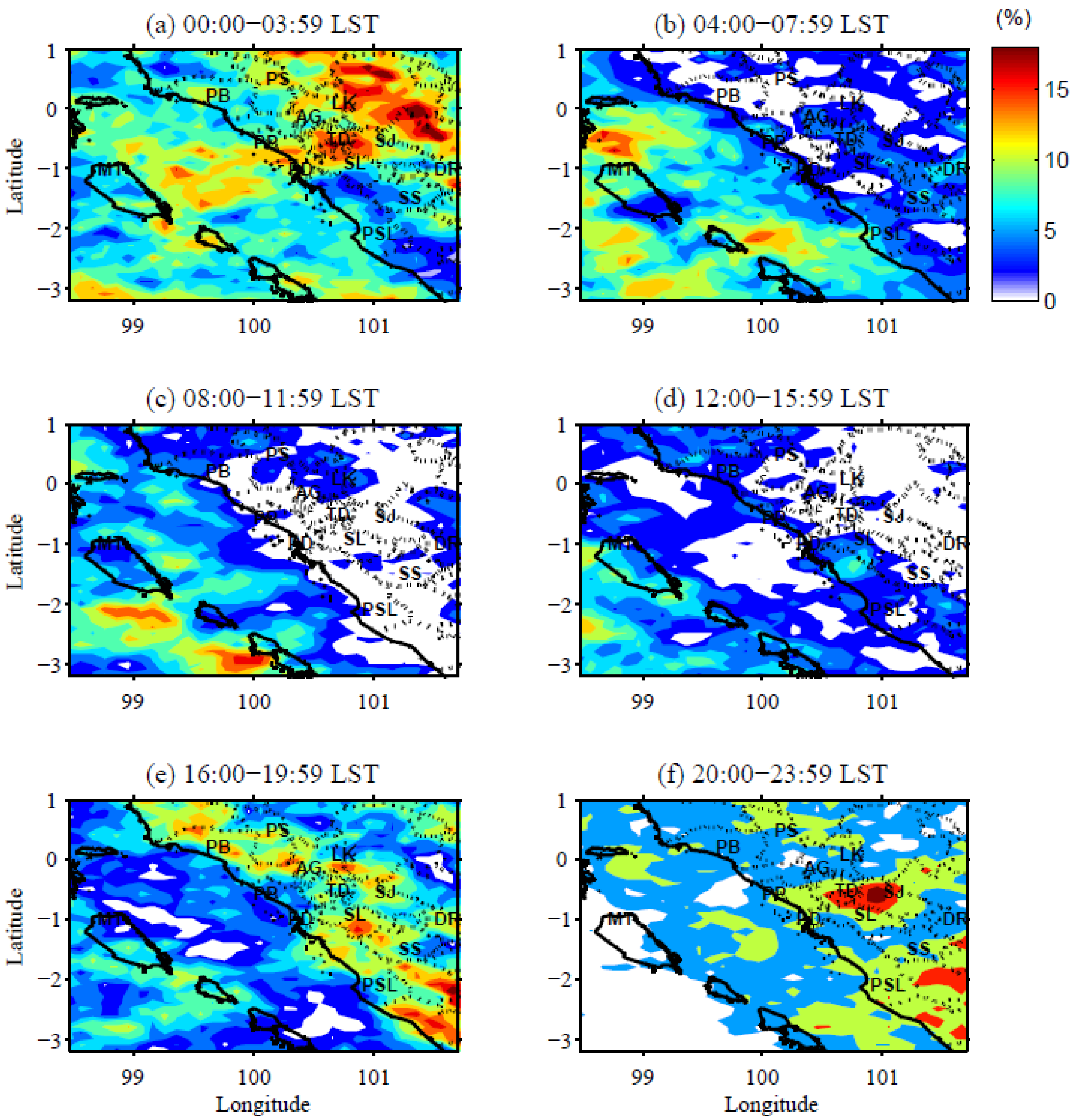

Figure 8. Diurnal Variation of Stratiform Rain Occurrence Frequency in West Sumatra during 1998–2013. The Abbreviations are the same as those in Figure 6

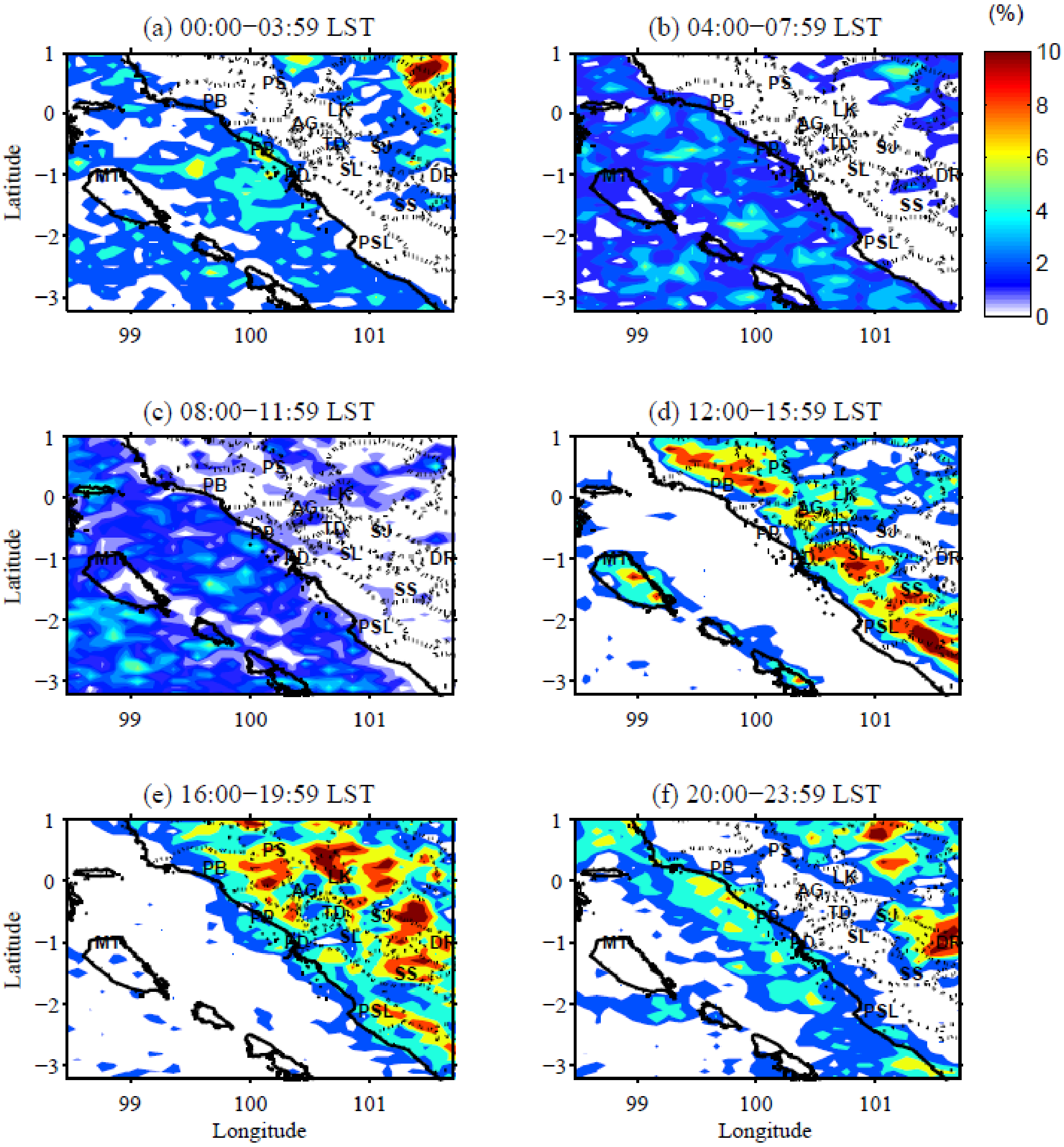

Figure 9. Diurnal Variation of Convective Rain Occurrence Frequency in West Sumatra during 1998-2013. The Abbreviations are the same as those in Figure 6

Conclusion

This study shows that lightning in West Sumatra occurs more frequently over land than over ocean and coastal area. This condition is different from the characteristics of precipitation in which the total rainfall is larger over the ocean, particularly over coastal areas, than over land. Stratiform precipitation occurs more frequently in West Sumatra than deep convective rains. In general, the lightning distribution is similar to the distribution of deep convective rainfall. Both lightning and deep convective precipitation is dominant in the land area at 16.00–20.00 LST. The diurnal cycle of lightning coincides with the diurnal cycle of cloud migration from the ocean to the inland of Sumatra as reported previously. Over land, the stratiform precipitation occurs more frequently from the afternoon to early morning (16.00–04.00 LST), whereas it occurs at 00.00–12.00 LST over the ocean. The relationship between rainfall and lightning in West Sumatra varies from one district to another mainly due to the difference in the topography and rain type factor. Lightning has the same distribution pattern as convective rainfall, indicating that the majority of lightning is associated with such type of rainfall. In addition to seasonal and diurnal variations, intra-seasonal variation of atmospheric cycle may also influence the lightning activity in West Sumatra. Therefore, the intra-seasonal variation of lightning activity in this area is being investigated and will be reported in a subsequent paper.

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References

[1] López, R.E., Holle, R.L., Heitkamp, T.A. 1995. Lightning casualties and property damage in colorado from 1950 to 1991 based on *Storm Data.* Weather. Forecasting. 10: 114-126, https://doi.org/10.1175/1520-0434(1995)010<0114:LCAPDI>2.0.CO;2.

[2] Cardoso, I., Pinto, Jr.O., Pinto, I.R.C.A., Holle, R. 2014. Lightning casualty demographics in Brazil and their implications for safety rules. Atmos. Res. 135-136: 374-379, https://doi.org/10.1016/j.atmosres.2012.12.006.

[3] Uman, M.A. 2001. The Lightning Discharge, Dover Publications.inc. New York. p. 377.

[4] Albrecht, R.I., Goodman, S.J., Buechler, D.E., Blakeslee, R.J., Christian, H.J. 2016. Where are the lightning hotspots on Earth?. Bull. Am. Meteorol. Soc. 97: 2051-2068, https://doi.org/10.1175/BAMS-D-14-00193.1.

[5] Pineda, N., Rigo, T., Bech, J., Soler, X. 2007. Lightning and precipitation relationship in summer thunderstorms: Case studies in the North Western Mediterranean region. Atmos. Res. 85(2): 159-170, https://doi.org/10.1016/j.atmosres.2006.12.004.

[6] Soriano, L.R., Pablo, F.D., Di´ez, E.G. 2001. Cloud to ground lightning activity in the Iberian Peninsula: 1992–1994. J. Geophys. Res. 106(D11): 1891-11901, https://doi.org/10.1029/2001JD900055.

[7] Xu, W., Adler, R.F., Wang, N.Y. 2014. Improving geostationary satellite rainfall estimates using lightning observations: underlying lightning–rainfall–cloud relationships. J. Appl. Meteor. Climatol. 52: 213-229, https://doi.org/10.1175/JAMC- D-12-040.1.

[8] Virst, K.S., Robert, A., Houze, J.R. 2015. Variation of lightning and convective rain fraction in mesoscale convective systems of the MJO. J. Atmos. Sci. 72: 1932-1944, https://doi.org/10.1175/ JAS-D-14-0201.1.

[9] Hamada, J., Yamanaka, M.D., Matsumoto, J., Fukao, S., Winarso, P.A., Sribimawati, T. 2002. Spatial and temporal variations of the rainy season over Indonesia and their link to ENSO. J. Meteorol. Soc. Jpn. 80(2): 285-310, https://doi.org/10.2151/jmsj.80.285.

[10] Marzuki, Hashiguchi, H., Kozu, T., Shimomai, T., Shibagaki, Y., Takahashi, Y. 2016. Precipitation microstructure in different madden–julian oscillation phases over Sumatra. Atmos. Res. 168: 121-138, https://doi.org/10.1016/j.atmosres.2015.08.022.

[11] Mori, S., Hamada, J.I., Tauhid, Y.I., Yamanaka, M.D., Okamoto, N., Murata, F., Sakurai, N., Hashiguchi, H., Sribimawati, T. 2004. Diurnal land–sea rainfall peak migration over Sumatera Island, Indonesian maritime continent, observed by TRMM satellite and intensive rawinsonde soundings. Mon. Wea. Rev. 132: 2021-2039, https://doi.org/10.1175/1520-0493(2004)132<2021: DLRPMO>2.0.CO;2.

[12] Virts, K.S., Wallace, J.M., Hutchins, M.L., Holzworth, R.H. 2013. Diurnal lightning variability over the maritime continent: Impact of low-level winds, cloudiness, and the MJO. J. Atmos. Sci. 70: 3128, https://doi.org/10.1175/JAS-D-13-021.1.

[13] Vadreas, A.K., Emeraldi, P., Hazmi, A. 2014. Sistem informasi petir (SIP) dengan metode lightning distribution (LD) di wilayah Sumatera Barat. JNTE. 3(2): 177-182, https://doi.org/10.25077/jnte.v3n2.83.2014.

[14] 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. Atmos. Res. 120-121: 268-286, https://doi.org/10.1016/j.atmosres.2012.09.004.

[15] Schumacher, C., R.A., Houze, J.r. 2003. Stratiform rain in the tropics as seen by the TRMM precipitation radar. J. Climate. 16: 1739-1756, https://doi.org/10.1175/1520-0442(2003)016<1739:SRITTA>2.0.CO;2.

[16] Kozak, S.A. 1998. Lightning strikes in Alberta thunderstorms: Climatology and case studies. Thesis. University of Alberta, Edmonton, Alberta. pp 129.

[17] Lay, E.H., Jacobson, A.R., Dowden, R.L., Holzworth, R.H., Rodger, C.J., Geophys. J. 2007. Local time variation in land/ocean lightning flash density as measured by the World Wide Lightning Location Network. J. Geophysic. Res. 112: 1-9, https://doi.org/10.1029/2006JD007944.

[18] Aldrian, E., Susanto, R.D. 2003. Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. Int. J. Climatol. 23: 1435-1452, https://doi.org/10.1002/joc.950.

[19] Marzuki, Hashiguchi, H., Shimomai, T., Randeu, W.L. 2016. Cumulative distributions of rainfall rate over Sumatra. Prog. Elec. Res. 49: 1-8, https://doi.org/10.2528/PIERM16043007.

[20] Ogino, S.Y., Yamanaka, M.D. 2016. How much is the precipitation amount over the tropical coastal region?. J. Climate. 29: 1231-1236, https://doi.org/10.1175/JCLI-D-15-0484.1

[21] Kikuchi, K., Wang, B. 2007. Diurnal precipitation regimes in the global tropics. J. Climate. 21: 2680-2696, https://doi.org/10.1175/2007JCLI2051.1.