Influence of topography on lightning density in Sumatra

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Abstract. Lightning is one phenomenon that plays an essential role in weather modeling and forecasts. Moreover, lightning also has an impact on humans and facilities. Lightning shows variations both temporally and spatially. In this study, the spatial distribution of lightning in Sumatra was examined to see topography's effect on lightning density in this region. We analyzed lightning data from the World Wide Lightning Location Network (WWLLN) observation. Topographic data, particularly the altitude and terrain slope data, were obtained from the digital elevation model (DEM) Shuttle Radar Topography Mission (SRTM). It was found that the lightning density is slightly correlated with the terrain slope and the altitude. High concentrations of lightning are observed in the land, consistent with some previous studies. Lower concentrations are seen on Sumatra's western side, particularly in the hillside of the Barisan Mountains. Although Sumatra's eastern side has a low elevation and a small topography slope, a high lightning concentration is observed in this region. The distribution of lightning shows seasonal variation in which the largest density is found during the dry season (MAM), which is different from the previous studies.

1. Introduction
The tropical region is an area with strong convection or significant amounts of latent heat of vaporization [1] and becomes the center of the formation process of global-scale atmospheric circulation. Indonesia's maritime continent is one of its regions in the tropics, consisting of many islands of varying sizes with a complex distribution of climate parameters and topography [2][3][4][5]. One of the big islands which has a complex atmospheric circulation is Sumatra island. Sumatra is in the western part of Indonesian that has a mountain range which is known as the Bukit Barisan as part of the world's ring of fire. Sumatra's position is almost vertical towards equatorial blocks atmospheric flow and clouds from the Indian Ocean towards the eastern part of the Sumatra. This condition will produce a variation in the diurnal rainfall cycle distribution and the atmospheric oscillation global and regional [2][3][4][5][6]. A good understanding of the diurnal precipitation oscillation mechanism in Sumatra is useful for weather predictions in this region and climate projections related to climate change due to global warming [1].
Another climate parameter, which is very interesting for this area, is the distribution and correlation of lightning with terrain slope or topography. The lightning phenomenon is physical parameters present variation and its maximum occurrence in tropical regions [7]. The maximum distribution of lightning activity over different geographical areas is of interest due to the substantial damages it causes to agriculture, electric power networks, property, and life [6]. As has been reported by several studies globally, lightning activity is closely related to the land surface conditions, the topography of the region and differs for the dry and moist environment [2]. Moreover, vegetation also has a connection to the overlying atmosphere by influencing surface energy and hydrological budgets [7].

Research on the distribution of lightning for the Indonesia region has been done by several researchers by using the LIS sensor from Tropical Rainfall Measuring Mission (TRMM) satellite data [2][5] [9]. The research on lightning activity in the Sumatra region is still minimal, especially those related to topography. Some studies only analyze a small part of western Sumatra [10] and minimum source data. The research that has also been done only discusses the relationship between lightning and rainfall [5][10]; there is nothing to do with topography. Therefore, this work will investigate the influence of elevation and terrain slope on the annual and seasonal lightning activity over Sumatra.

2. Research Method

We used data sets provided by The World Wide Lightning Location Network (WWLLN) during 2013-2018. The WWLLN is a ground-based global network of stations, which is operated by the University of Washington. This network detects very low frequency (VLF) signals from lightning discharges called “sferics” within the 3-30 kHz range [11]. With the network of spheric sensors, near-real-time maps of lightning activity over the entire Earth and twenty-temperature surface or upper tropospheric water vapor are produced [11].
The data are then grouped for each year and gridded into a 0.2x 0.2 box for latitude 10°S to 8.8°N and longitude 93°E to 108°E. The data are averaged for all years. To see the seasonal variation in lightning, the data are classified into four seasons, i.e., December, January, February (DJF), March, April, May (MAM), June, July, August (JJA), and September, October, November (SON), following Marzuki et al. [3].

We also used topographic data, particularly the altitude and terrain slope data. The data were obtained from the digital elevation model (DEM) Shuttle Radar Topography Mission (SRTM). Figure 1 and Figure 2 show the altitude and topography slope of Sumatra.

3. Result and Discussion
Figure 3 shows the count of lightning activity during 2013-2018. Overall, the maximum frequency of lightning was found in the Malacca Strait can reach about 11,000 flashes. There is no significant variation in the lightning density from year to year. High concentrations of lightning are observed in the land, but not in all land regions, consistent with previous studies [10].
Figure 3. Distribution of lightning activity over Sumatra from 2013 until 2018

Lower concentrations are seen on Sumatra's western side, particularly in the area very close to the Indian Ocean. This area is a hillside of the Barisan Mountains. Farther from the Indian Ocean, the number of lightning increases and this is observed up to the east coast of Sumatra. Thus, the lightning density increases when the topography slope increases. Although Sumatra's eastern side has a low
elevation and a small topography slope, a high lightning concentration is observed in this region. The average lightning density is given in Figure 4.

![Figure 4. The average frequency occurrence of lightning from WWLLN over Sumatra](image)

The distribution of lightning is closely related to the previously studied distribution of intense convective clouds. A high concentration of intense convective was observed over land [12], consistent with the characteristics of lightning found in this study. Thus, intense convective is associated with high lightning activity.

While the distribution pattern of lightning from TRMM satellite and WWLLN is similar, there are also some differences. The density of lightning from the WWLLN product is higher than that of the LIS sensor. The seasonal variation in lightning is also different. Figure 5 shows the distribution of lightning flash activity for some seasons. The maximum frequency is found in the dry season or during MAM (Figure 5b). This condition is different from the previous study in which a high abundance of lightning is found during the wet season (DJF).

The distribution of lightning is not very observable concerning the terrain slope. This condition may be due to the dense vegetation cover in the higher area [8], which is naturally formed. Another possibility is the condition of Sumatra, which is a humid area. The maximum lighting conditions are also found in more coastal areas, most likely the impact due to the interaction of sea and land areas. Due to enlargement of economical scale and acceleration of urbanization, atmospheric haze and fog increase in some big cities [13]. Haze and fog also influence the discharge development.
4. Conclusions
The results show that high concentrations of lightning are observed in land, consistent with some previous studies. Lower concentrations are seen on Sumatra's western side, particularly in the hillside of the Barisan Mountains. Farther from the Indian Ocean, the number of lightning increases and this is observed up to the east coast of Sumatra. Although Sumatra's eastern side has a low elevation and a small topography slope, a high lightning concentration is observed in this region. The distribution of lightning shows seasonal variation in which the largest density is found during the dry season, which is different from the previous studies. The current result is our preliminary result, and some advance analyses are being conducted and will be informed in other publications.

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