Lightning hazard region over the maritime continent observed from satellite and climate change threat

To cite this article: Y Ilhamsyah et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 56 012010

View the article online for updates and enhancements.

Related content
- An improved MODIS standard chlorophyll-a algorithm for Malacca Straits Water N Z Ab Lah, M N M Reba and Eko Siswanto
- Marked point process for modelling seismic activity (case study in Sumatra and Java) Hasih Pratwi, Lia Sulistya Rini and I Wayan Mangku
- The concept of geothermal exploration in west Java based on geophysical data Eddy Z Gaffar

Recent citations
- A. S. Habibie et al
Lightning hazard region over the maritime continent observed from satellite and climate change threat

Y Ilhamsyah$^{1,2,5}$, Y Koesmaryono$^1$, R Hidayat$^1$, J Murjaya$^3$, I W Nurjaya$^4$ and Rizwan$^1$

$^1$Applied Climatology, Graduate School of Bogor Agricultural University, Bogor 16680, Indonesia
$^2$Dept. of Marine Sciences, Faculty of Marine and Fisheries, Syiah Kuala University, Banda Aceh 23111, Indonesia
$^3$Head of Centre for Engineering Seismology, Potential Geophysics, and Standard Time, Agency for Meteorology, Climatology, and Geophysics (BMKG), Jakarta Indonesia 10720
$^4$Dept. of Marine Sciences and Technology, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor 16680, Indonesia
$^5$Tsunami and Disaster Mitigation Research Center (TDMRC), Syiah Kuala University, Banda Aceh 23111, Indonesia

Abstract. Climate change would lead to such hydrometeorological disaster as: flash-flood, landslide, hailstone, lightning, and twister become more likely to happen in the future. In terms of lightning event, one research question arise of where lightning would be mostly to strike over the Maritime Continent (MC)?. The objective of the research is to investigate region with high-density of lightning activity over MC by mapping climatological features of lightning flashes derived from onboard NASA-TRMM Satellite, i.e. Optical Transient Detector/Lightning Imaging Sensor (OTD/LIS). Based on data retrieved since 1995 -2013, it is seasonally observed that during transition season March to May, region with high vulnerability of lightning flashes cover the entire Sumatra Island, the Malacca Strait, and Peninsular Malaysia as well as Java Island. High-frequent of lightning activity over the Malacca Strait is unique since it is the only sea-region in the world where lightning flashes are denser. As previously mentioned that strong lightning activity over the strait is driven by mesoscale convective system of Sumatra Squalls due to convergences of land breeze between Sumatra and Peninsular Malaysia. Lightning activity over the strait is continuously observed throughout season despite the intensity reduced. Java Island, most populated island, receive high-density of lightning flashes during rainy season (December to February) but small part in the northwestern of Java Island, e.g., Bogor and surrounding areas, the density of lightning flashes are high throughout season. Northern and southern parts of Kalimantan and Central part of Sulawesi are also prone to lightning activity particularly during transition season March to May and September to November. In the eastern part of MC, Papua receive denser lightning flashes during September to November. It is found that lightning activity are mostly concentrated over land instead of ocean which is in accordance with diurnal convective precipitation event due to the existence of numerous mountainous island in MC. The malacca strait however is the only exception and turn into a unique characteristic of convective system over MC and the only sea-region in the world where lightning activity is the greatest.

1. Introduction
Lightning event often correspond to hazard, it is true as many reports in the community in which lightning is responsible for lethal impact, even the strike was also allegedly to have linked with early
2015 crash of Air Asia flight number QZ8501 which was later denied. The lightning turn into the deadliest weather phenomena over the Maritime Continent (MC), situated between 18.5N-15.5S and 90.5-162.5E.

As it is located over the tropical region with strong diurnal convection, MC grows into the most vulnerable region of lightning activity in the world [1]. Many areas over Indonesia for instance, which experience numerous amount of lightning flashes. One of the greatest is Cibinong Bogor, West Java - Indonesia, situated at 106.8E and 6.43S, is known to have the most severe lightning occurrences which was also documented in the 1988 Guinness Book of World Records. It was recorded that Cibinong Bogor experienced 322 thunderstorm days annually of only 80 days in normal. Following huge number of lightning flashes over MC, it then raise a question of which region over MC where flashes are denser mainly during transition season when it becomes more frequent to occur in this period. Whether the transition season is the highest, it also remains question since there is no intensive investigation of climatological features of lightning that cover a whole MC yet. If regions with intense lightning activity are identified, in the forthcoming years, spots of lightning hazard over MC could be widely known and well-predicted and focus could be given for anticipating future climate change threat over the regions [2].

Back to the regional density, lightning detection provided by Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) might be employed to detect regions with denser flashes. However, detection devices installed at BMKG stations are yet in the form of lightning detection network, but still only a single-operational system which has limited coverages of 300 km away from the source. The single-system also has weakness in determining the precise location of lightning strokes which require improvement using triangulation method with stations nearby. In addition to strokes location, BMKG’s lightning detection is yet to provide long-term measurement. Some ground-based stations has gathered more than ten years of lightning data particularly stations stretched in Java and North Sumatra but still many are newly-operated leading to difficulties in determining full climatology of lightning activity over MC. From space, lightning activity has been intensively monitored since 1995 using onboard optical sensor installed at NASA-Tropical Rainfall Measuring Mission (TRMM) under Optical Transient Detector/Lightning Imaging Sensor (OTD/LIS). Several research have employed one and half-years of satellite data (December 1997 to May 1999) to observe lightning distributions over Indonesian Archipelago [3, 4]. Meanwhile, from ground measurement network, since December 1994 to January 1996 lightning activity has been observed over Java Island [5]. Some research to observe diurnal variations of lightning had also been done using both LIS and ground measurement from World Wide Lightning Location Network as comparison [6, 7]. But still previous studies are yet to be sufficient to describe full climatology of lightning activity over MC. Since MC cover vast marine-continental region supported by the availability of long-term observation, thus, the utilization of lightning data derived from satellite is urgently required to identify regions with intense lightning activity over MC. On the other hand, the added value of detectable lightning flash density is that such information is increasingly demanded not only for lightning safety reason but also to be considered as part of cost-benefit analysis by leading national or private companies, such as: oil, electrical, and even insurance companies. The objectives of the research are to map lightning climatology over MC and to determine detection efficiency (DE) between satellite and local lightning detection system.

2. Materials and Methods

Lightning data are retrieved from OTD/LIS, onboard optical sensor installed at NASA-TRMM satellite [8, 9]. The device captured lightning flashes (both Intra-cloud and cloud-to-ground) since May 1995-December 2013. The data are in the gridded HDF format, available online at http://lightning.nsstc.nasa.gov/data/index.html [10, 11]. Spatial resolutions of the data are 0.5° longitude x 0.5° latitude, cover the entire MC between 18.5N-15.5S and 90.5-162.5E. Meanwhile, temporal resolution is monthly lightning flash density data. For validation, DE determination is carried out by comparing between flashes and lightning strokes density derived from BMKG’s cloud-to-ground lightning detection single-system over Bogor District in 2012. DE is calculated using the following expression:
\[ DE = \frac{\rho_{\text{SAT}_{\text{an}}}}{\rho_{\text{BMKG}_{\text{an}}}} \]  

(1)

Meanwhile, stroke density is calculated using the following expression:

\[ \rho_{\text{BMKG}_{\text{an}}} = \frac{S_{\text{tot}}}{L} \]  

(2)

Di mana :  
\[ \rho_{\text{BMKG}_{\text{an}}} = \text{annual density of BMKG (flashes/km}^2\text{/year)}. \]
\[ \rho_{\text{SAT}_{\text{an}}} = \text{annual density of satellite (strokes/km}^2\text{/year)}. \]
\[ S_{\text{tot}} = \text{Total annual strokes (stokes/year)}. \]
\[ L = \text{Areas (km}^2\text{)}. \]

The gridded lightning data are read and stored in text format using HDFView. The data processing and mapping utilize MATLAB-mapping toolbox with the following script:

```matlab
clear all
clf
load HRMC_COM_FR3.txt
flash1=HRMC_COM_FR3(100:220,400:700);
load HRMC_COM_FR4.txt
flash2=HRMC_COM_FR4(100:220,400:700);
load HRMC_COM_FR5.txt
flash3=HRMC_COM_FR5(100:220,400:700);
flashtotal=(flash1+flash2+flash3);
%------------------------
load Latitude_monthly.txt
lat=Latitude_monthly(100:220);
load Longitude_monthly.txt
lon=Longitude_monthly(400:700);
max(max(flashtotal))
axesm('MapProjection','mercator','MapLatLimit',[-18 19],'MapLonLimit',[88 165])
framem;
plabel('PlabelLocation',5); mlabel('MlabelLocation',10);
contourfm(lat,lon,flashtotal,0.05:0.01:0.4)
colorbar
load coast
geoshow(lat, lon,'Color','red');
axis off
```

3. Results and Discussion

According to 2013 Intergovernmental Panel on Climate Change (IPCC) report, it is projected that in the near-future tropical region will be “very likely” to “suffer from” weather and climate extreme events. There is a curious statement that wet areas become wetter, why so?. It then certainly implies the tropical region including the MC. MC would tend to be wetter because the accumulation of heat would concentrate over the region which have an effect on the increase of sea-surface temperature. As temperature increase, the release of water vapor in the atmosphere would be higher and convective system would grow stronger and spread widely, cover a whole MC. These processes becomes vulnerable to the development of deep cumulonimbus clouds that initiate the growth of multicell to supercell thunderstorms. The event is often regarded as local disaster where torrential rain resulted from intense thunderstorms could lead to flash-flood, landslide and frequently accompanied by
vulnerable on intense thunderstorms particularly supercell thunderstorms. Similarly, the release of latent heat which is continuing to increase also trigger the development of deep convective clouds over the ocean, and when merge with convective clouds from the land, it might drive the formation of mesoscale convective system accompanied with lines of thunderstorm (refer to squall-line thunderstorm), distributed widely and cover most parts of MC. One of the famous squall line thunderstorms that is Sumatra Squall-lines that occurred over the Malacca Strait due to convergences of land breeze coming from Sumatra Island and Peninsular Malaysia that produce heavy rainfall and frequent lightning activity in the morning along eastern coast of the island. This is one example, and of course, MC will be vulnerable to future hidrometeorological disaster as a result of the changing climate, e.g., heavy rainfall, hailstone, twister, lightning and perhaps these events has been underway in the present time. In order to anticipate such worst events, it is necessary to map regions with high vulnerability of hydrometeorological disaster over MC. Thus, adaptation could be implemented to cope with future climate change impact.

In relation to lightning occurrence, based on data retrieved since 1995-2013, it is seasonally observed that during transition season March to May, region with high vulnerability of lightning flashes cover a whole Sumatra Island, the Malacca Strait, and Peninsular Malaysia as well as Java Island (Figure 1). Strong intensity of lightning activity over the Malacca Strait is unique since it is the only sea-region in the world where lightning flashes are the greatest. As previously mentioned that strong lightning activity over the strait is driven by mesoscale convective system of Sumatra Squalls due to convergences of land breeze between Sumatra Island and Peninsular Malaysia. Lightning activity over the strait is continuously observed throughout season despite the intensity reduce.

Meanwhile, Java Island, most populated island, receive high-density of lightning flashes during rainy season (December to February) but small part in the northwestern of Java Island, e.g., Bogor and surrounding areas, the density of lightning flashes are high throughout season (Figure 2). Northern and southern parts of Kalimantan and Central part of Sulawesi are also vulnerable to lightning activity particularly during transition season March to May and September to November. In
the eastern part of MC, Papua receive denser lightning flashes during September to November (Figure 3).

Figure 2. Seasonal Combined Flash Rate Density Dec-Jan-Feb (1995-2013), units (flashes/km$^2$/day).

Figure 3. Seasonal Combined Flash Rate Density Sept-Oct-Nov (1995-2013), units (flashes/km$^2$/day).
It is interesting to observe that during dry season, lightning achieve higher density in the western part of MC (e.g., Sumatra Island, the Malacca Strait, and Peninsular Malaysia). Dry season particularly over Sumatra often relate to forestfire, whether high-density of lightning activity over the region has strong correlation on forestfire?, it remains interesting subject to be investigated further. One thing that could be taken into account that convective system over the region is very active, even during dry season it might lead to atmospheric disturbances over the region (Figure 4).

Figure 4. Seasonal Combined Flash Rate Density Jun-Jul-Aug (1995-2013), units (flashes/km²/day).

Figure 5. Combined Flash Rate Density Climatology (1995-2013), units (flashes/km²/year).
Based on seasonal and full climatology observation, it is well-identified that there are four spots of intense lightning activity which later correspond to lightning hazard region over MC. Sumatra remains at the top of lightning hazard region, while Java is the second vulnerable region of lightning hazard. Central Sulawesi and South Kalimantan are the third and fourth lightning hazard region over MC, respectively (Figure 5). In the near-future where climate change becomes unequivocal and hydrometeorological hazard is very likely to occur, the regions require crucial attention to anticipate severe lightning disaster. In addition, The mapping of lightning climatology would benefit to assist the development of lightning protection around industrial areas and transmission lines, to harvest lightning for future renewable energy, to describe the development of potential agricultural areas, describe areas of potential mining.

It is found that lightning activity are mostly concentrated over land instead of ocean which is in accordance with diurnal convective precipitation event due to the existence of numerous mountainous island in MC [12]. The malacca strait however is the only exception and turn into a unique characteristic of convective system over MC and the only sea-region in the world where lightning activity is the greatest.

![Figure 6. Anomaly of Annual Trends of Lightning Climatology over the Malacca Strait (1998-2014), units (flashes).](image-url)

In relation to climate change, it is shown that anomaly of annual trends of lightning flashes over the Malacca Strait and Greater Jakarta Areas (Jabodetabek) have significantly increased from year to year (Figure 6 and 7). The Malacca Strait, equatorial-type climate, showed that in the period of El Niño 2002-2003 and 2009-2010, lightning is higher in the beginning of the event. On the contrary, over Jabodetabek which is monsoonal-type climate, lightning is lower at first. It is interesting to investigate more details of the relationship between lightning flashes and El Niño event particularly in monsoonal-type climate region which is largely affected by El Niño.
Figure 7. Anomaly of Annual Trends of Lightning Climatology over Greater Jakarta Areas, Jabodetabek (1998–2014), units (flashes).

Figure 8. Spots of lightning hazard in Bogor District.
For DE, Bogor District, 1988 Guiness book of world records of thunderstorm days, is chosen for lightning validation between flashes derived from satellite and strokes detected by BMKG’s lightning detection. It is obtained from equation (2) that lightning density over Bogor District is 50 strokes/km²/year (Figure 8). According to Figure 5, flash density over Bogor District observed from satellite is 45 flashes/km²/year. By using equation (1), we arrive at 90% of DE, indicating that lightning activities are well-observed from space. Thus, satellite service is superior in its application on lightning investigation [13].

4. Concluding remarks
Specifically, regions with high-density of lightning activity are well-identified seasonally and annually. Most of them are stretched in the eastern coast of Sumatera, the Malacca Strait, Peninsular Malaya, West Java, South Kalimantan and Central Sulawesi. DE is nearly-perfect. Generally, lightning activity are mostly concentrated over land instead of ocean. Climate change threat become likely to occur near-future as indicated by the increase of annual trends of lightning activity over MC.

Acknowledgments
Authors express gratitude to Ministry of Research, Technology, and Higher Education Indonesia under Postgraduate Scholarship Program for financial support of the research.

5. References
[1] Kodama YM, Tokuda M and Murata F 2006 J. Meteor. Soc. Japan 84A 133-149
[2] IPCC 2013 The Physical Science Basis (Geneva: Working group I contribution to the IPCC fifth assessment report climate change 2013)
[3] Hamid EY, Kawasaki ZI and Matsuura K 1999 Journal of Atmospheric Electricity 19 153-164
[4] Hamid EY, Kawasaki ZI and Mardiana R 2000 Power Engineering Society Winter Meeting IEEE 3 2077-2081.
[5] Hidayat S and Ishii M 1998 J. Geophys. Res.-Atmos. 103(D12) 14001–14009
[6] Virts KS, Wallace JM, Hutchins ML and Holzworth RH 2013 J. Atmos. Sci. 70 3128-3146
[7] Virts KS, Wallace JM, Hutchins ML and Holzworth RH 2013 Bull. Amer. Meteor. Soc. 94 1381-1391.
[8] Buechler DE, Koshak, WJ, Christian HJ and Goodman SJ 2014 Atmos. Res. 135-136 397-403
[9] Boccippio DJ, Koshak WJ and Blakeslee RJ 2002 J. Atmos. Oceanic Technol. 19 1318-1332
[10] Cecil DJ 2006 LIS/OTD 0.5 Degree High Resolution Monthly Climatology (HRMC) (Alabama: NASA Global Hydrology Resource Center DAAC)
[11] Cecil DJ, Buechler DE and Blakeslee RJ 2014 Atmos. Res. 135-136 404-414
[12] Qian J-H 2008 J. Atmos. Sci. 65 1428-1441.
[13] Rudlosky SD and Shea DT 2013 Geophys. Res. Lett. 40 1–5