Spatial distribution and diurnal characteristics of rainfall in South Sumatra and surrounding areas based on Tropical Rainfall Measuring Mission (TRMM) data

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Abstract. This study aims to obtain information about the characteristics of rainfall in South Sumatra and its surroundings (Longitudes 99° - 107° East and Latitudes 1° - 5° South), which includes climatological anomalies and shifts in the time of diurnal rainfall peak events. This research data comes from TRMM PR 3B42 v7 with grid spatial resolution of 0.25° x 0.25° and temporal resolution of 3 hours, which includes two categories, namely climatology data for ten years (2008 – 2017) and 12 months actual data (October 2018 – September 2019), with main attention in December 2018 to February 2019. Climatologically the pattern of rainfall is similar to "Type A" of the Aldrian’s rainfall pattern. Meanwhile, the calculations of anomalies indicated a significant rainfall deficiency, starting in July to September 2019, which can be understood as the impact of the positive Indian Ocean Dipole. On the other hand it was found that the peak of rainfall on the west coast of Sumatra generally occurred at 16:00 to 19:00 (local time), which then shifted increasingly late towards both East (mainland Sumatra) and West (Indian Ocean) as stated by Vincent and Lane. Finally, about 30% of the study area did not experience a shift in peak rainfall time (RP time shift) and 40% of the other area experienced it of ± 3 hours and the rest experienced it with a longer time.

1. Introduction
For most people in Sumatra and Kalimantan, the long dry season is synonymous with forest and land fires, which in the past decade have occurred twice, in a scale of disaster that is more than a national scale, namely in 2015 and, most recently in 2019. Forest and land fires (Karhutla) in Indonesia, especially on peat lands in Sumatra and Kalimantan, always occur along with severe drought in both regions. This incident had an impact to penetrate national borders, even throughout Southeast Asia [1] [2]. Two seriously affected countries who often protest to the Indonesian government are Singapore and Malaysia. In both countries, the impact has been on policies to dismiss schools and various outdoor activities, while in some areas the number of cases of health problems, especially among children, has increased sharply [3] [4]. Of course there are many records of losses in many other sectors [4].

The dry season in Indonesia is characterized by low amounts of rainfall. The Meteorology, Climatology and Geophysics Agency (BMKG) defines it with rainfall figures of less than 50 mm/10-day period for three consecutive periods of ten days, or less than 150 mm in the month. In two season system (dry and rainy), the months with conditions outside above terminology are mentioned as a rainy
season. Departing from this definition and the closeness of its geographical position, based on climatological data from 1981-2010 BMKG divides the Indonesian land area into 342 Season Zones (ZOM) and 65 Non Zone Zones (Non ZOM) [5]. Unlike the ZOM, the Non-ZOM differences are not obtained between the dry and rainy months, each year.

Indonesia as a maritime continental country (Indonesian Maritime Continent - IMC), with its unique position on the equator and located between two continents (Asia and Australia) and two Oceans (Indian and Pacific), not only has a large wealth with the distribution of regional rainfall patterns each year, but also has a variety of diurnal rainfall patterns that are rich as a result of geographical conditions (many large and small islands flanked by sea/strait) and land topography (mountains to lowlands and sea (shallow or deep). In terms of external influences, climate patterns and IMC seasons are influenced by cycles resulting from interactions between the surface (ocean and land) and the atmosphere, on a global and regional scale such as ENSO, IOD, MJO and Asia-Australia Monsoon [2, 5-6].

This research is only the first step, with the aim of describing the monthly rainfall conditions and diurnal cycle patterns associated with typical climate/season phenomena in 2019. Because the latest data that can be obtained is only until September 2019, specific studies are limited only for three months, starting from December 2018 to February 2019.

The research area stretches from (99°E - 107°E and 1°S - 5°S), covering the Indian Ocean and Bengkulu to the west, a small part of Riau, a portion of West Sumatra and Jambi in the North, throughout South Sumatra, Bangka and Belitung Islands with the surrounding sea to the east and part of Lampung to the South (Figure 1). Based on the BMKG definition above, this region covers 30 ZOMs and 8 Non-ZOMs in Sumatra, with climatological characteristics of the beginning of the dry season varying from the start of the 3rd 10-day period of April to 2nd 10-day period of June and the end of the dry season from 3rd 10-day period of August to 2nd 10-day period of November. One thing that is generally accepted is that the rainfall in December to February (DJF) in this region is quite high (> 152 mm/month) [5], a condition of the rainy season that is good enough to be observed [7].

![Figure 1. Research Study Area.](image-url)

2. Data and Methods
Rainfall data is taken from TRMM PR 3B42 v7 [8, 9], with grid spatial resolution of 0.25° x 0.25° and a temporal resolution of 3 hours. The data accessed includes climatology data for 10 years (2008-2017) and actual study data from October 2018 to September 2019, with coverage of study areas between (99°E, 1°S) to (107°E, 5°S).

Then, all of the above data is separated into two groups: the first group is monthly (cumulative) data (DB) and the second group is monthly 3-hour data (cumulative) (DB3J). In this case, if the basic component of data (cumulative) per 3-hour is expressed as $X_{gymdh}$, with the index $g$ representing grid,
y (year), m (month), d (day, date of the month) and h (hour, in 3-hour units), then for each data grid in certain years and months must be fulfilled the relationship

\[ \sum_{h=1}^{8} DB3J_{gymh} = \sum_{d=1}^{N_d} X_{gymdh} \]  

with

where \( N_d \) is the number of days in the month involved.

Thus through DB can be obtained information about climatology and anomalies for each grid and month, while through DB3J will be obtained similar information but related to a specific time group (per 3-hour) from which the time of diurnal peak rainfall occurrence can be obtained.

**Figure 2.** Climatology and anomaly of rainfall in the study area in Dec 2018, Jan 2019 and Feb 2019.

3. Results and Discussion

3.1. Rainfall Climatology and Anomalies.

Figure 2 represents the climatology and anomaly of rainfall of the study area in Dec 2018, Jan 2019 and Feb 2019 respectively. The 2008-2017 climatology map (Figure 2 (a), (c) and (e)) shows that in December to February (DJF) the rainfall in the Indian Ocean (west of Sumatra) was generally greater than in land and sea in the east of Sumatra, as confirmed by Vincent and Lane [7]. Meanwhile, over time, rainfall has fallen sharply from December to January, then slightly decreased from January to February, both on land and sea.
In the perspective of anomalies, as shown in Figure 2 (b), (d) and (f), it was revealed that the rainfall deficiency in December 2018 and February 2019 happened in almost the most of the Indian Ocean, while in January 2019 it has been surplus rainfall in the northern part and a deficit of rainfall in the southern part. Unlike the conditions in the Indian Ocean, rainfall anomalies on the mainland as well as islands and waters in the eastern part of Sumatra changes gradually to more surplus condition.

Complete descriptions of the climatology of rainfall are shown in Table 1, and the anomalies from October 2018 to September 2019 represented in Table 2. Similar to what is desired in Figure 2, Table 1 shows the distribution of rainfall in relation to the area represented by each of the rainfall interval values on the map, from which we obtain monthly climatological rainfall of the region under study, the Cumulative Rain Rate (CRR). Meanwhile Table 2 is the same thing as Table 1 but applies to rainfall anomalies. From this data surplus or deficit of rainfall at a certain time, compared with the value of the climatology, can be obtained too.

### Table 1. Rainfall Climatology (2008-2017): area composition (%) and Cumulative Rainrate (CRR).

| RR (mm/hour) | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| < 0.1       | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0.1 - 0.2   | 1.5 | 1.5 | 1.8 | 1.5 | 1.5 | 43.3| 44.6| 45.6| 37.1| 3.9 | 0.0 | 0.0 |
| 0.2 - 0.3   | 14.2| 14.2| 12.3| 7.7 | 12.3| 68.1| 24.2| 21.4| 27.0| 41.8| 1.3 | 0.2 |
| 0.3 - 0.4   | 42.3| 28.6| 45.3| 37.9| 27.6| 19.8| 11.9| 3.3 | 4.9 | 22.9| 16.0| 21.4|
| 0.4 - 0.5   | 28.1| 40.2| 32.5| 40.5| 2.8 | 10.3| 17.0| 8.7 | 11.6| 8.7 | 33.8| 33.2|
| 0.5 - 0.6   | 9.5 | 13.9| 6.5 | 13.1| 0.0 | 0.0 | 0.0 | 10.8| 11.9| 17.2| 24.3| 24.2|
| 0.6 - 0.7   | 3.3 | 1.6 | 1.6 | 0.3 | 0.0 | 0.0 | 0.0 | 8.3 | 4.6 | 5.6 | 14.2| 19.0|
| 0.7 - 0.8   | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.3 | 0.0 | 7.2 | 2.1 |
| > 0.8       | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.1 | 0.0 | 0.0 | 0.0 |

CRR values, generated from climatological data in Table 1, show that the climatological pattern of rainfall in the study area has a "Type A" as indicated by Aldrian [10], but with the position of maximum and minimum rainfall at different times. This is because of Table 1 above illustrates the climatological conditions of the region consisting of various zones and non zones of different rain patterns.

### Table 2. Rainfall Anomalies, Oct 2018 – Sep 2019: area composition (%) and Surplus/Deficit-Rate.

| RR (mm/hour) | Jan 2018 | Feb 2018 | Mar 2019 | Apr 2019 | May 2019 | Jun 2019 | Jul 2019 | Aug 2019 | Sep 2019 | Oct 2018 | Nov 2018 | Dec 2018 |
|-------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| < -0.35     | 0.0      | 0.2      | 0.0      | 0.0      | 0.0      | 0.0      | 22.5     | 27.3     | 0.0      | 0.0      | 0.3      |          |
| -0.35 - 0.25| 1.1      | 4.9      | 0.0      | 0.0      | 0.0      | 0.5      | 1.3      | 5.7      | 3.9      | 0.0      | 0.0      | 5.4      |
| -0.25 - 0.15| 5.6      | 11.3     | 2.1      | 10.9     | 8.7      | 6.5      | 22.7     | 16.5     | 14.5     | 3.9      | 0.8      | 10.6     |
| -0.15 - 0.05| 16.2     | 14.2     | 29.4     | 33.5     | 44.6     | 20.6     | 44.1     | 53.9     | 49.0     | 20.9     | 11.9     | 21.1     |
| -0.05 - 0.00| 34.6     | 21.2     | 41.8     | 32.5     | 37.7     | 36.6     | 26.5     | 1.3      | 5.1      | 34.2     | 39.2     | 36.1     |
| +0.05 - +0.15| 32.7   | 30.7     | 22.9     | 18.6     | 7.7      | 19.1     | 4.4      | 0.0      | 0.2      | 12.3     | 31.9     | 21.2     |
| +0.15 - +0.25| 8.2    | 12.7     | 3.4      | 4.1      | 1.0      | 6.5      | 1.0      | 0.0      | 0.0      | 10.5     | 7.5      | 4.4      |
| +0.25 - +0.35| 1.5    | 3.3      | 0.3      | 0.3      | 0.2      | 5.2      | 0.0      | 0.0      | 0.0      | 9.0      | 7.4      | 0.8      |
| > +0.35     | 0.2      | 1.5      | 0.0      | 0.0      | 0.2      | 4.9      | 0.0      | 0.0      | 9.3      | 1.3      | 0.0      |          |

The S/D-R values in Table 2 show the surplus and deficit of rainfall. From these values it can be seen that normal conditions (with excess or lack of rainfall below the value of standard deviation of the related climatological data) are still being fulfilled until the sixth month (June) of 2019. Furthermore, starting in July there was an even greater reduction in rainfall as a result of the positive Indian Ocean Dipole (IOD) phenomenon that emerged since May and continued to increase and reach its peak in mid-November 2019. Many climatologist called the year 2019 to be one of the years with the strongest positive IOD, as happened in 1994 and 1997. This strengthening positive IOD is thought to be the main
cause of the long and dry drought in most parts of Indonesia, which even delays the beginning of the rainy season up to 6 weeks. Please note that because the latest TRMM rainfall data is in September 2019, the October-December data is taken from the conditions in 2018, which of course can be very different from the conditions in 2019.

3.2. Rainfall Peak (RP): time and time shift
Assuming the adequacy of rainfall as stated above the review of the RP is limited to only three months of study, December, January and February (DJF). Figure 3 reveals the time and time shift of peak rainfall events in the study area in Dec 2018, Jan 2019 and Feb 2019. As shown in Figure 3 (a), (c) and (e), in accordance with Vincent and Lane’s confirmation [7], rainfall intensity peak generally starts between 16.00-19.00 local time along the west coast henceforth it shifted further more night towards the high seas and into the mainland of the island of Sumatra. Except for a few on the eastern mainland and on a few islands, like Bangka and Belitung, RP almost never occurs in the morning until noon (07.00-13.00 local time), while this is common in the high seas.

![Figure 3](image-url)
Figure 3 (b), (d) and (f) and Table 3 show that about 30% of the region are not experiencing RP time shift and almost 40% of other region encounter it between -3 hours (before) to +3 hours (later) of the related RP climatology. It makes sense that longer shifts have a smaller chance of occurrence, but apart from information about composition by area and spatial distribution of regions where RP time shifts occur, as shown in the Figures and Tables referred to, there is not enough indication to explain more about this phenomenon. In this case, besides verification and calibration of TRMM data, a study of various other relevant aspects is needed.

### Table 3. Shifting Times of Rainfall Peak: composition by area (%).

| Time Shift (hour) | DECEMBER 2018 | JANUARY 2019 | FEBRUARY 2019 |
|------------------|---------------|--------------|---------------|
| -9               | 5.23          | 4.74         | 3.43          |
| -6               | 12.09         | 9.48         | 6.86          |
| -3               | 19.77         | 16.01        | 12.75         |
| 0                | 31.86         | 29.41        | 36.60         |
| 3                | 18.30         | 21.90        | 20.42         |
| 6                | 7.03          | 10.78        | 10.62         |
| 9                | 3.43          | 4.58         | 5.56          |
| 12               | 2.29          | 3.10         | 3.76          |

(-) forward (leading), (+) backward (lagging)

### 4. Conclusion

The existence of TRMM data has been able to describe the spatial distributions and diurnal patterns of rainfall as an indicator of climate/season conditions in South Sumatra and surrounding areas. From which information is obtained about the climatological conditions of rainfall as well as the diurnal cycle pattern of rainfall that is in accordance with the BMKG study results and as confirmed by Vincent & Lane. Although various quantitative information has been obtained, the anomaly and the shift in RPs still cannot be explained due to lacking background knowledge of their occurrences. As a preliminary study, this research still needs more elaborations i.e.: verification and calibration of TRMM data to (in-situ) surface data should be done, especially in fulfilling data validity in areas with specific local conditions. The data of 2019 should be applied in order to see the effect of climate change to the season in 2019, and some study should be deployed in order to understand the effects of global/regional phenomena in the long dry season in 2019 which caused forest and land fires, especially in Sumatra and Kalimantan.

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