Utilization of remote sensing data for mapping the effect of Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) in Sumatra Island

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Abstract. IOD and ENSO are two global phenomena that are quite influencing the territory of Indonesia. Sumatra is one of the islands in Indonesia with unique local characteristics and is located in the westernmost. This study attempts to analyze how much the IOD and ENSO have affected rainfall in the Sumatra Island and which is more dominant, and the distribution that can be used as a reference in forecasting seasons and rainfall. In a period of 37 years (1981-2017), the influence of IOD and ENSO was analyzed using a correlation method which was then mapped. The rainfall data used was obtained from CHIRPS with a scale of 0.05. Data is processed using Climate Data Operator (CDO) and R-statistics to obtain correlation maps. Correlation calculations are carried out on the whole data and in the season period. The effect of IOD was seen to be significant in the southern part of Sumatra, with a maximum correlation of 0.4, while in the north and center, the correlation only -0.25. The effect of ENSO looks more evenly compared to the impact of IOD, with a correlation reaching -0.4 in the northern and southern parts of Sumatra. In contrast, the middle part shows a smaller correlation value with ranges of -0.1 to -0.3. In the DJF and MAM season periods, a positive correlation between rainfall and IOD occurred throughout Sumatra, and in the JJA and SON, a dominant-negative correlation occurred. In comparison, the ENSO shows dominant negative correlation in each period. Based on the correlation, ENSO is more influential on Sumatra compared to IOD in overall data. However, on seasonal data, IOD is more significant than ENSO. The southern part of Sumatra Island is the most affected by ENSO and IOD compared to other parts.

Keywords : Rainfall, IOD, ENSO, CHIRPS, Sumatra

1. Introduction

The relationship between the land, ocean, and atmosphere in a region is closely related to its weather and climate [1]. Indonesia is located between two oceans, the Indian Ocean and the Pacific Ocean, and two continents, Asia and Australia. Based on the location, the variability of rainfall in Indonesia is intensely estimated to be influenced by several climate control systems. The global climate systems that affect rainfall variability of Indonesia are Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) [2]. ENSO is a phenomenon of anomaly in sea surface temperature (SST) that
occurs due to the interaction between atmosphere and ocean in the middle and eastern Pacific Ocean near the equator. Meanwhile, IOD is the same anomaly but appears in the Indian Ocean.

Supari et al [3] researched on ENSO effect in all around Indonesia and found out that ENSO events influence the duration, intensity, and frequency of extreme rainfall and total precipitation in Indonesia. ENSO and IOD phenomena influence Indonesia's rainfall variation during the dry season and an unclear effect on the wet season [4]. Those results were also shown in Hendon research [5] that in the dry season, ENSO can explain 50% of the rainfall variation, while IOD explains for 25%. Those two global climate systems have a significant role to account to the rainfall variation of Indonesia.

Sumatra is located in the westernmost of Indonesia and the nearest island to IOD monitoring region. It is interesting to find the effects of ENSO and IOD in this area since in Hendon [5] research found out that ENSO has influence more than IOD. This study aimed to determine which global climate system is more influential to rainfall fluctuation in Sumatra using ENSO index, IOD index, and rainfall anomaly. The results of this study can help to identify the factors of monthly rainfall in Sumatra.

2. Data and Method
The data used in this research is based on the remote sensing observation data of monthly rainfall from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) [6] with a resolution of 0.05° x 0.05°. The data was downloaded from IRI/LDEO Climate Data Library [7]. The period of data in this study is from 1981 to 2017 in Sumatra Island.

The IOD phenomenon was determined by the values of Dipole Mode Index (DMI). DMI is accurate to represent the dipole mode in SST [8]. DMI is defined as the difference in SST anomaly between the tropical western Indian Ocean (50° – 70°E, 10°S – 10°N) and the tropical south-eastern Indian Ocean (90° – 110°E, 10°S – equator), positive DMI is associated with cold SST anomaly in south-eastern Indian Ocean and warm anomaly in western Indian Ocean, the opposite applies to negative DMI [9]. DMI data is downloaded from Japan Agency for Marine-Earth Science and Technology (JAMSTEC) website [10].

ENSO phenomenon was determined by the values of Oceanic Nino Index (ONI). ONI is the running 3-month mean SST anomaly in Nino 3.4 region (5°N – 5°S, 120° – 170°W) to identify ENSO phenomenon (El Nino and La Nina) and used by National Oceanographic and Atmospheric Administration (NOAA) [11]. El Nino is associated with the warm phase of Nino 3.4 region and La Nina is the cool phase. The research of Bamston et al [12] stated that the Nino 3.4 region is the most representative to identify ENSO. ONI data is downloaded from NOAA website [13]. Figure 1 shows the regions of DMI to monitor IOD and Nino 3.4 to monitor ENSO.

![Figure 1. Regions of DMI and Nino 3.4](image-url)
Monthly rainfall data from CHIRPS is processed into rainfall anomaly using CDO, which can be defined as the difference between the observed rainfall value in the \( i \)-month and the average rainfall in the same month period. The following formula can calculate rainfall anomaly data:

\[
X_{\text{mean}} = X_i - \left( \frac{1}{N} \sum_{i=1}^{N} X_i \right)
\]

(1)

The rainfall anomaly are then grouped into four groups using CDO based on seasonal periods, they are, DJF (December - January - February), MAM (March - April - May), JJA (June - July - August), and SON (September - October - November). DJF was chosen because it represents the normal period of Asian monsoon season (peak rainy season), while MAM represents the transitional season or the transition from the rainy season to the dry season and JJA represents the Australian monsoon season or the peak of the dry season in parts of Indonesia [15]. Furthermore, rainfall anomaly were processed using the R-Statistics application. Data is in the net-CDF format (*.nc) and opened in R-Statistics using the ncdf4 package [16]. Then, the rainfall anomaly in each grid were correlated with DMI and ONI then mapped using the map package [17] to see the correlation of rainfall variabilities with ENSO and IOD indices.

3. Results and Discussion

The result of correlation map between rainfall anomaly and the index of dipole mode and Nino 3.4 can be seen in Figure 2. The period used in this research is from 1981 until 2017 and located in Sumatra island. The correlation map between rainfall anomaly and DMI can be seen in Figure 2 (a). The correlation result shows that all of Sumatra have negative correlations, but in a small part of the north and northeast regions shows positive correlations with DMI. The highest negative correlation is in the southern part, with a maximum correlation value of -0.4. The correlation map between rainfall anomaly and ONI can be seen in Figure 2 (b). The correlation shown is a negative correlation across Sumatra, with a high correlation value in the south and north reaching -0.4, while a small value in the central part is only reaching -0.2.

![Figure 2. (a) Correlation Maps between Rainfall Anomaly and DMI (b) Correlation Maps between Rainfall Anomaly and ONI](image-url)
Then, the results of correlation maps of rainfall anomaly with DMI and ONI are divided into seasonal periods of DJF, MAM, JJA, SON to see in more details. The results show different values in correlation in each seasonal period and in each part of Sumatra.

3.1 December – January – February (DJF) Period
Based on the correlation map analysis between rainfall anomaly and DMI in the DJF period, which can be seen in Figure 3 (a) shows a positive correlation over Sumatra. The correlation ranges from 0.1 to 0.3, with the strongest positive correlation in the central part of Sumatra, while the southern and northern parts have the weaker correlation. This positive correlation shows that during the DJF period, the rainfall anomaly and SST anomaly in the DMI region move in the same direction. It can be described when anomaly SST in DMI region is increased, so the rainfall in Sumatra tends to be also increased.

![Figure 3](image)

**Figure 3. (a) Correlation Maps between Rainfall Anomaly and DMI in DJF Period (b) Correlation Maps between Rainfall Anomaly and ONI in DJF Period**

The correlation map analysis between rainfall anomaly and ONI in the DJF period is shown in Figure 3 (b). It can be seen in the figure that not all regions in Sumatra show the same correlation. It shows a positive correlation in the central part, while it shows a negative correlation in the north and south. The positive correlation in the central part of Sumatra ranges from 0.1 to 0.3, while the negative correlation in the north and south ranges from -0.1 to -0.5. A negative correlation shows that during the DJF period, the rainfall anomaly and SST anomaly in the Nino 3.4 region move differently. It can be described when anomaly SST in the Nino 3.4 region is increased, so the rainfall in Sumatra tends to be decreased. In contrast, when anomaly SST in the Nino 3.4 region is decreased, so the rainfall in Sumatra tends to be increased.

In this season period, the correlation value of rainfall anomaly is not much different between DMI and ONI, however the correlation between rainfall anomaly and DMI in Sumatra shows a higher positive correlation value. Rainfall anomaly correlation with DMI shows the overall positive correlation while ONI shows negative correlation in the north and south.

3.2 March – April – May (MAM) Period
The correlation map analysis between rainfall anomaly in Sumatra and DMI in the MAM period is shown in Figure 4 (a). The correlation across Sumatra during this season period shows the consistent correlation as the previous season period, shown as a positive correlation but with different values.
The correlation values throughout Sumatra range from 0.1 to 0.4. Central Sumatra shows the highest correlation range reaches up to 0.4, while other parts of Sumatra only have a correlation value that reaches up to 0.3. It can be described that IOD is more influential in the central part of Sumatra than in other parts during the MAM season period. In this season period, the higher correlation value is indicated by the correlation between rainfall anomaly and DMI with positive correlation.

![Figure 4. (a) Correlation Maps between Rainfall Anomaly and DMI in MAM Period (b) Correlation Maps between Rainfall Anomaly and ONI in MAM Period](image)

Based on the correlation map analysis between rainfall anomaly and ONI in the MAM period, Figure 4 (b) shows a positive correlation in southern Sumatra and a negative correlation in central and north parts of Sumatra. In this season period, the northern Sumatra shows the same negative correlation with the previous season period but with a higher value. The correlation value in the north of Sumatra ranges from -0.1 to -0.5. Sumatra's central part shows a negative correlation with lower values than the northern part, which ranges from -0.1 to -0.3. Meanwhile, the southern part shows a different correlation, which shows a positive correlation with a range of 0.1 to 0.3. In the MAM season period, the higher correlation value is indicated by the correlation between rainfall anomaly and DMI with positive correlation.

3.3 June – July - August (JJA) Period
The correlation map analysis between rainfall anomaly in Sumatra and DMI in the JJA period is shown in Figure 5 (a). The correlation across Sumatra in this season period is divided into two parts with the northern part which is consistent with positive correlations such as the two previous season periods, DJF and MAM, while in the southern part it shows a negative correlation. In the north, positive correlations indicate values ranging from 0.1 to 0.3. Meanwhile, in the southern part the correlation value ranges from -0.1 to -0.4.

Based on the correlation map analysis between rainfall anomaly and ONI in the JJA period, Figure 5 (b) shows dominant negative correlation in across Sumatra and small northern part shows a positive correlation. During this season the fluctuation of rainfall in southern Sumatra shows a higher correlation with SST in the Nino 3.4 region compared to other parts of Sumatra. The correlation value in the southern part reaches -0.5, while in the middle and part of the north it shows a smaller negative correlation value, which only reaches up to -0.3. The positive correlation in the northern part of Sumatra shows a small value and only reaches 0.2. In this JJA period, the correlation between rainfall
anomaly and ONI shows a negative correlation value that is higher than the correlation value between rainfall anomaly and DMI.

3.4 September – October – November Period
The correlation between rainfall anomaly and DMI in the SON season period can be seen in Figure 6 (a). Based on the results of the correlation maps, the southern part of Sumatra shows a negative correlation, while in the northern part some shows a positive correlation, and some are negative. The negative correlation value in the southern part of Sumatra shows a high value, reaching -0.6. In this season period, the correlation value between DMI and the rainfall anomaly is the highest compared to the previous season periods. In the north it shows correlation values from 0.1 to 0.3, while negative correlations in northeast Sumatra show a range of values between -0.1 to -0.4.
The map of the correlation between rainfall anomaly and ONI is shown in Figure 6 (b). Based on the results of the correlation map, most of Sumatra shows a negative correlation and a small part of the north shows a positive correlation. Likewise, the correlation of rainfall anomaly with DMI, where the southern part of Sumatra shows the highest value compared to other regions. In the southern part, the correlation value between the rainfall anomaly and SST in the Nino 3.4 region reaches up to -0.5 but is dominant with a value of -0.4. Meanwhile, in the northern part, it shows a smaller value ranging from -0.1 to -0.3. A small part of the north shows a low positive correlation value, only ranging up to 0.2. In the SON season period, the higher correlation value is indicated by the correlation between rainfall anomaly and DMI.

SST anomaly on the west coast of Sumatra due to the IOD phenomenon has a significant correlation in southern Sumatra, especially during the SON season period. This shows the same results as the research conducted by Mulyana [18] which looked for the impact of dipole mode to rainfall in Indonesia using rainfall data from the Global Historical Climate Network (GHCN). Hermawan [19] conducted a study on the analysis of normal rainfall in West Sumatra and South Sumatra using the Fast Fourier Transform method and found that the Dipole Mode phenomenon had an effect on rainfall, especially during the JJA and SON period seasons.

4. Conclusion
Rainfall anomaly correlation with IOD and ENSO in spatial patterns in Sumatra Island for the period 1981 to 2017 using the data of CHIRPS, ONI, and DMI have been studied with seasonal analysis. The results show that remote sensing data from CHIRPS can provide good results in explaining the interactions between rainfall anomaly and IOD and ENSO phenomena in Sumatra. Furthermore, the remote sensing data can be used to analyze rainfall patterns that usually point observation data are not covered.

The DMI value has a high correlation with rainfall anomaly in Sumatra occurring during the transition season period, JJA and SON. The JJA period shows a positive correlation of up to 0.4 in the central part of Sumatra. During the SON period, the negative correlation is the highest, reaching -0.6 in Sumatra's southern part. The correlation between rainfall anomaly in Sumatra and ONI is generally not clear in the central part of Sumatra. The highest correlation in the southern part of Sumatra occurs during the season periods of JJA and SON. However, the value is not as high as the correlation between rainfall anomaly and DMI. In general, the correlation value for rainfall anomaly in Sumatra has a higher value when it is associated with DMI compared to ONI. Nevertheless, the correlation of rainfall anomaly using the entire data shows that the correlation with ONI has higher negative correlation values in all parts of Sumatra compared to the DMI.

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