The Effect of ENSO and IOD on The Variability of Sea Surface Temperature and Rainfall in The Natuna Sea

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The Effect of ENSO and IOD on The Variability of Sea Surface Temperature and Rainfall in The Natuna Sea

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Abstract. The Natuna Sea is located at the northwestern part of Indonesia. Previous studies had showed that ENSO has a stronger impact on SST than chlorophyll-a. According to several studies, Indonesian oceans are heavily impacted by IOD. This study uses SST data with high-resolution satellite imagery (MODIS and Pathfinder) and rainfall and wind data from the Reanalysis Model (ERA-5) which is processed using a composite method and correlation grid. This research results, when *La-Niña* negative IOD SST will decrease 1°C and rainfall rises 7 mm/day while when *El-Niño* IOD positive SST will increase by 1°C while in rainfall will decrease by 3 mm/day. The variation of SST and rainfall is more influenced by ENSO than IOD.

1. Introduction

Indonesian oceans are located between two large oceans, namely the Pacific Ocean and the Indian Ocean. Natuna Sea, which is located in the northwestern part of the Indonesian oceans is thought to be affected by the two oceans. One aspect of climate variability related to sea surface temperature is the *El-Niño* Southern Oscillation (ENSO), where ENSO is an anomaly of sea surface temperature at the equator of the Pacific Ocean. ENSO has three phenomena including normal ENSO, El-Niño, and La-Niña. SST anomaly does not only occur in the Pacific Ocean but also occurs in the Indian Ocean. IOD or Indian Ocean Dipole is an SST anomaly that occurs in the Indian Ocean which affects Indonesian oceans as well as being affected by IOD [1].

Previous research conducted by several researchers [2,3,4,5] has studied extensively the climate variability of ENSO and IOD, but the research that assessing the simultaneous impact of ENSO and IOD on SST and rainfall has yet to be carried out, particularly in the Natuna Sea. Continuing from previous research, [5] stated that ENSO greatly affects SST in the Natuna Sea and [3] found that IOD

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has a strong influence on rainfall distribution. This study is intended to obtain a combined description of the effects of the two phenomena above (ENSO and IOD) on SST and rainfall in the Natuna Sea.

2. Research Method

This research focuses on the Natuna Sea region, with coordinates (2^o- 13^o N and 101^o - 119^o E) which can be seen in Figure 1. This location is between the Malacca Strait and the South China Sea (SCS).

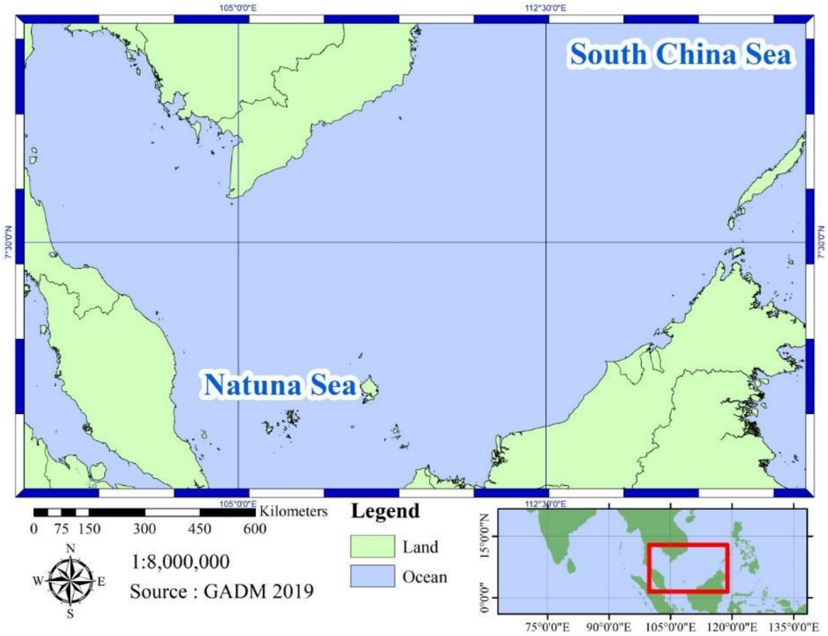

Figure 1. The study area at the Natuna Sea

SST data were obtained from high-resolution satellites (Pathfinder and MODIS) Level 3 and rainfall data were obtained from the ERA-5 reanalysis model data with the Common Data File Net (NetCDF) data format. SST data can be downloaded from the website https://data.nodc.noaa.gov/pathfinder for Pathfinder SST data and the https://oceancolor.gsfc.nasa.gov website for MODIS SST data, while for ERA-5 rainfall data through the website https://cds.climate.copernicus.eu. SST data uses a resolution of 4 km, while the rainfall data uses a resolution of 0.25^o. Supporting data in this study using wind data from ERA-5.

ENSO and IOD climate variability was determined by index. The ENSO index or Ocean *Niño* Index (ONI) is the ENSO climate variability index data taken from the temperature anomaly values in the *Niño3.4* region (5^oN-5^oS and 120^oE 170^oE). SST anomaly greater than 0.5^oC is called *El-Niño*, SST anomaly less than -0.5^oC is called *La-Niña*, and SST anomaly between -0.5^oC - 0.5^oC is called normal condition. Meanwhile, the IOD index uses the Dipole Mode Index (DMI). DMI is an SST anomaly from the West Sea Indian Ocean (10^oN-10^oS and 50^oE-70^oE) with the East Sea of the Indian Ocean (0^oN - 10^oS and 90^oE - 110^oE). IOD has three phenomena, namely positive IOD (SST anomaly greater than 0.25^oC), negative IOD (SST anomaly less than -0.25^oC, and normal conditions (SST anomaly between -0.25^oC - 0.25^oC).

The data used are daily data for 20 years (1998 - 2018). Daily data was processed into monthly data and reprocessed into monthly climatological data using the following formula:

$$\underline{X}b(x,y) = \frac{1}{mh}\sum_{j=1}^{mh} xi(x,y,t) \quad (1)$$

Description:

$\underline{X}b(x, y)$ = The median daily
$xi(x, y, t)$ = The daily data to – i at position (x) longitude, latitude (y), time (t)
mh = the number of hours in 1 day
$j = 1$ = day – i
If xi = NaN, then the data has no value (empty value) and not included in the calculation of average daily.

Different with Dewi et al. [6] who investigated the effect of ENSO and IOD to the variability of SST in JAva sea using composite event of ENSO and/or IOD, we conducted the correlation analysis to determine the correlation between SST and rainfall on ENSO and IOD. The correlation equation is used to determine the relationship between 2 variables, namely ENSO with SST, ENSO with rainfall, IOD with SST, and IOD with rainfall, and multi-correlation is used to determine the relationship between ENSO and IOD with SST and ENSO and IOD with rainfall. According to Maisyarah et al. [5], the correlation formula is written in the following equation:

$$r = \frac{N(\sum XY) - (\sum X \sum Y)}{\sqrt{(N(\sum X^2 - \left(\sum X)^2\right) - (N(\sum Y^2 - \left(\sum Y)^2\right)}} \tag{2}$$

Description:
r = correlation coefficient value
x = the value of the first variable
y = the value of the second variable
N = number of data

3. Results and Discussion

3.1. *Monsoonal Variation of SST and Rainfall in the Natuna Sea*

Monsoonal variations in the Natuna Sea are shown in Figure 2. The results of monsoonal variations have different patterns for each monsoon. The west monsoon (February) has cooler SST and less rainfall compared to the east monsoon (July) where SST is warmer and rainfall is high. The wind movement in the west monsoon is faster and moves southward (towards the Java Sea) than the wind movement in the east monsoon which is slower and moves towards the north (towards the Pacific Ocean).

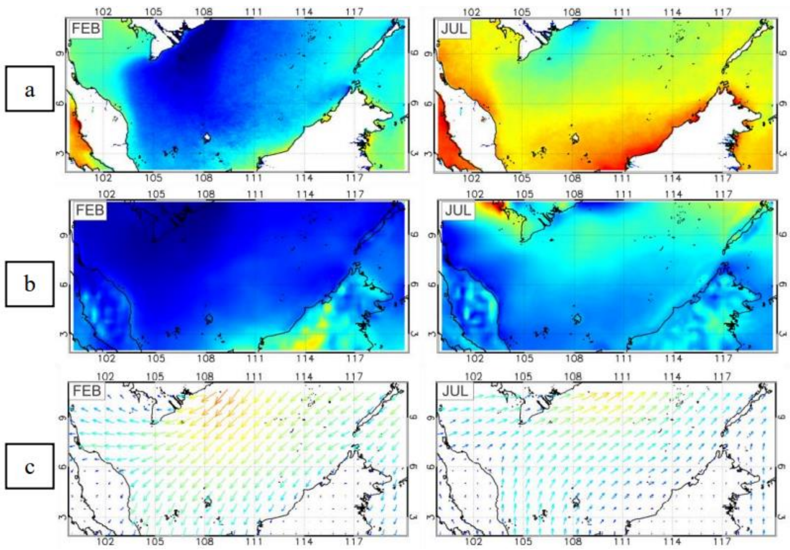

Figure 2. Monsoonal Variations of SST (a), Rainfall (b), and Wind (c) for 20 years (1998 - 2018) in the west monsoon (February) and east monsoon July) in the Natuna Sea

The strength of the monsoon winds can affect SST. The stronger the sea surface winds, the more the transport ekman increases and the water mass in the bottom layer rises to the top. This event is known as upwelling. Increasing upwelling in water will cool these waters [5]. The east monsoon has a weaker wind speed than the west monsoon. The weaker wind speed makes the SST in the waters heats up. Research conducted by [7] found that SST tends to be cold in the east monsoon in the South Java Sea, this is because the southeast (east) monsoon winds have faster wind speeds than in the west monsoon so that the waters in the east monsoon will be cooler in the South Java Sea. Wind speed also affects the release of energy into the atmosphere as studied by [8] so that the faster the surface winds, the greater the heat energy released from the waters.

Rainfall that occurs in the Natuna Sea (Figure 2b) has little rainfall in the western monsoon. The research presented by [6] that the faster the surface wind speed, the lower the SST and this will affect evaporation and continued by the research of [2] stated that SST will affect rainfall in waters. It can be seen from Figure 2b that the rainfall will fall when SST is low and vice versa when SST is high, rainfall will be high.

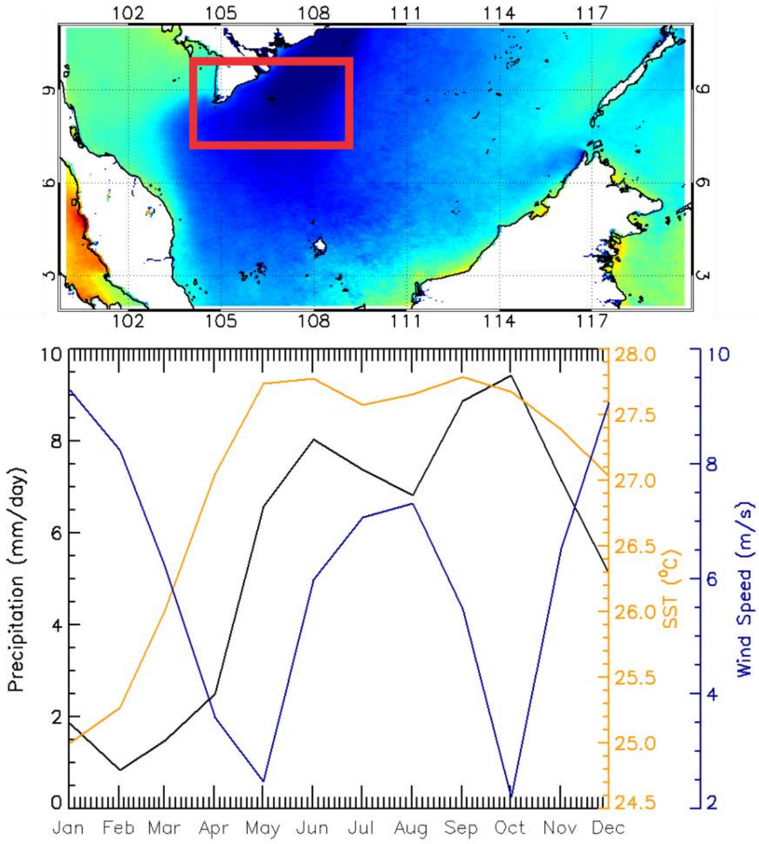

Figure 3. Time Series Graph of Monsoonal Variation of SST and Rainfall with Wind Speed in the Natuna Sea

The influence of wind will cause changes in SST and rainfall. The wind speed in the west monsoon (December, January, and February) is experiencing its peak. This is shown in Figure 3 where high winds are accompanied by SST and low rainfall. Meanwhile, during the eastern monsoon (June, July August) the wind speed is lower than in the west monsoon, which causes higher SST and higher rainfall. Strong monsoon winds will affect changes in SST and make the mixing of vertical water masses resulting in a decrease in SST, this decrease in SST also affects rainfall which follows due to the lack of heat in the ocean [3,8,9]. Apart from the monsoon wind factor, there is also a factor in solar radiation. According to [10], there is a difference in the sun's radiation between the west and east monsoons resulting in the northern hemisphere in the east monsoon, the waters tend to be warmer because they get more intensive sun exposure. In the eastern monsoon, the sun is in the northern hemisphere which makes the northern hemisphere part experience hot summer, especially in July, while in the west monsoon, the sun has shifted to the southern hemisphere so that the sun's radiation is more intensive on the southern hemisphere and makes the waters the northern hemisphere cooler.

3.2. *Effects of ENSO and IOD in the Natuna Sea*

The correlation coefficient shows an indication of the relationship between two variables. The relationship between ENSO and IOD on rainfall and SST during the western monsoon (February) is shown in Figure 4. The correlation between rainfall and ENSO (Figure 4a) shows that there is a strong negative correlation ($r \leq -0.6$) while the correlation between rainfall with IOD (Figure 4c) shows a weak positive correlation and some weak negative ($-0.1 \leq r \leq 0.4$) but the relationship between ENSO and IOD together with rainfall is high for some areas, especially the northeastern Natuna and northwestern Natuna Sea ($r \geq 0.6$) although other parts of the Natuna Sea have a low correlation ($r \leq 0.4$). The correlation between SST and ENSO (Figure 4b) in the western monsoon (February) shows a strong correlation, both positive and negative ($r \leq -0.6$ and $r \geq 0.6$). Just like rainfall, the correlation between SST and IOD also tends to be weak, both positive and negative ($-0.1 \leq r \leq 0.4$). The results of the correlation between ENSO and IOD together with SPL (Figure 4f) have varied correlations. The eastern part of the Natuna Sea has a weak correlation ($r \leq 0.4$) while the middle part of the waters tends to have a strong correlation ($r \geq 0.6$).

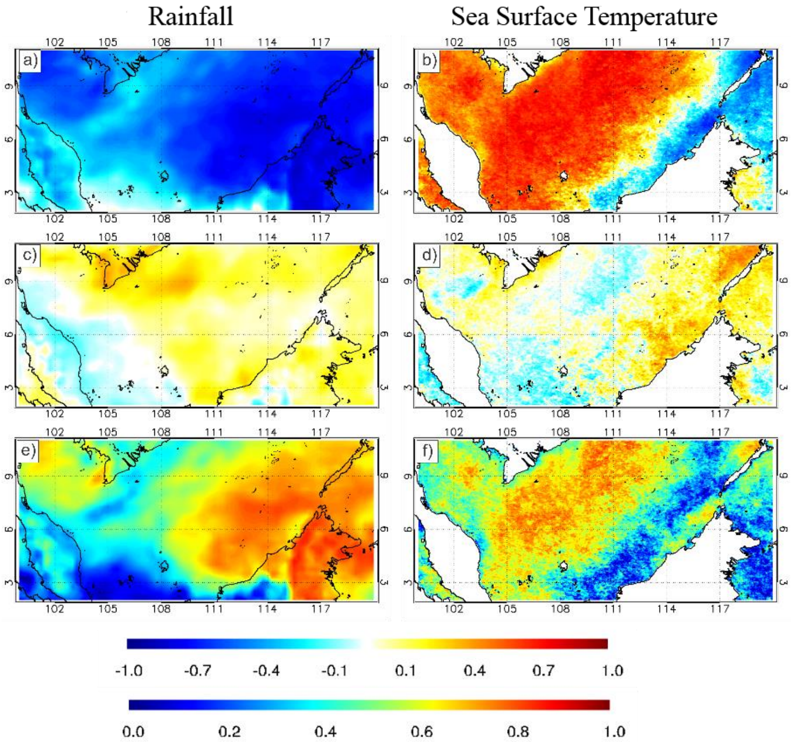

Figure 4. Rainfall Correlation with ENSO (a), IOD (c), ENSO and IOD (e) and SST Correlation with ENSO (b), IOD (d), ENSO and IOD (f) in the West Monsoon (February) in the Natuna Sea

The relationship between ENSO and IOD on rainfall and SST in the eastern monsoon (July) is shown in Figure 5. The correlation of rainfall to ENSO (Figure 5a) has a weak negative correlation ($-0.4 \leq r \leq -0.1$) while the IOD correlation with rainfall (Figure 5c) has a variable correlation but is classified as weak. The western part of the Natuna Sea has a very weak negative correlation ($-0.1 \leq r \leq 0$) and the northern, central and eastern regions of the Natuna Sea have a weak positive correlation ($0 \leq r \leq 0.4$). While the correlation value of ENSO and IOD on rainfall (Figure 5e), most of the Natuna Sea tends to have a weak correlation ($r \leq 0.4$), although in the north of the Natuna Sea there are waters that have a moderate correlation ($0.4 \leq r \leq 0.6$). The correlation between ENSO and SST in the east monsoon

(July) is shown in Figure 5b, which produces variable but weak correlations. The eastern region of the Natuna Sea has a weak positive correlation ($0 \leq r \leq 0.4$) while the western part of the Natuna Sea has a weak negative correlation ($-0.4 \leq r \leq -0.1$). The correlation between IOD and SST (Figure 5d) shows that all waters have a weak negative correlation ($-0.4 \leq r \leq -0.1$) and the correlation between ENSO and IOD towards SST (Figure 5f) shows a weak correlation ($r \leq 0.4$).

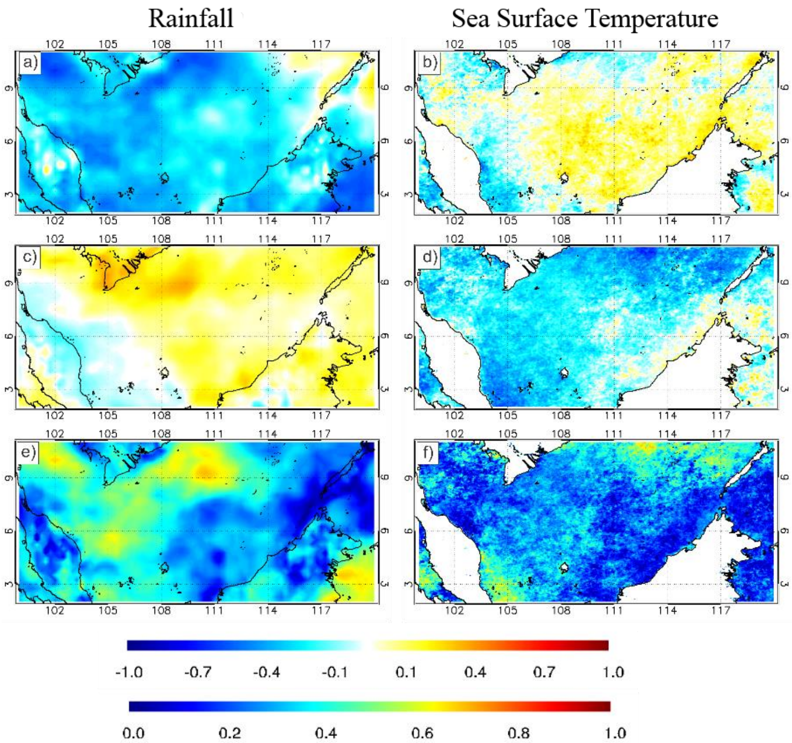

Figure 5. Rainfall Correlation with ENSO (a), IOD (c), ENSO and IOD (e) and SST Correlation with ENSO (b), IOD (d), ENSO and IOD (f) in the East Monsoon (July) in the Natuna Sea

The results of the correlation between ENSO and IOD on SST and rainfall show that in the western monsoon ENSO and IOD are more influential than in the east monsoon. Climate variability (ENSO and IOD) according to [3] that IOD greatly affects rainfall. This is also supported by research by [1] that ENSO and IOD fall into rainfall and SST in Indonesia. In line with the research of [5] who obtained results that in the eastern monsoon SST was not too influenced by the ENSO phenomenon, this made this study more focused on the western monsoon.

Anomalous results of rainfall (Figure 6a), SST (Figure 6c), and wind (Figure 6e) in the west monsoon (February) when *La-Niña* IOD occurs is negative. Rainfall anomaly when *La-Niña* IOD was negative (Figure 6a) there was an increase in rainfall with the highest increase of 7 mm/day, while the SST anomaly when *La-Niña* IOD was negative (Figure 6c) in some areas experienced an increase in SST as in the coast of Kalimantan Island is 1°C while in the central to the northern part of the Natuna Sea it has decreased by 1°C but overall most of the Natuna Sea has decreased in SST. The wind anomaly when there is a *La-Niña* negative IOD (Figure 6e) shows an increase in the speed of 0.2 - 3 m/s.

Anomalous results of rainfall (Figure 6b), SST (Figure 6d), and wind (Figure 6f) in the west monsoon (February) when *El-Niño* positive IOD. Rainfall anomaly when El-Niño and positive IOD (Figure 6b), most of the Natuna Sea has decreased rainfall (1 - 3 mm/day) although in some locations (northeast) there is an increase in rainfall (1 mm/day). SST anomaly when *El-Niño* and positive IOD (Figure 6d), almost all waters experienced a temperature increase of 1°C, only the coast of Kalimantan Island experienced a decrease in SST. The occurrence of positive *El-Niño* and IOD caused the wind anomaly (Figure 6f) to experience a decrease in speed, especially in the northern part of the Natuna Sea, which experienced the greatest decline of 3.5 m/s.

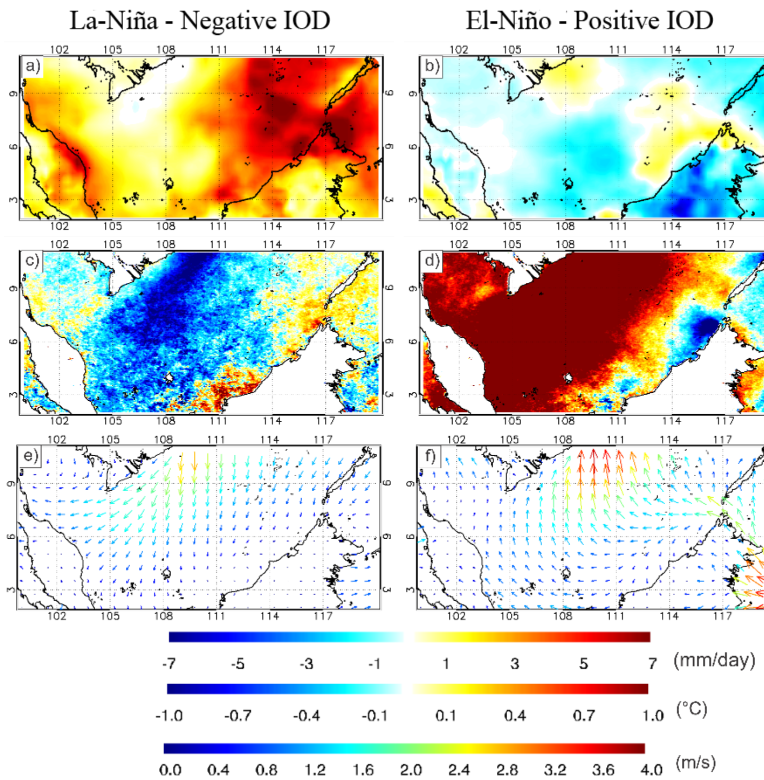

Figure 6. Rainfall Anomaly (a. *La-Niña* Negative IOD, b. *El-Niño* Positive IOD), SST Anomaly (c. *La-Niña* Negative IOD, d. *El-Niño* Positive IOD) and Wind Anomaly (e. *La -Niña* Negative IOD, f. *El-Niño* Positive IOD) in the West Monsoon (February)

The correlation between ENSO and SST variability in the western monsoon has a high value so that the Natuna Sea is strongly influenced by ENSO during the western monsoon. The correlation shown in Figure 4 shows a strong positive correlation, meaning that when the ENSO Index rises, the SST will also increase. It can be seen from the anomaly (Figure 6) that when the *La-Niña* negative IOD phenomenon, the SST will experience a decrease in temperature, while when the *El-Niño* and positive IOD phenomena the SPL will experience an increase in temperature. According to [10] *El-Niño* is an event of heating surface water temperature on the west coast of Peru and *La-Niña* is an event of cooling of surface water temperature on the west coast of Peru, then positive IOD occurs when sea surface temperature in the western Indian Ocean warms up and negative IOD occurs when the temperature sea level in the western Indian Ocean is cooling. The IOD correlation to SST in the Natuna Sea is not as strong as the correlation between ENSO and SST. This is different from the Java Sea, where IOD is quite influential. However, the results of this study found a fairly high correlation between ENSO and IOD simultaneously on SST. The decrease in SST is also followed by an increase in wind speed, this causes the release of heat from the sea to the atmosphere and the movement of water masses from the inner layer to the surface so that the SST on the surface cools as described in [8]. This happens in reverse when *El-Niño* positive IOD with a weaker wind speed, the wind is not too strong to make the mixing and discharge process of SST so that the SPL in this phenomenon is hotter.

Rainfall relationship to ENSO has a greater effect than IOD (Figure 4) but the relationship of climate variability between ENSO and IOD on rainfall is also high. Rainfall, when SST increases due to *El-Niño* and positive IOD, decreases in rainfall, and conversely, when La-Niña negative IOD, it will experience an increase in rainfall, this is also shown in the correlation. According to research conducted by [11], it shows that IOD has a negative correlation in Indonesian waters. From this study, it can be seen that the patterns found in the Natuna Sea have the same pattern. According to research by [1], when *El-Niño* positive IOD, the rainfall in Indonesia decreased, while when there was a *La-Niña* negative

IOD, the rainfall would increase. This is also in line with research conducted by [3] which shows that the rainfall will be higher when *La-Niña* negative IOD than when *El-Niño* positive IOD, this is because when negative IOD, SST in the East Indian Ocean will be higher than SST in the West Indian Ocean which causes There is an oscillating shift in rainfall from the West Indian Ocean to the East Indian Ocean so that rainfall will increase in the East Indian Ocean.

4. Conclusion

The influence of climate variability in the Natuna Sea on SST and rainfall appears to be more influenced by ENSO than by IOD. The results of the correlation analysis showed a strong enough relationship between ENSO and IOD with a relation coefficient value (r) greater than 0.6 and the relationship to IOD was weak (r) less than 0.4 but the relationship between the two climate variability and rainfall and SST was high (r) greater than 0.6. The mechanism of the relationship between ENSO and IOD on rainfall and SST is related to wind. SST during *La-Niña* negative IOD appears to have a higher wind speed compared to positive *El-Niño* IOD. Rainfall itself is also affected by wind or wind oscillations due to ENSO and IOD.

Acknowledgement

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