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Exploration of Seasonal Dynamics of Tropical Indo-Pacific Ocean during Dry, Wet and Neutral Years in Indonesia using Composite Method

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Abstract

Applying rainfall data for each month from Princeton University from January 1948 to December 2016, the impact of the Pacific El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), which is focused in the Indian Ocean, on rainfall in Indonesia was examined. IOD occurrences are significantly correlated with rainfall, as seen by the simultaneous association of seasonal rainfall anomalies during the peak of the rainy season (NDJ) in Indonesia's dry, wet, and neutral years, as well as other climatic indices in both climates. Rainfall has occurred in parts of South Sumatra, Java, South Kalimantan, Nusa Tenggara, Sulawesi, and East Papua. Meanwhile, ENSO events significantly correlate with rainfall in the southern regions of Sumatra, Java, Kalimantan, Sulawesi, and Papua. El Niño is associated with low sea surface temperature anomalies in the Indonesian Sea and southeast Indian Ocean. The low SST anomaly lowers the mean sea surface level (MSL). It reduces the amount of water vapor in the atmosphere, suppressing atmospheric convection in Indonesia and leading to a very sharp decrease in rainfall. Based on the forecasting and exploration of rainfall patterns in Indonesia described in this study, this research can be used as a reference for the government to prepare preventive measures against extreme global climate change events and to predict hydrometeorological disasters in disaster-prone areas.

Keywords: *IOD; ENSO; Variability of Rainfall; Composite Method; Ocean-Atmosphere Dynamics*

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INTRODUCTION

The Indo-Pacific region's tropical climate is significantly influenced by wind from the west and east, which also affects precipitation globally [1]. The yearly tropical-Indo-Pacific atmospheric interactions, specifically the El Niño Southern Oscillation (ENSO) in the equatorial Pacific and the Indian Ocean Dipole (IOD) in the tropical Indian Ocean, are connected to this global teleconnection [2], [3]. The primary reason for the unusual unpredictability of the tropical climate in the Indian Ocean is this IOD phenomena. Low sea surface temperature (SST) anomalies in the southeast Indian Ocean and high SST anomalies in central and northwest India are characteristics of the IOD event's positive phase [4], [5]. The condition is related to southeasterly wind anomalies around Sumatra's west coast and close to southern Java, and easterly wind anomalies along the equator [6]-[8]. The eastern, middle, and western basins of the Indian Ocean, as well as the eastern tropics, are where the oceanic and atmospheric circulation is found. Furthermore, these modifications increase air convection across the western and central Indian Oceans while suppressing it over the eastern Indian Ocean's warm pool [9], [10]. East Africa, Asia, India, and Australia experience higher humid conditions as a result of these events [11]. On maritime continents, ENSO-induced dryness may intensify favorable IOD events. In the meantime, interactions between the ocean and atmosphere in the equatorial Pacific make up ENSO occurrences [12]. The equatorial Pacific's annual change in ocean surface temperature is known as ENSO. Prior studies have demonstrated that ENSO affects the global environment and socioeconomic system [13].

In Indonesia, there was a substantial correlation between ENSO and precipitation anomalies. In many regions of the world, ENSO influences surface air temperature, rainfall, agricultural output, and disease epidemics [14], [15]. In order to present a thorough picture of the possible effects of the two main climatic systems, this article assesses and investigates the degree to which rainfall in Indonesia is influenced by Indian and Pacific equatorial phenomena. It also re-analyses the data. Indonesia experiences the effects of Indo-Pacific tropical phenomena, such as ENSO and IOD, on rainfall [16], [17]. The purpose of this study is to thoroughly and thoroughly examine the temporal fluctuations and spatial distribution of Indonesian rainfall as influenced by IOD and ENSO in the Pacific and Indian Oceans. While identifying some of the fundamental structural features of a meteorological or climatological occurrence that is hard to view in its totality, like a hurricane, squall line thunderstorm, or cold front, composite analysis is frequently a helpful technique. Lastly, a composite method was used to evaluate the dynamics of IOD and ENSO effects on precipitation throughout the Indonesian region. Every climatic mode event—positive IOD, negative IOD, El Niño, and La Niña events—was subjected to the composite analysis.

Through the mapping of interannual rainfall patterns in Indonesian territory based on precise and scientific regional identification, this research advances a number of scientific domains that are closely related to efforts to foresee hydrometeorological disasters [11], [18]. However, a thorough investigation could yield research findings that accurately and consistently characterize the interannual rainfall patterns in the Indonesian region. By mapping rainfall patterns generated by this research, the government can utilize this study as a guide to build mitigation measures for extreme global climate change events and provide preventive action to predict hydrometeorological disasters in disaster-prone areas [19], [20].

METHOD

Monthly rainfall data observed from the period January 1948 to December 2016 with a horizontal resolution of 0.50 x 0.50 was taken from Monthly Precipitation data from Princeton University in link https://www.ncdc.noaa.gov/cdo-web/datasets. In this study, the climate parameters were analyzed monthly low-pressure winds and sea surface temperatures published by NCEP/NCAR in link https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html. The monthly data used are hydrometeorological parameter data from Daily Precipitation from Princeton University, Sea Surface Temperature (SST) from The Hadley Center Global Sea Ice and Sea Surface Temperature (HADISST), Wind and Mean Surface Level (MSL) from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR), Monsoon Index from the Australian Bureau of Meteorology (BOM), Dipole Mode Index (DMI) from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Niño3.4 Index from National Oceanic and Atmospheric Administration (NOAA) with a time interval from January 1948 to December 2016. Data was available from January 1854 to the present with a horizontal resolution of 2.50 x 2.50. The data used in this research covers the same period as the rainfall data, namely January 1948 to December 2016.

This study used the dipole mode index (DMI) and the Niño3.4 index to classify IOD and ENSO events. The DMI is an index representing the anomaly of the SST gradient between the western equatorial Indian Ocean area (500E - 700E, 100S - 100N) and the eastern area (900E - 1100E, 100S - equator). Meanwhile, the Niño3.4 index is obtained by averaging SST anomalies for the Niño3.4 region, which covers 5°N-5°S, 170°W-120°W. Classify IOD and ENSO events from Jan 1948 to Dec 2013 with Table 1 [1], [21].

Table 1. Classification of years in which El Niño or La Niña and/or positive or negative IOD events occurred and conditions in neutral years (non-El Niño/La Niña and/or non-Positive/Negative IOD) [1], [21]

Climate Anomalies	Years
El Niño	1951, 1957, 1963, 1965, 1968, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1994, 1997, 2002, 2004, 2006, 2009, 2015
La Niña	1949, 1950, 1954, 1955, 1964, 1970, 1971, 1973, 1974, 1975, 1983, 1984, 1988, 1995, 1998, 2000, 2005, 2007, 2008, 2010, 2011
Positive IOD	1961, 1963, 1967, 1967, 1972, 1976, 1982, 1983, 1987, 1991, 1994, 1997, 2002, 2003, 2006, 2006, 2008, 2011, 2012, 2015
Negative IOD	1954, 1956, 1958, 1960, 1989, 1992, 1996, 1998, 2010
PIOD dan El Niño	1976, 1982, 1987, 1991, 1994, 1997, 2006
NIOD dan La Niña	1974, 1984, 1998

Monthly SST data from the Hadley Center Global sea-ice and Sea Surface Temperature (HadISST) data with spatial resolution at 1°× 1° from 1948–2016. Researchers classify ENSO and IOD phenomena in the Pacific and Indian Ocean by referring to calculations for five consecutive months where DMI and Nino34 values are positive or negative. The study period was classified into 15 El Niño, 16 La Niña, and 12 neutral years, for the ENSO phase (Table 1). The IOD intensity is represented by the SST gradient which is an anomaly between the western equatorial Indian Ocean (50°E–70°E and 10°S–10°N) and the southeastern equatorial Indian Ocean (90°E–110°E and

10°S–10 °N), and was referred to as the Dipole Mode Index (DMI). Positive IOD year occurs when the average standard deviation for five consecutive months was at least equal to or greater than 1 (−1). Neutral Years without IOD and ENSO phenomena were also observed by researchers by looking at the average SST and MSL in these neutral years [22], [23]. It was seen the dynamics of SST and MSL when no IOD and ENSO phenomena occur.

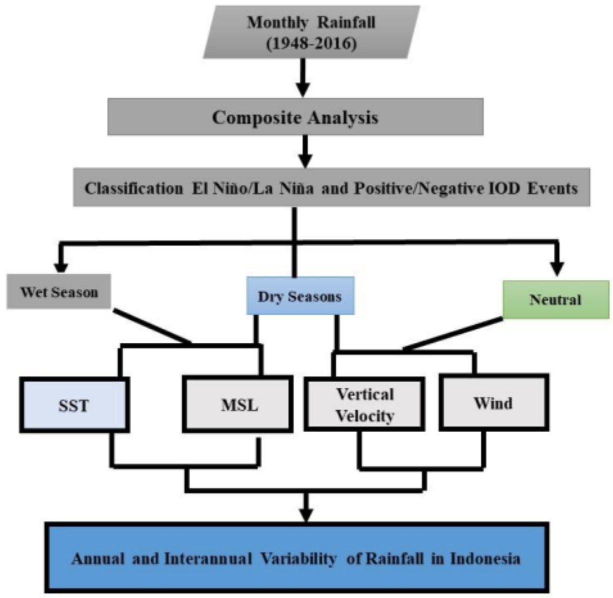

Figure 1. Procedures of Research

The research procedures can be seen in Figure 1. The test was carried out by observing the impact of the two climate modes on rainfall throughout Indonesia. First, the anomaly field is defined as a deviation from the monthly climatology. Then, the seasonal average rainfall was calculated based on the peak of the dry season in Indonesia, namely ASO, and the peak of the wet season in Indonesia, namely NDJ. The standard deviation at each location pixel normalizes seasonal rainfall anomalies. Simultaneous correlation analysis was used here to evaluate possible correlations between rainfall in Indonesia and the two climate modes [5], [24]. Finally, the dynamics of the influence of IOD and ENSO on rainfall in Indonesia are evaluated using composite techniques. Combined analysis was applied to each climate mode event, namely positive IOD, negative IOD, El Niño, and La Niña events.

Composite analysis involves collecting a large number of cases of observed climate phenomena. Composite analysis was carried out to examine the variability of parameters (P) at time t from rainfall, SST, MSL and wind data. Mathematically, it can be described as follows [11], [16], [19]:

$$comp = \frac{x_1 + x_2 + x_3 + \cdots \ldots + x_n}{n} \quad (1)$$

Comp is the result of composite analysis, x is the data to be composited, and n is the amount of data to be composited. In this study, the data used in the composite was analyzed based on the years of each climate anomaly event. Then, after calculating the sample average for the ENSO and

IOD phenomena, the researchers then evaluated the data by looking for confidence intervals in the composite results that had been carried out. The confidence interval for a mean was the range of values that possibly contains the population mean with a certain level of confidence. The confidence level interval value was calculated by [12], [25]

$$Confidence\ Interval = \bar{x} \pm t\left(\frac{s}{\sqrt{n}}\right) \quad (2)$$

The sample average is expressed by x ̄, t is the t-values, the sample standard deviation is expressed by s and n is the number of samples.

RESULTS AND DISCUSSION

The initial step taken by researchers was to calculate the mean and standard deviation (STD) of rainfall to identify spatial patterns of rainfall variations in Indonesia (see Figure 2).

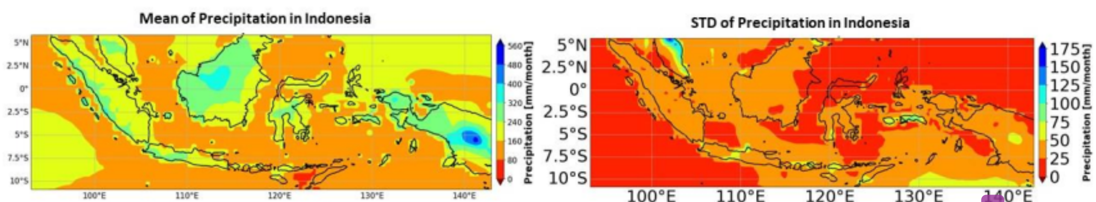

Figure 2. Variability of Rainfall in Indonesia based on average and standard deviation calculated from January 1948 to December 2016

The standard deviation or standard error is the distribution of the data in a sample to see how far away or how close the value of the data is from its mean value. In other words, the standard deviation is the value of the square root of the variance and shows the standard deviation of the data from its average value. The smaller the standard deviation value, the closer it is to the mean. However, the larger the standard deviation value, the greater the variation in the data. The standard deviation is used to see how far the distribution of the rainfall data used is from the average or mean. The north-central region of Kalimantan and the southeast region of the Papua Islands are the two regions with high rainfall (>350 mm/month) in the total average rainfall, according to the average and spatial standard deviation data [3], [26], and [27]. In addition, it is demonstrated that regions with a comparatively high percentage of rainfall are found in the south coasts of West and Central Java, Central Sulawesi, and West Papua, as well as the west coast of Sumatra. In contrast, coastal regions exhibit comparatively greater fluctuations than either highland or lowland regions, as seen by the rainfall standard deviation. Apart from that, researchers also observe Indonesia's spatial climatology every month. Based on Figure 2, it can be seen that the peak of the dry season in Indonesia occurs in August-September-October (ASO). In contrast, the rainy season occurs in November-December-January (NDJ).

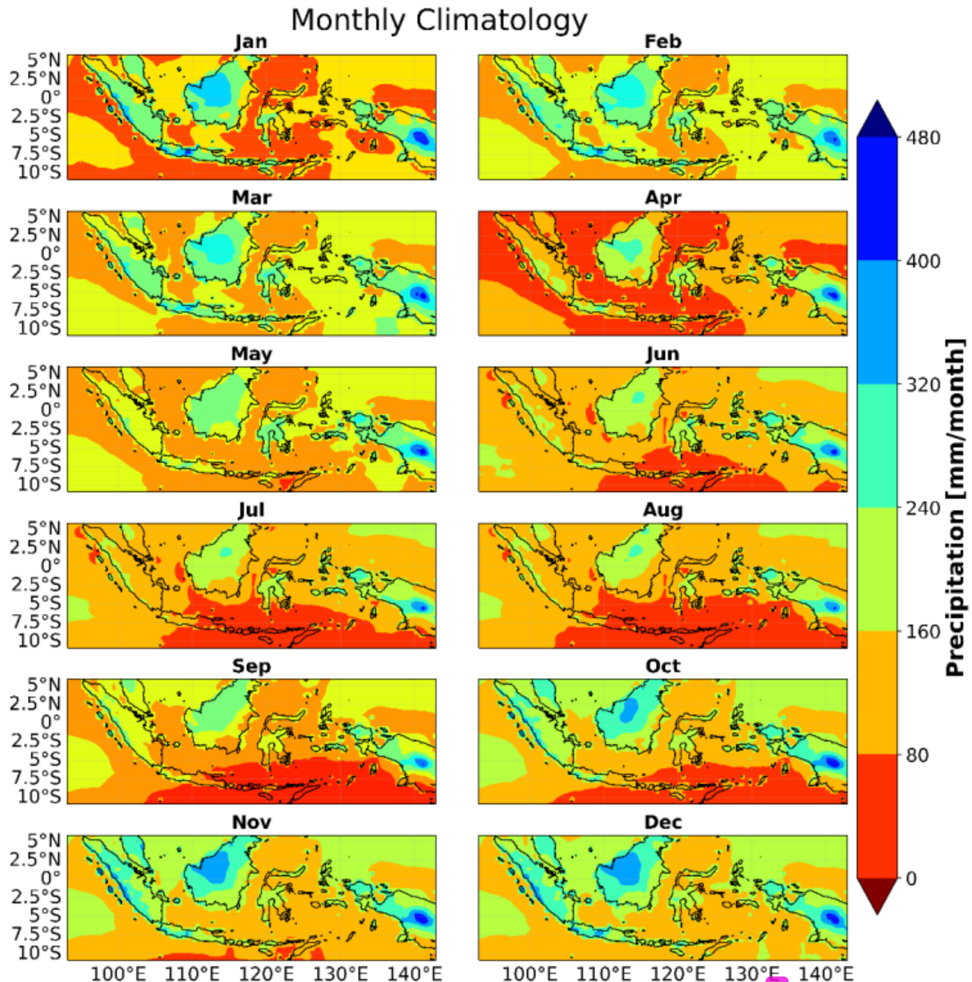

Figure 3. Monthly Climatology based on average and standard deviation calculated from January 1948 to December 2016

Furthermore, to evaluate the seasonal variation of rainfall across Indonesia, the mean and standard deviation of rainfall for each season were calculated spatially, as shown in Figure 4. As expected, low rainfall occurs during the end of the dry season in Indonesia, i.e., ASO. In contrast, high rainfall occurs almost all year round across Indonesia at the beginning of the wet season in Indonesia, i.e., NDJ. It is evident from Figure 3's monthly climatology statistics that Papua and the Kalimantan Islands get heavy rainfall all year long. Sumatra also has rather significant rainfall throughout the NDJ season. In contrast, Nusa Tenggara experiences very little rainfall (less than 100 mm) during the ASO season. Compared to other islands, Maluku Island experiences less rainfall throughout the year.

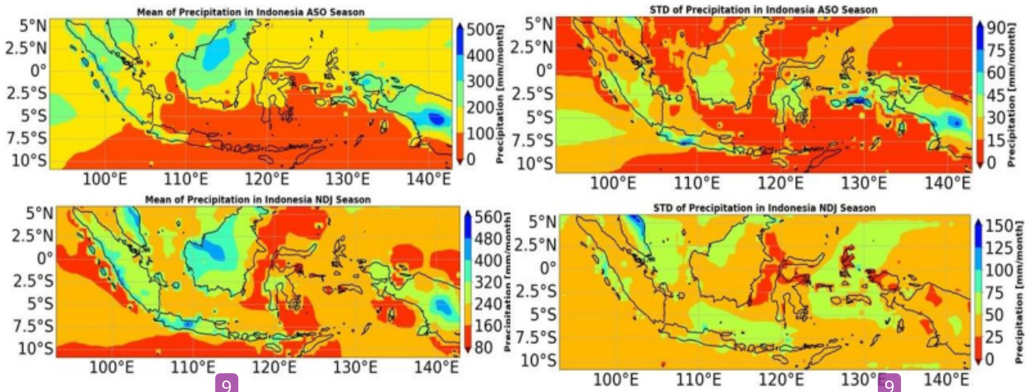

Figure 4. Average and standard deviation of rainfall in the ASO and NDJ seasons calculated from January 1948 to December 2016

The potential impact of IOD and ENSO occurrences on rainfall in Indonesia is evaluated by calculating simultaneous correlations between seasonal rainfall (ASO and NDJ) and the Indonesian climate mode. For every season, Figure 5 displays the simultaneous inter-seasonal correlation between rainfall and the DMI and Niño3.4 indices. There is a strong association between rainfall during the dry season (ASO) and both IOD and ENSO events. However, the IOD event only has a significant correlation (r ≤x-0.25, significant at the 95% confidence level) with rainfall in East Kalimantan and South Java Island in the ASO season, and the NDJ season is correlated in most of Sulawesi Island. In contrast, ENSO events during the ASO season have a strong correlation with rainfall in Sumatra, Java, Kalimantan, Sulawesi, and Papua's southern provinces. With the exception of the Malacca peninsula and the western portion of Sumatra Island, ENSO has a negative correlation with the majority of Indonesia during the NDJ season. It should be mentioned that neither IOD nor ENSO phenomena have consistently showed a substantial link with northern Sumatra.

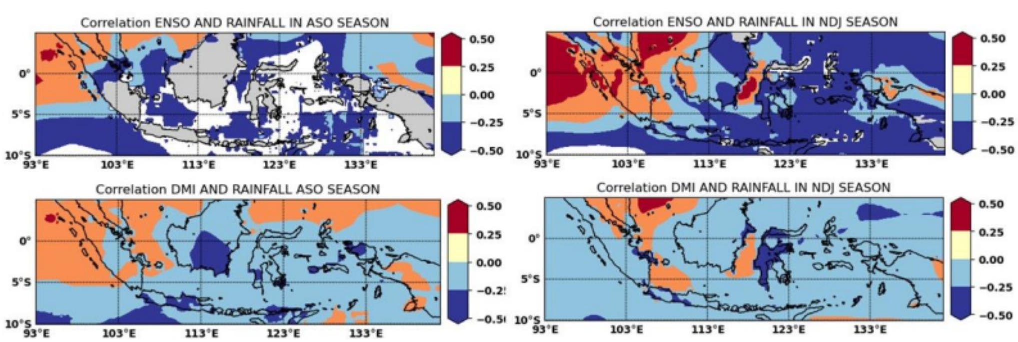

Figure 5. Correlation of DMI, NINO34 and rainfall in Indonesia during the ASO and NDJ seasons

The influence of each climate mode event (i.e., IOD and ENSO) on rainfall in Indonesia is calculated by applying a combination of rainfall, SST, zonal level winds and meridian winds (850 mb) calculated using the composite method during the IOD and ENSO events, in the ASO season and NDJ season. As a result, the ASO season shows an interconnected pattern between rainfall and the ENSO and IOD climate mode indices. Seven positive IOD events co-occurred with El Niño events, while six negative IOD events occurred in three La Niña years and three non-El Niño/La Niña years. On the other hand, inter-annual variations in rainfall in the NDJ rainy season are not closely related to ENSO/IOD. However, rainfall tends to be abundant in "neutral" (non-ENSO/IOD) years. This phenomenon is influenced by the winter monsoon in the northern hemisphere with the force of cold and dry northerly waves.

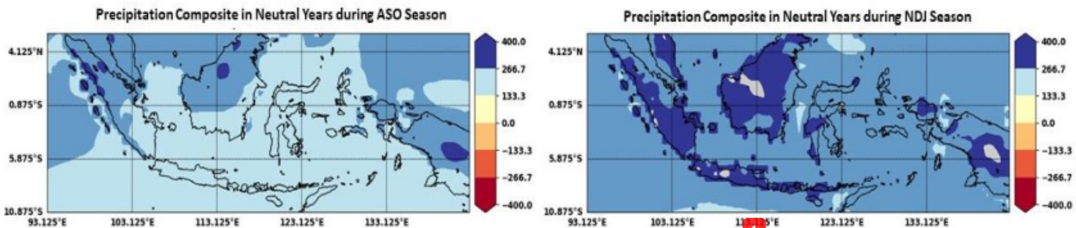

Figure 6. Composite Rainfall in Indonesia during Neutral Years in the ASO Season and NDJ Season

The average anomaly of Indonesian rainfall variations at the peak of the dry season (ASO) and the beginning of the rainy season (November–January, NDJ) in neutral years are shown in Figure 6. Visualization of the composite distribution of rainfall over Indonesia in Neutral Years in the ASO and NDJ Seasons shows that during early neutral years the NDJ monsoon tends to be much wetter and fluctuations in rainfall are very evident between the ASO and NDJ seasons. ASO season, drought years (normal rainfall anomaly ≤ −1.0) occur during El Niño include 1952, 1957, 1963, 1965, 1968, 1972, 1976, 1982, 1986, 1991, 1994, 1994, 1997, 2002, 2006, 2009, and 2015. Ten of the sixteen drought years corresponded to positive IOD years. In contrast, wet years (normalized rainfall anomaly ≥ 1.0) occurred in 1949, 1950, 1954, 1955, 1964, 1970, 1971, 1973, 1983, 1988, 1995, 1998, 2000, 2005, 2007, 2010, and 2011. Three of the seventeen wet years coincided with the occurrence of negative IOD phenomena (including years with the simultaneous occurrence of La Niña). In addition, rainfall anomalies tend to vary in La Niña years. The composite mean SST, MSL, Zonal Winds and Meridian Winds for ASO and NDJ in Neutral Years from 1948-2016 are shown in Figure 7.

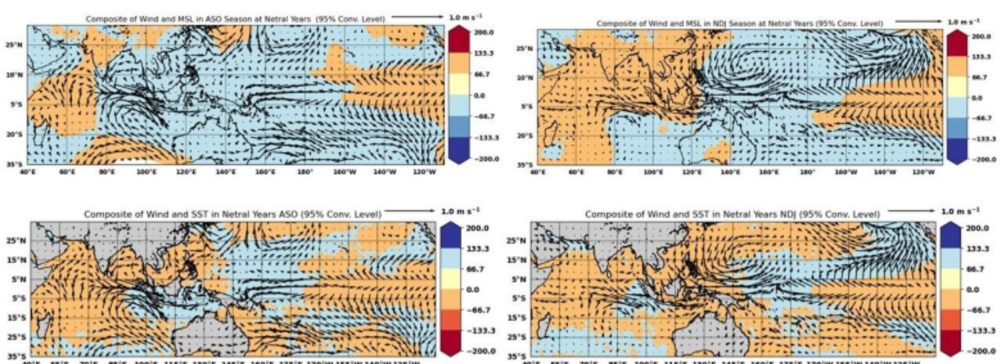

Figure 7. Composite of Average SST, MSL, Zonal Wind and Meridian Wind for ASO and NDJ in Neutral Years in the range 1948-2016.

In general, based on the mean SST values shown in Figure 7, during the study period, there was an increase in the monthly mean SST value (positive anomaly) at the beginning of the rainy season. A decrease in monthly mean SST values (negative anomaly) was found during the dry season in Indonesia in neutral years. While Figure 8 explains that the combined pattern of rainfall anomalies throughout Indonesia during the ASO season for both types of IOD and ENSO phenomena, namely positive/negative IOD and El Niño/La Niña. During positive IOD events, most areas of Indonesia experience a rainfall deficit during the ASO season. The peak rainfall occurs in the NDJ season in the southern part of Sumatra, Java and southern Kalimantan receive more rainfall than other regions. However, it is interesting to note that the northern part of Sumatra does not experience a rainfall deficit in peak positive IOD event (ASO) years, instead receiving a relatively large rainfall surplus in positive IOD years. The combined rainfall anomaly during negative IOD events shows a unique pattern.

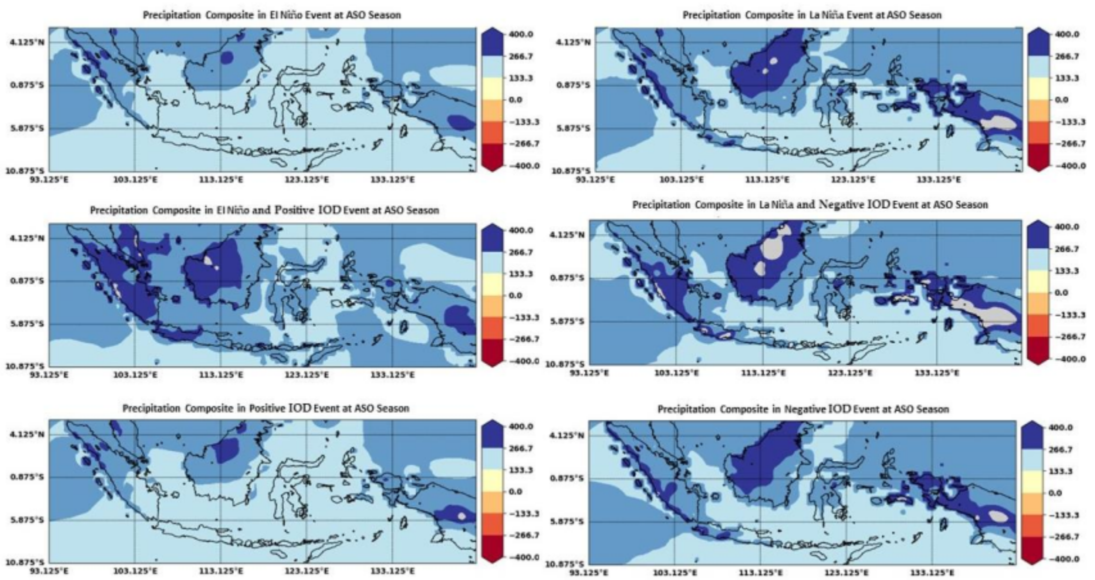

Figure 8. Composite of Rainfall in Indonesia during ENSO Years and IOD in the ASO Season

Figure 8 illustrates the distribution of rainfall during the ASO season in ENSO and IOD years. It reveals that central Indonesia receives more rainfall during the ASO season, whilst northern Sumatra and eastern Papua receive less. In the meantime, the majority of Indonesia suffers from a rainfall deficiency during the ASO season. Positive IOD episodes exhibit a similar pattern to the combined rainfall anomalies in El Niño events. However, compared to positive IOD events, drought (negative precipitation anomaly) during Niño events, particularly during the ASO season, is less severe but spans a larger area" However, as illustrated in Figure 8, during the La Niña occurrence, all regions of Indonesia experience an excess of rainfall throughout the ASO season, with the exception of northern Sumatra. During the NDJ season, Kalimantan, Sulawesi, and Papua saw positive rainfall anomalies due to the La Niña event.

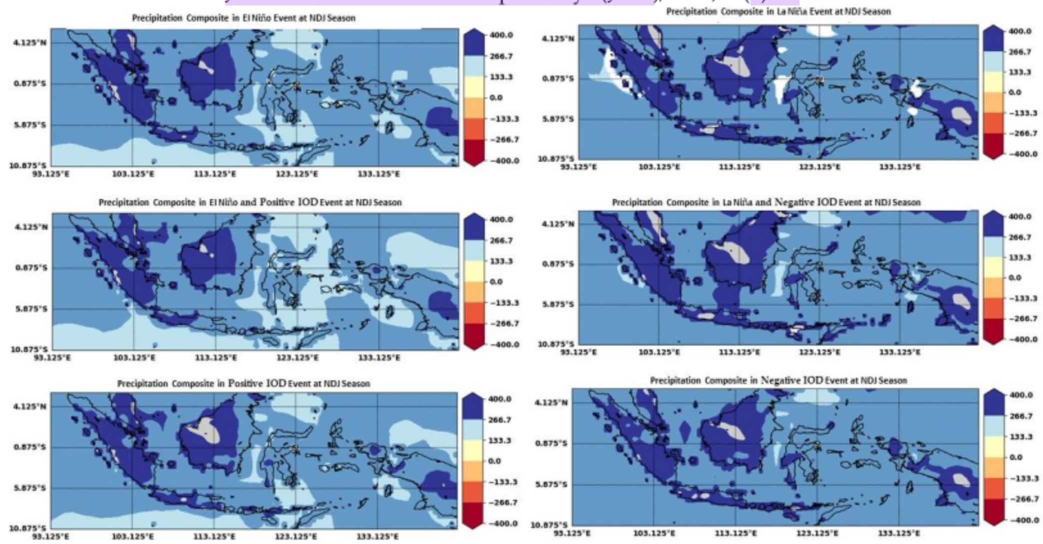

Figure 9. Composite of Rainfall in Indonesia during ENSO and IOD Years in the NDJ Season

Figures 10 and 11 display the combined spatial distribution of low-level wind anomalies, SLP anomalies, and SST anomalies in El Niño/La Niña years and positive/negative IOD years in the ASO and NDJ seasons. The SST anomalies in the eastern equatorial Pacific Ocean and the western equatorial Indian Ocean during these two episodes were comparatively warm (over +1.50C). In the meantime, the western equatorial Pacific Ocean, encompassing the Indonesian sea area, and the southeast equatorial Indian Ocean both showed chilly SST anomalies (less than -1.50C). The ASO season is when negative SST anomalies across Indonesian sea areas are at its strongest. Along the tropical Pacific (Indian) Ocean, significant anomalous westerly (easterly) winds were also seen at the same time. Because of this circumstance, Indonesia experiences less convection activity, which results in a shortage of rainfall in this area [28], [29].

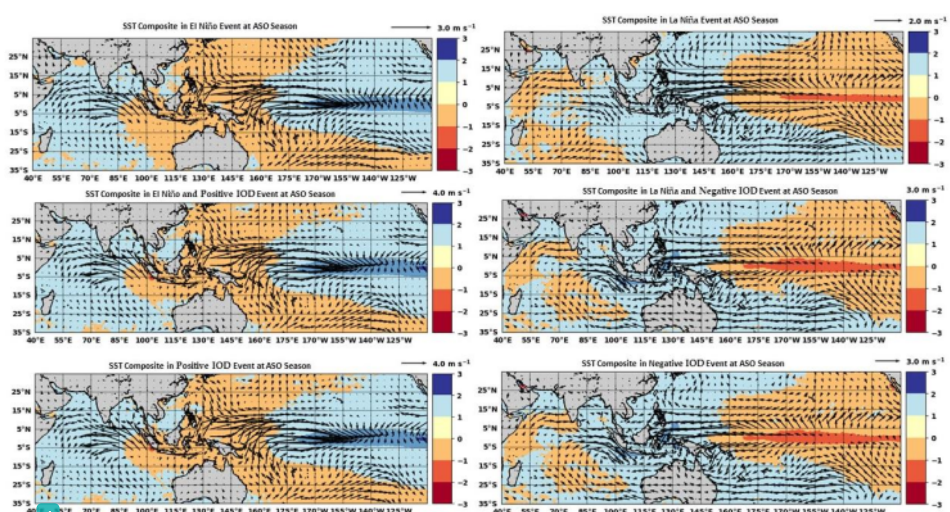

Figure 10. Composite of SST, Zonal Wind and Meridian Wind for ASO Season

Positive IOD years and El Niño events tend to coincide with dry season drought. Moreover, heavy rainfall tends to occur during negative IOD years compared to single La Niña years. In contrast, rainfall in Indonesia at the beginning of the wet season is generally not related to ENSO or IOD. Drought occurred in three El Niño years (1982, 1987 and 2002, two years coinciding with positive IOD) and wetness in two La Niña years (1998 and 2000). However, precipitation in each EOF mode tends to be abundant in neutral years. There were three neutral years: 1978, 1981 and 1989. A significant increasing trend in the amount of rainfall and rainy days occurs at the peak of the NDJ rainy season. In neutral years (non-ENSO and non-IOD) there is a tendency towards abundant precipitation, especially during the rainy season. Figure 11 shows a significant downward trend in precipitation during the wet season. At the beginning of the analysis period these neutral years appear. This is associated with interdecadal variations in the intensity and timing of the onset of monsoonal precipitation [30], [31].

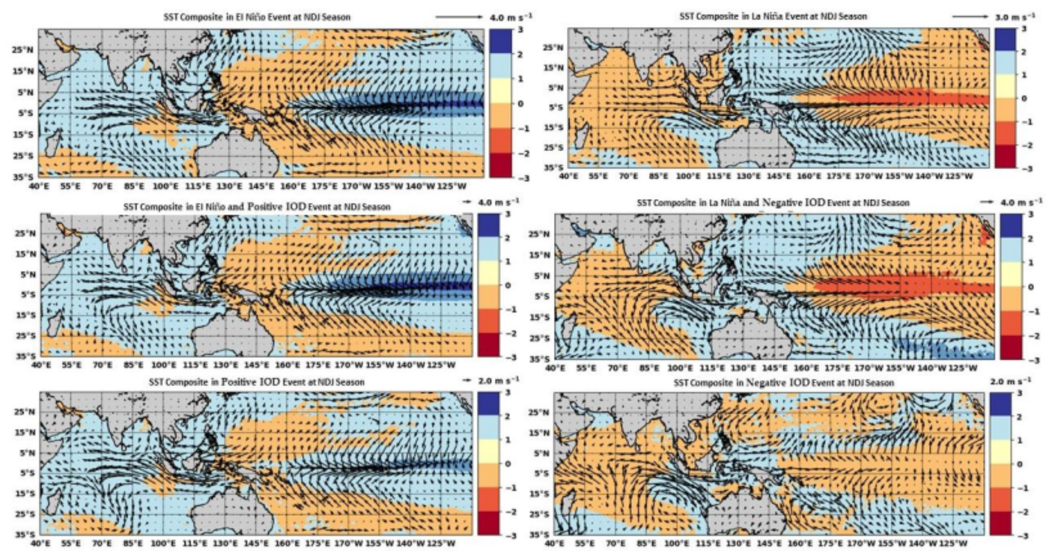

Figure 11. Composite of SST, Zonal Wind and Meridian Wind for NDJ Season

In addition to SST anomalies, Mean Surface Level (MSL) anomalies around Indonesian maritime waters are also observed using the composite method as a way to complement the ocean dynamics that occur during the ENSO and IOD phenomena. The visualization results of the MSL distribution are not symmetrical like those of the SST distribution discussed earlier. MSL anomalies in Indonesian maritime waters during the ASO and NDJ seasons are shown in Figure 11 and Figure 12. During the ASO season, SST in Indonesian maritime waters is negative while MSL is positive. This demonstrates that while the SST in Indonesian waters is extremely cold during the ASO season, when the El Niño event and positive IOD occur, sea level rises. When the positive IOD and El Niño phenomena happen at the same time, this anomaly is easier to see. On marine continents, large-scale convergence is also seen. Rainfall in Indonesia is increased by this circumstance, particularly in the western Sumatra region, which is where winds from the northern and southern hemispheres meet or congregate. On the other hand, during the peak season of the rainy season, when the La Niña or Negative IOD phenomenon occurs, namely the NDJ season, differences in SST, MSL and wind are also clearly visible. Rainfall in Indonesia can clearly be seen as a very significant increase, especially when negative IOD and La Niña occur simultaneously during the NDJ season. This explanation can be observed in Figure 12.

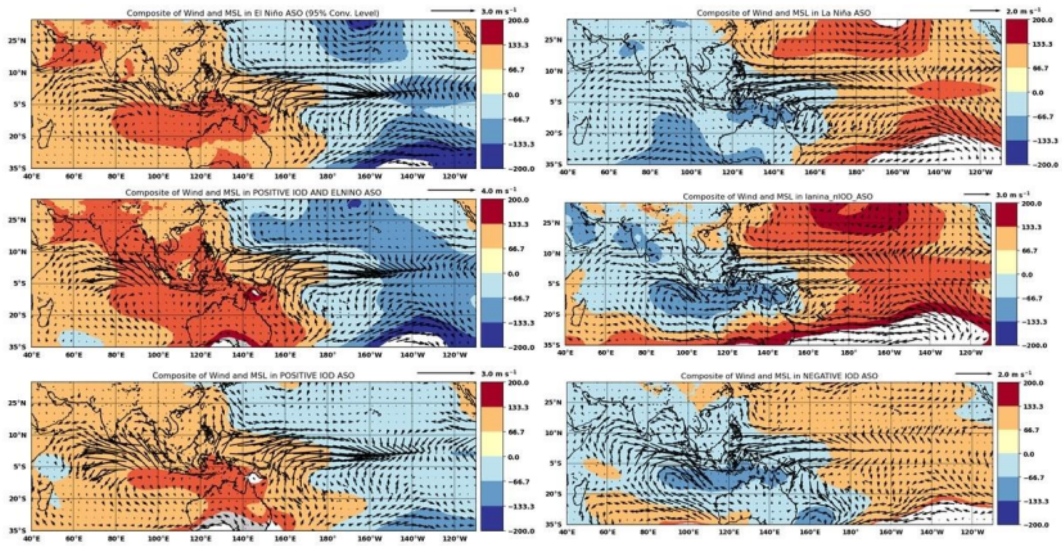

Figure 12. Composite MSL, Zonal Wind and Meridian Wind for ASO

However, in contrast to positive IOD and El Niño events, the combined pattern of SST anomalies, SLP anomalies, and low-level wind anomalies during negative IOD and La Niña events exhibits notable changes. Compared to the southeastern tropical Indian Ocean and Indonesian Sea, the SST anomaly over the equatorial western Indian Ocean and eastern equatorial Pacific is colder. During negative IOD episodes, SST anomalies in the Indonesian region are warmer than during La Niña events. The maximum intensity of the positive SST anomaly in this region was approximately +0.70 C during La Niña, as depicted in Figure 12, but it reached +1.00 C during the IOD event. greater water vapor in the lower atmosphere, low-level wind convergence, and greater atmospheric convection activity over the maritime continents are all consequences of warmer SST anomalies. This situation causes Indonesia to receive more rainfall [32]-[34].

Furthermore, Figure 13 show researchers have not only evaluated the average SST anomaly for each rainfall, however, to see ocean dynamics and anomalies regarding rainfall, researchers have also observed the Mean Surface Level (MSL) in the form of sea level rise in each observation season. Based on the analysis results, it was found that in the ASO and NDJ seasons there were both ENSO and IOD events. This shows that during the dry season (ASO) and rainy season (NDJ), the higher the sea level, the greater the rainfall and conversely, the lower the sea level, the lower the rainfall. The findings are consistent with research by Hamada (2003), which found that during Indonesia's dry season, winds will carry sea currents away from Indonesian waters, causing the sea level of the country's maritime continent to drop. This lowers atmospheric evaporation, which in turn affects rainfall. rain in Indonesia. Vice versa, during the NDJ season, the wind will direct towards local Indonesian waters at high speed, causing sea levels to rise in Indonesian waters [35], [36]. This results in an increase in atmospheric evaporation and rainfall in Indonesia during the NDJ season.

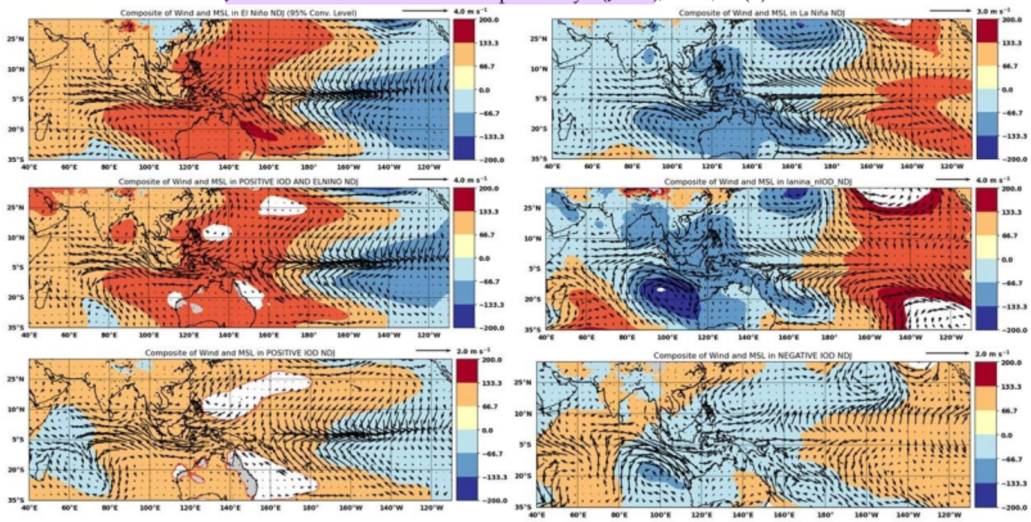

Figure 13. Composite MSL, Zonal Wind and Meridian Wind for NDJ Season

La Niña years (non-IOD negative), especially during the rainy season (NDJ), tend to have abundant rainfall. At the beginning of the analysis period, these wet years occur. Monthly and yearly rainfall totals in the Brantas watershed in East Java decreased between 1955 and 2005. Additionally, they observed that the monsoon's declining dominance was causing the yearly climate pattern to shift and the dry season to lengthen [10], [11], [21]. In the western equatorial Pacific, an SST anomaly with a center around 160°E occurs in the NDJ. The occurrence of this anomaly is related to the concentration of rainfall and warm water pooling in Indonesia before El Niño develops in the Pacific Ocean. Simulating the impact of SST and rainfall fluctuations on the magnitude of the emerging El Niño in Indonesian and eastern equatorial Indian Ocean waters. El Niño has been shown to be associated with substantially more precipitation in eastern Pacific [25], [37], [38].

The EOF method used to analyze rainfall data with Princeton analysis grid data is carried out by analyzing rainfall anomalies during the rainy, dry, and neutral seasons. The seasonal response to local seas around Indonesian waters—specifically, the end of the ASO dry season and the start of the NDJ rainy season—is the main focus of the investigation. These results provide clear information on monthly to seasonal climate predictions in Indonesia. From a climatological perspective, the ENSO and IOD phenomena will cause extreme rainfall in Indonesia. El Niño and Positive IOD resulted in a significant decrease in rainfall intensity in several regions of Indonesia. Meanwhile, La Niña and Negative IOD have increased rainfall intensity in several regions of Indonesia, especially during the dry season. Therefore, the ENSO and IOD phenomena are included as hydrometeorological disasters. However, from an oceanographic perspective, these phenomena may have different impacts. For example, the El Niño and IOD phenomena positively influence the upwelling process in waters south of Java, which impacts the distribution and concentration of surface chlorophyll in waters south of Java [39], [40]. The increase in chlorophyll concentration in the waters of southern Java due to this phenomenon will significantly impact fish catch areas in this area. Therefore, the El Niño and positive IOD phenomena positively impact fisheries.

Research has been able to map the impact of each climate anomaly phenomenon (El Niño, La Niña, positive IOD, and negative IOD) on Indonesia's dominant rainfall pattern. Information about the dominant pattern and intensity of rainfall due to the climate anomaly phenomenon and the trend in the evolution of the climate anomaly phenomenon that is known at least one season in advance can be used to determine the mitigation policies that must be implemented. When the climate anomaly tends towards El Niño and positive IOD, mitigation policies are directed at anticipating an extreme dry season with a decrease in rainfall intensity below average conditions (normal conditions). On the other hand, when the evolutionary trend leads to La Niña, and a negative IOD, the mitigation policy prepared is aimed at anticipating an increase in rainfall intensity. It is hoped that future research will be able to map rainfall patterns in Indonesia using the Self Organizing Method (SOM) machine learning method as a comparative mapping to the results of mapping using the EOF method, which has been carried out with the latest data so that it can be used to predict the dynamics of climate anomalies in the Indo-Pacific region.

CONCLUSION

Papua and Kalimantan have high rainfall throughout the year, compared to Maluku; the island of Sumatra also has relatively high rainfall during the NDJ season; the island of Nusa Tenggara has very low rainfall (< 100 mm) during the ASO season; and the seasonal analysis reveals that low rainfall is observed during the ASO season, while high rainfall is observed in almost all regions of Indonesia during the NDJ season. This study explores the role of individual IOD and ENSO events on rainfall variability in Indonesia and the tropical Indo-Pacific Ocean dynamics. IOD and ENSO are clearly visible in the results of the simultaneous association between seasonal rainfall and climatic indices for these two climate modes. During Indonesia's NDJ and ASO seasons, this phenomenon is highly correlated with rainfall. In southwest Indonesia, there is a strong link between rainfall and IOD incidents. In the meantime, rainfall in South Sumatra, Java, Kalimantan, and the Papua Islands is substantially correlated with ENSO episodes. The mechanism behind the connection between rainfall over the Indonesian region and the Indo-Pacific climate mode is evaluated through a composite seasonal study. The results demonstrate that ASOs typically occur in conjunction with El Niño and the emergence of positive IOD occurrences, when abnormally low sea surface temperatures are noted in the tropical southeast Indian Ocean and Indonesian waters. The event lowers precipitation and inhibits atmospheric convection over Indonesia. According to the composite analysis, El Niño and positive IOD episodes typically cause the Indonesian region to be significantly impacted by drier-than-normal circumstances. The Indo-Pacific Region's heat equilibrium data can be used to inform future studies. The thermodynamics of ocean-atmosphere interactions that take place during climatic anomaly phenomena are revealed by heat balance data.

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AUTHOR CONTRIBUTIONS

All authors read and agree final script. Melly Ariska as coordinator of data processing and checking the accuracy of research results. Suhadi reviewed references, Supari edited the manuscript and made the programming code. Muhammad Irfan edited the data and Iskhaq Iskandar checked the manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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