Influence of the positive Indian Ocean Dipole in 2012 and El Niño-southern oscillation (ENSO) in 2015 on The Indonesian Rainfall Variability

Lesi Mareta¹, Rahmat Hidayat², Rini Hidayati², Givo Alsepan³

¹Applied Climatology Study Program, Graduate School, Bogor Agricultural University, Bogor 16680
²Department of Geophysics and Meteorology, Bogor Agricultural University, Bogor 16680
³Department of Natural History Science, Graduate School of Science, Hokkaido University, Sapporo, Japan

Email:lesi_mareta@apps.ipb.ac.id

Abstract. Indian Ocean Dipole (IOD) and El Niño-southern oscillation (ENSO) are coupled ocean – atmosphere variability in the Indo – Pacific Oceans that play important roles to the Indonesian rainfall variability. This study is focused on the influence of the positive IOD in 2012 and El Niño in 2015 on the rainfall in Indonesia using satellite-derived precipitation data. Sea surface temperature (SST), rainfall and wind components, are analyzed to evaluate the detailed evaluation of those events. The results show that, in 2012, the positive IOD develops in July - October and reaches its peak in September. During the positive IOD in 2012, there is a negative SST anomaly in the eastern Indian Ocean (western Sumatra). This causes a shift in the warm water pool to the western Indian Ocean. This shifted warm pool is accompanied by a shift in the convective region, leading to decreased rainfall in the western Sumatra. Meanwhile, in 2015, El-Niño started to develop from July to November. Negative anomalies of rainfall in the transition period II and the east monsoon season are in line with the SST elevation in the eastern and central Pacific Ocean. So that the eastern and central of the Pacific Ocean become to center of low pressure which causes the air in the eastern Pacific Ocean to upward (convection) which will form a clouds that contain water, so that the eastern and central of the Pacific Ocean will experience an increase in the amount of rainfall while in the western of the Pacific Ocean or the eastern of Indonesia will experience a rainfall deficit.

1. Introduction
Indonesia is a country crossed by the equator surrounded by two ocean and two continents. This location make Indonesia the region of Hadley cell circulation and Walker circulation which greatly affects the diversity of rainfall in Indonesia. Walker circulation strongly influences the tropical climate in the Indo-Pacific region and also has a global effect, as can be seen from rainfall patterns in many parts of the world. This global relationship is associated with interannual tropical Indo-Pacific coupled ocean-atmosphere interaction, namely the Indian Ocean Dipole (IOD) in tropical Indian Ocean and the ENSO in the equatorial Pacific Ocean [1]. Indonesian rainfall is strongly correlated with ENSO and also correlated with IOD event [2]. The tropical Indian Ocean (IO) basin, which is the center of seasonal low-level wind variability including direction reversal (monsoonal flow) exhibits notably weak
interannual variability in sea surface temperature and surface winds, especially in comparison with the Pacific ehere interannual ENSO variability is impressive and influential [3].

The rainfall climatology of Indonesia Maritime Continent, which is dominated by strong southeast Asian Monsoon implying wet rainy season and Australian East Monsoon implying dry season, is much affected by the ENSO phenomena that cause irregular climate anomalies to most of Indonesia regions [4]. ENSO is a phenomenon of changes in atmospheric pressure differences in the tropical region of the eastern Pacific Ocean (Tahiti island) and atmospheric pressure above the tropical region of the western Pacific Ocean (Darwin, Australia)[5]. The Indian Ocean Dipole (IOD) is a natural ocean-atmosphere couple mode that play important role in seasonal an interannual climate variation. A positive IOD event can be identified by the negative SST anomaly in the tropical eastern Indian eastern Indian Ocean and Positive SST anomaly in the tropical western Indian Ocean [6].

During El Niño, air-sea interactions cause an increase in positive SST and sea level anomalies in the central and eastern Pacific and corresponding negative anomalies in the western Pacific [7]. Because maritime Indonesia is a large and complex area consisting of approximately 17,000 islands with high mountains, several important atmospheric and oceanic processes imposed by SST variability may influence various parts of the region [8]. One indication of this relationship is very significant correlation between Indonesian rainfall and tropical Pacific SST, as in the Niño 3.4 region [9]. The influence of IOD and ENSO on Indonesian rainfall are investigasi for seasonal timescale [10]. Indonesia will experience a deficit rainfall when changes in this ocean-atmosphere circulation cause ascending air motion in the western Indian Ocean and descending air morion in the eastern Indian Ocean[10][11]. Positive IOD and negative IOD phenome have an important role in rainfall in Indonesia. The positive IOD phenomenon causes a decrease in the intensity of rainfall in the Indonesian region. While, the negative IOD causes the Indonesian region to receive rainfall above average [12]. Because of the condition, a study is needed to see the important influence of the positive IOD phenomenon in 2012 and El Niño on 2015 the Indonesia rainfall variability.

2. Methodology
The study area is the Indonesian located in the tropical region ranging from 10°N - 10°N to 95°E - 150°E as shown in figure 1.

![Study area the Indonesian tropical region (10°N - 10°N to 95°E - 150°E)](Source: www.google.co.id/search?q=map+indonesia&safe) [13]

**Figure 1.** Study area the Indonesian tropical region (10°N - 10°N to 95°E - 150°E).

2.1. Data
The data used in this study are Sea Surface Temperature (SST), horizontal and vertical wind, Niño 3.4 index and Dipole Mode Index. DMI is defined as the SSTA difference between the western (50ºE – 70ºE, 20ºS – 10ºN) and southern (90ºE – 110ºE, 10ºS to equator) region of the tropical Indian Ocean. While, the region is bounded by (5ºN – 5ºS, 170ºW-120ºW); the area-average SST. The data length is
11 years (2005 – 2015) covering the Indian and Pacific Ocean. Rainfall data has an area (10°N - 10°N to 95°E - 150°E) for 11 years (2005 - 2015). Table 1 is the details of the data used.

### Table 1. Data used in the study.

| No | Data                        | Source      | Resolution     | Period          |
|----|-----------------------------|-------------|----------------|-----------------|
| 1  | Sea Surface Temperature     | APDRC       | 0.25° × 0.25°  | Jan 2005 – Dec 2015 |
| 2  | Rainfall                    | TRMM        | 0.25° × 0.25°  | Jan 2005 – Dec 2015 |
| 4  | Vwind                       | NCEP/NCAR   | 2.5° × 2.5°    | Jan 2005 – Dec 2015 |
| 5  | Uwind                       | NCEP/NCAR   | 2.5° × 2.5°    | Jan 2005 – Dec 2015 |
| 6  | Omega                       | NCEP/NCAR   | 2.5° × 2.5°    | Jan 2005 – Dec 2015 |
| 7  | DMI dan Niño 3.4            | ERSST-V4    | -              | Jan 2005 – Dec 2015 |

2.2. The Processing Data

This research focuses on analysing influence of the positive IOD phenomenon in 2012 and El-Niño in 2015 to Indonesia rainfall variability. Data processing is using software Grid Analysis and Display System (GRADS). The IOD and El-Niño phenomena are climate deviation from climatological condition. Therefore, to understand the influence of the positive IOD phenomenon in 2012 and El-Niño in 2015 the Indonesia rainfall variability, the first step is to calculate the climatology value of rainfall, SST and wind. Secondly, the calculation of anomaly value is the deviation value of the climatology value.

2.2.1. Climatology Calculation

Climatology is a general climate condition or an average that occurs in an area for a certain period. In this research, climatology calculation is used to see the average variability of the data. Climatology calculation uses the following equation 2.1 [12]:

\[
\bar{X}_i = \frac{\sum_{j=1}^{N} x_{ij}}{N},
\]

where \( \bar{X}_i \) is the climatological value for a particular month, \( N \) is sum of data for the year of observation, and \( i \) and \( j \) is the month and year of observation, respectively.

2.2.2. Anomaly Calculation

The IOD and El-Niño phenomena are climate deviations from their climatology. Therefore, to understand the events of IOD and El-Niño it is, necessary to calculate the climate parameter anomaly. Anomaly is a deviation from climatology expressed by equation 2 as follows [12]:

\[
A_i = B_i - \bar{X}_i,
\]

where \( A_i \) is anomaly value in a particular month, \( B_i \) is raw data, and \( \bar{X}_i \) is the value of the climatological parameter for a particular month.

2.2.3. Standard Deviation Calculation

Standard deviation is calculated using the following equation 3 [12]

\[
S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}
\]

where \( S \) is the standard deviation, \( x_i \) is the original data, \( \bar{x} \) is the average value, and \( n \) is amount of data.
3. Results and analysis

3.1. Climatological Rainfall
Normal state (climatology) is a climate condition in general or on average that occurs in a area for a certain period. The Indonesian rainfall climatology from 2005 – 2015 is shown in figure 2. Figure 2 shows that Indonesian rainfall climatology is in the range of 2 – 16 mm/day. Indonesian rainfall climatology in the east monsoon season (June - August) and transitional period II (Sept - Nov) has a low climatology value. This shows that in the east monsoon season and transition II Indonesian rainfall, generally have lower rainfall intensity than in the west monsoon season and the transition season I. While, in the western monsoon season (Dec - Feb) and the transition period I (March - May) in the Indonesian region have high rainfall climatology, this means that in the western monsoon season and the transition season I in general the Indonesia region will receive a higher rainfall intensity than during the east monsoon and transition period II.

3.2. Standard deviation
Indonesian rainfall distribution in the western of Sumatera during the east monsoon season (June - August) and transition period II (Sept - Nov) has a high standard deviation value, this means that the higher the standard deviation value, the more varied the distribution of rainfall value.

3.3. Correlation coefficient between DMI and Niño 3.4 and rainfall
Figure 4 shows that relationship between Indonesian rainfall and (a) DMI and (b) Niño 3.4, in the region (95ºBT – 115 BT and 10ºLU - 10ºLS). In figure 6 the DMI and niño 3.4 values are multiplied by negative, this is to equalize Indonesian rainfall value, with the negative multiple in figure 3.5 show that when DMI and niño 3.4 are negative then the value of rainfall is negative. When negative DMI value (positive IOD) and niño 3.4 are negative, the Indonesian region will experience a deficit of rainfall. Figure 4 shows that from 2005 – 2015, there are two Positive IODs, namely, in 2006 and 2012 and El-Niño occurred in 2009 and 2015. This research focused on positive IOD in 2012 and El-Niño in 2015. The correlation of rainfall to DMI is 0.5, while value correlation of rainfall to Niño 3.4 is 0.36.
Figure 3. Standard deviation of Indonesia rainfall.

Figure 4. Time series of Indonesian rainfall and (a) DMI (b) Niño 3.4; (white line: DMI, green line: rainfall Indonesia).

Spatial correlation is calculated from the correlation between Indonesian rainfall and DMI (dipole mode index) and Niño 3.4. Figure 5 shows that correlation between Indonesian rainfall with DMI and rainfall with Niño 3.4 has a positive correlation and negative correlation. The relationship between the Indonesian rainfall and DMI and Indonesian rainfall and Niño 3.4 are negative which means that Indonesia has a deficit rainfall. Figure 5 shows that in the east monsoon seasonal and the transition period II Indonesia rainfall has a high negative correlation with DMI, this means that in the east monsoon and period II Indonesia region has low rainfall caused by positive IOD phenomena.
The spatial correlation between rainfall and DMI shows that the negative correlation is high in the east monsoon season and the transition season II of southern Indonesia. However, the spatial correlation of Indonesian rainfall and Niño 3.4 shows that in the eastern monsoon and transition season II almost all of Indonesia has a high negative correlation. Meanwhile, in the western monsoon season and the transition season I in the northeastern part of Indonesia the rainfall is negatively correlated. The spatial correlation between Indonesian rainfall and Niño 3.4 is shown in figure 6.

3.4. Sea Surface Temperature, Zonal and Meridional Wind Anomalies during Positive IOD 2012 and El-Niño 2015

Indonesia rainfall anomalies are influenced by the SST in the pacific and indian region [14-15]. In the eastern monsoon season in the eastern Indian ocean (western Sumatera) there is a negative SST anomaly.
Negative SST anomalies are accompanied by an increase in surface pressure. Thus, east of the Indian ocean becomes a high pressure center which causes the wind to move from the east of the Indian ocean to the west of the Indian Ocean or easterly winds. While, on the west coast of Sumatera and the southern coast of Java are dominated by southeast winds. SST and wind anomalies during positive IOD on 2012 are shown in figure 7.

In 2015 when El-Niño happened, in the transition season II and eastern monsoon season the eastern Pacific ocean region along the equator experienced an increase in SST from its climatology. so that the eastern of Pacific Ocean will become a centre of low pressure which causes the wind to towards the eastern Pacific Ocean. SST an wind anomalies during El-Niño on 2015 are shown in figure 8.

3.5. Walker Circulation during IOD and El Niño
Vertical wind profiles or walker circulation is atmospheric circulation that occurs as result of the encouragement of SST gradient along the equator. The character of this circulation is determined by the interaction between ocean and atmosphere of the tropical area [16]. Walker circulation analysis is carried out by combining two vector components, namely zona wind and vertical wind ($\omega$). The zona wind component is obtained by averaging the value of the zonal wind at a latitude $5^\circ$S - $5^\circ$N. Meanwhile, the vertical wind component is obtained by looking at the wind movement vertically from the elevation of pressure between 1000hPa to 100hPa.
Walker circulation when an IOD phenomenon occurs, easterly wind along the equator cause the surface current to move west of the Indian ocean so that there will be severe advection towards the Indian Ocean. Adveective heat to the west of the Indian ocean causes a shift in the warm water pools to the west of the Indian ocean. This warm water pools shift accompanied by a shift in convection zones. In figure 9 shows that in the eastern monsoon season (DJF) in the year of positive IOD in 2012, the convection zone above the Indonesia region was smaller and in the transition season II the convection zone shifted towards center of the Indian ocean. Thus, in the eastern monsoon season and transition season II the Indonesian regio experienced a rainfall deficit.

Figure 9. Seasonal Walker circulation anomalies using zonal wind (u; m/s) and vertical velocity (ω; 10^{-2} Pa/s) level 1000-100 hPa during positive IOD 2012.
In figure 10, it can be seen that in the transition period II and the east monsoon season in the Pacific Ocean region (150ºBT – 180 BB) the air condition is moving upwards (convection). The reverse condition in the western of the Pacific Ocean region (120ºBT - 160ºBT) are downward (subsidence). This is in line white the increase in SST in the eastern Pacific Ocean.

![Figure 10](image)

**Figure 10.** Seasonal Walker circulation anomalies using zonal wind (u; m/s) and vertical velocity (ω; 10⁻²Pa/s) level 1000-100 hPa during El Niño 2015.

3.6. Rainfall Anomalies

3.6.1. Rainfall Anomalies 2012

The discovery of this dipole mode that accounts for about 12% of the SST variability in the Oceans, and in its active years, also causes severe rainfall in eastern Africa and drought in Indonesia [17]. Figure 11 is a rainfall anomaly when a positive IOD in 2012, it is seen that there is a negative rainfall anomaly in June to October. So that, the positive IOD in 2012 began in June to October and peaked in September. In 2012 there were negative rainfall anomalies in the western of Indonesia while the eastern of Indonesia had positive rainfall anomalies. That is, in 2012 when a positive IOD phenomenon experienced a rainfall deficit was the western of Indonesia while the eastern of Indonesia did not experience a rainfall deficit.
3.6.2. Rainfall Anomalies 2015

Negative rainfall anomalies in 2015 when El-Niño occurred in the western region of Indonesia, it started from July to November. Negative anomalies of rainfall in the transition period II and the east monsoon season are in line with the SST elevation in the eastern and central Pacific Ocean, so that the eastern and central of the Pacific Ocean become to center of low pressure which causes the air in the eastern Pacific Ocean to upward (convection) which will form a clouds that contain water, so that the eastern and central of the Pacific Ocean will experience an increase in the amount of rainfall while in the western of the Pacific Ocean or the eastern of Indonesia will experience a rainfall deficit. Based on the result on figure 12, the range of rainfall anomalies was high that was around -10 mm/day to 10 mm/day.
4. Conclusion

Indonesian rainfall climatology in the east monsoon season (JJA) and transitional period II (SON) has a low climatology value. This shows that in the east monsoon season and transition period II Indonesian rainfall, generally have lower rainfall intensity than in the west monsoon season and the transition season I. However, in 2012 and 2015 there was rainfall anomaly in the Indonesia region.

The positive IOD in 2012 began in June to October and peaked in September. In 2012 there were negative rainfall anomalies in the western of Indonesia while the eastern of Indonesia had positive rainfall anomalies. That is, in 2012 when a positive IOD phenomenon experienced a rainfall deficit was the western of Indonesia while the eastern of Indonesia did not experience a rainfall deficit.

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The spatial correlation between rainfall and DMI shows that the negative correlation is high in the east monsoon season and the transition season II of southern Indonesia. however, in contrast the result of the correlation between Indonesian rainfall and niño 3.4. The results of the spatial correlation of Indonesian rainfall and niño 3.4 show that in the eastern monsoon and transition season II almost all of Indonesia has a high negative correlation.

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