The dynamics of negative Indian Ocean Dipole (nIOD) and its relation to the anomalous high rainfall in West Java Province, Indonesia

R B Hatmaja, A H Rusmanansari and I M Radjawane

1 Earth Sciences Department, Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Jl. Ganeca no. 10, Bandung – West Java 40135, Indonesia
2 Meteorology Department, Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Jl. Ganeca no. 10, Bandung – West Java 40135, Indonesia

Abstract. West Java Province is the most vulnerable region to hydro-meteorological disasters (i.e. flood and landslide) in Indonesia. One of the main causes of these disasters is high level of rainfall. There were many global phenomena caused an increase in rainfall level in Indonesia, one of them was the Indian Ocean Dipole (IOD), especially its negative phase. By using the Dipole Mode Index (DMI), IOD strength or intensity can be determined. Besides, the composite analysis of anomalous sea surface temperature (SST), wind, and rainfall were constructed to examine the dynamics of the negative IOD and its relation to the high rainfall level in West Java. During the negative IOD (nIOD), the significant positive (negative) anomalous SST appeared around May in eastern (western) Indian Ocean. The intensity of anomalous SST in the following months reached its peak in September and accompanied by strong anomalous north-westerly wind. Furthermore, the high SST and anomalous wind increased the convection activity in the southern Java Island, and consequently, the level of rainfall in West Java increased up to 8.92 mm/day and may lead the risk of hydro-meteorological disaster.

Keywords: Indian Ocean Dipole (IOD), anomalous high rainfall, West Java

1. Introduction
Indian Ocean Dipole (IOD) is a dipole mode phenomenon with an interannual pattern which is identified by differences in sea surface temperature anomalies (SST) on eastern and western Indian Ocean, followed by wind anomalies and precipitation. There are two IOD phases, namely positive IOD and negative IOD. Positive IOD is characterized by the emergence of SST positive anomalies on the eastern side of the Indian Ocean and negative SST anomalies on the western Indian Ocean, while the opposite characteristics occur when negative IOD event [1, 2]. The IOD phenomenon has a significant correlation with global SST, rainfall, and atmospheric circulation anomalies, such as the Walker Cycle [3]. Negative IOD (nIOD) is a global phenomenon and often associated with high rainfall in Indonesia. Increased SST anomalies can increase convective cloud formation and rises the rainfall in Indonesia. In 2016, there was a nIOD event that happened from June to December with the peak in September, as well as an increase in rainfall in Indonesia [4, 5].
Along with increased rainfall in Indonesia, hydro-meteorological disasters also experienced an increase. One of the most common and most fatal hydro-meteorological disasters is landslides, especially in areas of steep hills and slopes such as in south of West Java Province [6]. In general, West Java region has a monsoonal type of rainfall because of its characteristics that are strongly influenced by the Asia-Australia monsoon system [7]. Hence, the movement of the Asia-Australia monsoon system will also be a trigger factor for high rainfall in West Java.

In interannual time scale, Indonesia’s climate has been considered to be closely linked to El-Nino Southern Oscillation (ENSO) in the Pacific Ocean [7]. However, rainfall variability of West Java is significantly correlated with IOD compared to ENSO [8]. Thus, by the study of the dynamics of the IOD, especially the negative phase, and its impact on increased rainfall anomalies, it is expected to be a reference and consideration in efforts to mitigate hydro-meteorological disasters, such as landslides and floods that often occur in West Java Province, Indonesia.

2. Data and Methods
To analyze the dynamics of negative IOD (nIOD), the composite analysis will be conducted on three parameters, i.e. sea surface temperature (SST), wind, and rainfall in the area about 15°N–15°S and 40°–120°E (see Figure 1a). Data used in this research were monthly data for 30 years (1987–2017) of SST and 10 m surface wind (zonal and meridional), which are retrieved from European Centre for Medium-Range Weather Forecasts (ECMWF) (http://apps.ecmwf.int/datasets/data/interim-full-moda/levtype=sfc/) [9], and also global rainfall data, which were retrieved from Global Precipitation Climatology Project (GCPG) (https://climatedataguide.ucar.edu/climate-data/gpcp-monthly-global-precipitation-climatology-project). All those data have spatial resolution about 1° × 1° and 0.25° × 0.25° for SST, wind, and rainfall data, respectively. Dipole Mode Index (DMI) was also used to determine the IOD events years. The DMI was retrieved from National Oceanic Atmospheric Administration (NOAA) (http://stateoftheocean.osmc.noaa.gov/sur/ind/dmi.php), which is calculated using Reynolds OIv2 SST analysis [10].

Furthermore, to analyze the relationship between IOD and rainfall in West Java, the data used in this study are rainfall data of 16 rain gauges in West Java region from PUSAIR (Center for Water Resources Research & Development) (see Figure 1b) for 30 years (1987–2017), GPCP global rainfall data in the area about 5.75°S–8°S and 106.25°–108.75°E (see Figure 1b), and DMI data. Due to substantial gaps in rain gauge records, all station rainfall data will be averaged. Thus the rainfall in West Java was assumed to be homogenous. In addition, an analysis of rainfall anomalies especially in boreal autumn season was also conducted to avoid the influence of intra-seasonal phenomena such as Madden-Julian Oscillation (MJO).

![Figure 1. (a) Study area of Indian Ocean Dipole (IOD) phenomenon and (b) for anomalous rainfall analysis in West Java Province.](image-url)
3. Results and Discussions

3.1. Spatial and Temporal Analysis of the Negative Indian Ocean Dipole (nIOD)

The IOD event year is defined as the year of DMI value below or above 0.5°C (one standard deviation) for two to three consecutive months during August to November [3, 11]. Based on the time series of the DMI during 1987-2016, which is presented in Figure 2, it can be seen that the years of the negative IOD (nIOD) events were in 1992, 1996, 1998, 2010 and 2016. Based on those five nIOD events, the composite analysis is conducted on three parameters, i.e. SST, wind, and rainfall, to analyse the dynamics of nIOD events in space and time.

![Figure 2](image)

**Figure 2.** The time series of Dipole Mode Index (DMI) during 1987 to 2016. Negative IOD (nIOD) events are shown by yellow boxes.

![Figure 3](image)

**Figure 3.** Composites of sea surface temperature (SST) anomalies associated with negative IOD events (based on five nIOD events) from May to December.
Figure 3 shows the dynamics of the Indian Ocean SST anomalies from May to December during nIOD event. Based on the figure, it can be seen that the dynamics of the SST anomaly begins with a positive SST anomaly on the eastern side of the Indian Ocean (0°–10°S and 90°–110°E) in May, followed by negative anomaly on the western side (10°N–10°S and 40°–60°E) about 2 months later and negative anomaly on the central side (5°–10°S and 70°–80°E) in the following month. The anomalous SST reaches the peak in September and decays in the following months [1]. During the peak of negative IOD events, the anomalous SST reached –0.88 °C on the western side and 1.63 °C on the eastern side.

![Figure 3](image)

**Figure 3.** Composite SST anomalies associated with nIOD events from May to December.

Figure 4 shows the dynamics of surface wind anomalies on the Indian Ocean from May to December during nIOD event. Based on the figure, it can be seen that there is anomalous north-westerly wind, which starts to blow in June and reaches the peak in October. During the peak, the anomalous easterlies wind reaches 4.49 m/s. Spatially, the anomalous wind blows in the area about 5°N–10°S and 70°–110°E.

During nIOD event, anomalous SST and north-westerly wind are also accompanied by anomalous high rainfall in Indonesia [12]. Figure 5 shows the dynamics of rainfall anomalies from May to December during nIOD event. Based on the figure, it can be seen that there is positive rainfall anomalies in the eastern Indian Ocean (near Indonesia) and negative anomalies in the western Indian Ocean (Eastern Africa). The anomalous high rainfall tends to move eastward and become higher in the following months. Then, it reaches the peak in October up to 7.63 mm/day. It is suggested that higher
SST can trigger higher convective activities, moreover the north-westerly wind will blow the convective cloud eastward.

Figure 5. Composites of rainfall anomalies associated with negative IOD events (based on five nIOD events) from May to December.

3.2. The Relationship between Negative Indian Ocean Dipole (nIOD) and Anomalous High Rainfall in West Java Province

Before further analyzing the relationship between rainfall in West Java Province and the IOD phenomenon, it will be examined in advance the monthly rainfall profile or seasonal cycle of rainfall in West Java Province. Figure 6 shows the monthly rainfall profile of West Java Province. In the figure, it is seen that the highest rainfall occurred in January and February and decreased until it reached the lowest rainfall in August, then rainfall will increase until the end of the year. High rainfall in December to February due to coinciding with the west season (boreal winter) or the blowing of the northwest monsoon wind which carries moisture from the Asian Continent, while the rainfall is low in August due to coinciding with the east season (boreal summer) or the blowing of the southeast monsoon which tends to bring dry air from the Australian Continent [7, 13]. Based on this analysis, the type of rainfall in West Java Province is a monsoonal type due to its characteristics which are strongly influenced by the Asia-Australia monsoon system [7].
If correlated linearly, the correlation coefficient between DMI and rainfall in West Java Province is very low ($r = -0.32$). This shows that the relationship between DMI and rainfall in West Java Province is not linear, so the relationship between the two is only assessed in extreme events, namely where the DMI value is below $-0.5$ and there is rainfall anomaly above one standard deviation (about 79 mm/month). To analyze the relationship between IOD and rainfall in West Java Province, the DMI value in October was compared to SON rainfall anomalies (September, October, and November). This is because the peak of IOD formation occurred in October. SON anomalies of seasonal rainfall are better used as a comparison than the average rainfall in October to avoid the influence of intra-seasonal phenomena, such as Madden-Julian Oscillation (MJO) [14].

Based on Figure 7 which shows the comparison between SON rainfall anomalies in West Java Province with the DMI value in October in time series, it was seen that in the years the incidence of negative IOD (DMI $<-0.5$) occurred an increase in extreme rainfall anomalies (above standard deviation of 79 mm/month).

To further examine the relationship between DMI and rainfall in West Java Province, Figure 8 presents a scatter plot between SON average rainfall and the DMI value. In the figure, it can be seen that the lower the DMI value is below $-0.5$, rainfall tends to increase significantly with the coefficient of determination ($R^2$) of 0.57. This shows that there is a fairly strong relationship between DMI and rainfall.

Further examining the relationship between rainfall and IOD, the rainfall that occurs in a particular range of DMI (above 0.5, between 0 and 0.5, between 0 and $-0.5$, and below $-0.5$) is evenly distributed level up. Figure 9, which presents the relationship between the DMI value and the average rainfall, shows that there is a significant increase in rainfall when the DMI value is below $-0.5$, so it is clear that there is a significant effect of nIOD on increasing rainfall in West Java Province, which was increased averagely up to 8.92 mm/day.
Figure 8. Scatter plot of seasonal rainfall SON (September, October, and November) in West Java Province with the DMI in October.

Figure 9. Relationship between DMI and average rainfall based on certain DMI ranges.

Figure 10 shows a comparison between monthly rainfall profiles with rainfall profiles when the nIOD events in 1992, 1996, 1998, 2010 and 2016, to see how the characteristics of rainfall in West Java Province when the incidence of nIODs. Based on the picture, it is seen that the rainfall in West Java Province from January to May tends not to be much different from the monthly profile (not too far above the standard deviation), but in the following months there was a significant increase in rainfall until the peak was in the month October which is the peak of the incidence of nIOD. From November to December, when the IOD has faded and disappeared, the rainfall returns to normal.

Figure 10. Comparison of monthly mean (seasonal cycle) rainfall in West Java Province with rainfall profile in West Java Province during the negative IOD events in 1992, 1996, 1998, 2010 and 2016.

4. Conclusion
Based on the composite analysis of five nIOD events, the significant positive (negative) anomalous SST appeared around May in eastern (western-central) of Indian Ocean during negative IOD event. The intensity of anomalous SST in the following months reached its peak in September and accompanied by
strong anomalous north-westerly wind. Furthermore, the high SST and anomalous wind increased the convection activity in the southern Java Island. Consequently, the average rainfall in West Java may significantly increase up to 8.92 mm/day and also lead the risk of hydro-meteorological disaster. Thus, by this study, it is suggested as reference and consideration in efforts to mitigate hydro-meteorological disasters by the government of West Java Province, particularly.

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