Analysis of El Niño and IOD Phenomenon 2015/2016 and Their Impact on Rainfall Variability in Indonesia

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Abstract. The El Niño phenomenon that occurs in 2015/2016 fell into category of strong intensity. The El Niño phenomenon had a very large impact on meteorological droughts in Indonesia. The aim of this study is to determine the dynamics of the atmosphere and the sea during the phenomenon of El Nino 2015/2016 and its impact on rainfall in the Indonesia region. The research methods consisted of several steps, in order to obtain an overview of the spatial conditions of rainfall during the El Niño period, data processing of both accumulation and anomaly of rainfall per-season (MAM, JJA, SON, DJF) were evaluated. The results showed that strong intensity of the El Niño occurred from early July 2015 to early March 2016. The shift of the convection center occurred in the Pacific Ocean during this period where the sea surface temperature anomaly in the eastern Pacific appeared warmer 2-3°C than normal temperature (1981-2010). In 2015, the positive Indian Ocean Dipole (IOD) also occurred in the Indian Ocean from August to November. These phenomena resulted wider drought impacts throughout Indonesia especially during the transition from dry season to wet season period (September-November).

1. Introduction
Indonesia is an archipelago country and its territorial position lies between the Pacific and Indian Oceans. This unique geographical profile has lead to rainfall variability in Indonesia, which is strongly influenced by the interaction between the atmosphere and the oceans around Indonesia. El Niño - Southern Oscillation (ENSO) is a phenomenon that consists of two phases, i.e, heat phase (El Niño) and cold phase (La Nina). Southern Oscillation is the changes of wind circulation caused by the difference of sea surface temperature (SST) between eastern and western Pacific Ocean [1]. This difference causes reversal of atmospheric circulation over the ocean located near the equator [2], and causes a global climate anomaly [3]. El Niño occurs when there is an increase of SST in the eastern and central Pacific Ocean equatorial areas, whereas La Nina is the opposite condition where there is cooling temperature. Several previous studies have shown that when the El Niño phenomenon in the equatorial Pacific Ocean appears to be associated with decreased rainfall in Indonesian territory [4-9].

El Niño with strong intensity had occurred in 2015/2016. In the El Niño period, there was also an ENSO-like phenomenon in the Indian Ocean commonly called the Indian Ocean Dipole (IOD). IOD is
the difference in temperature conditions of the east coast of Africa and the west coast of Sumatra [10]. In the case of positive phase of IOD, the sea surface anomaly in the western Indian Ocean is warmer, whereas in the eastern part it is colder than normal. Positive phase of IOD has been reported to have relationship with rainfall reduction in part of Indonesia [6, 8-11]. The relation of ENSO with rainfall variability over Indonesia has been studied by many researchers. The variability of SST in the Pacific Ocean especially the location of El Niño 3.4 affects 50% of the variation in rainfall throughout Indonesia while the variability of ocean surface temperature in the ocean affects only 10-15% [12]. Several other studies have shown that the positive El Niño and IOD impacts have resulted in the reduction of rainfall in Indonesia, thus the dry season tends to be longer and is getting dry [8 - 9]. Research on the influence of ENSO on rainfall in Java based on RegCM3 modeling and image interpretation has been done [13]. The results showed a strong correlation of ENSO and rainfall in Java Island compared to other islands in Indonesia. This is because Java Island is the center of Asia-Australia monsoon region. The impact of El Niño on reducing rainfall appears significant in the transition of the dry season to the rainy season (SON period), and also significant in the rainy season (DJF). This El Niño can be predicted based on an indicator of SST conditions in the Pacific Ocean as well as on the difference in surface pressure between Tahiti and Darwin better known as Southern Oscillation Index (SOI). How the dynamics of the atmosphere and oceans during the ongoing El Niño 2015/2016 and how their impact was toward the intensity and distribution of rainfall in Indonesia by using a database of Global Satellite Mapping of Precipitation (GSMaP) will be discussed in this study. This research is very important to assess the impact of El Niño as an evaluation in an effort to raise awareness of any areas that have the potential drought. Currently, the satellite-based remote sensing is the only practical way to measure rainfall on a global scale. Satellite sensors can produce high-resolution rainfall measurements and cover a wide and diverse area on the Earth's surface such as oceans, deserts and high mountains, which are not feasible to be monitored by conventional rain gauges or meteorological radar [14]. The use of satellite data GSMaP in this study is a good alternative considering the limited amount of rainfall observation stations in Indonesia or the unsustainability of available data. The use of weather satellites in measuring rainfall intensity is very useful for monitoring weather conditions that continue to develop. To generate global rainfall maps with high-resolution and high-precision retrieval. The GSMaP incorporates rainfall from TRMM and other polar orbit satellites [15]. The GSMaP is a project of the Japan space agency to approach the value of rainfall using space satellite media. The goal of the project is mapping global rain with a spatial resolution and high temporal and has a high accuracy using satellite with MWR sensor (microwave radiometer) [16]. GSMaP is managed by the Earth Observation Research Center (EORC) of Japan Aerospace Exploration Agency (JAXA) [15].

2. Data and Methods
In this study used several indexes global phenomenon to determine the atmosphere and sea dynamics that occurred in the Pacific Ocean and the Indian Ocean associated with El Niño 2015/2016 and IOD positive phase. These data are the Sea Level Pressure (SLP), Zonal Wind, Outgoing Longwave Radiation (OLR) and SST for El Niño 3.4 location. The data were obtained from NOAA [17]. While the Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD) data was obtained from the Australian Bureau of Meteorology [18]. Furthermore, to determine the pattern of rainfall in Indonesia during the 2015/2016 El Niño and its distribution in zonal and meridional used rainfall data obtained near real time from the GSMaP satellite [19]. The GSMaP data that are used in this study have a spatial resolution is 0.1 x 0.1 degree latitude/longitude and temporal resolution is daily. The impact on rainfall in Indonesia region was spatially observed by comparing the data of rainfall anomaly to its normal condition (1979-2000), based on IRI data [20]. The IRI data has a spatial resolution is 2.5 x 2.5 degrees latitude/longitude and temporal resolution is seasonally (3 monthly). Two types of data resolution is used in this research because of the limitations of new high-resolution GSMaP data that was available in 2014. The boundaries of this research area include the territory of Indonesia and its surroundings that are bounded between 12N-12S and 90-150E. The
research methods consisted of several steps. First of all was to collect main data and supporting data during period of 2015/2016. The second step was plotting the index of SST and IOD for analysis of period and intensity level of the phenomenon. The third step was to extract the satellite data that covering Indonesia for rainfall and OLR parameters. In order to obtain an overview of the spatial conditions of rainfall during the El Niño period, data processing of both accumulation and anomaly of rainfall per-season (MAM, JJA, SON, DJF) were evaluated. Based on GSMaP rainfall data, we processed the mean of latitude and mean longitude versus time to know the spatial distribution of rainfall in zonal and meridional. Data processing and display of rainfall spatial pattern in this research was proceeded by using Grid Analysis and Display System (GrADS) tools. The final step was analysis and interpretation of the results.

3. Results and Discussions
As an indicator of El Niño activity in the Pacific Ocean, the study used SST in the Pacific Ocean, especially in the Niño 3.4 region (5N-5S and 120-170W). The results indicated that the Niño 3.4 index was the strongest index that can illustrate the relationship of SST anomaly and indicator of drought or wetness in Indonesian region. The anomaly of SST of El Niño 3.4 during the period of January 2015 to June 2016 was indicated by the red color graph on Figure 1. Figure 1 shows that in mid-March 2015 to late June 2015, the phenomenon of El Niño started with weak intensity (SST anomaly 0.57°C), and continued to increase with moderate intensity (an anomaly of SST 1.37°C). The El Niño phenomenon arrived in strong intensity in early July 2015, where SST anomaly was over 1.5°C. Strong intensity lasted until early March 2016 and then gradually weakened. The El Niño peak with strong intensity occurred in November 2015 where SST anomaly reached 2.48°C. The current results were in accordance with the monitoring on the atmospheric dynamics conducted by Meteorology, Climatology and Geophysics Agency (BMKG), which suggested that El Niño was at a Moderate status and was predicted to decline slowly to Neutral in April-May 2016 [21].

Apart of the analysis of El Niño which occurred in the Pacific Ocean, the analysis of anomalies in the Indian Ocean, i.e. IOD, was important as an indicator of drought in some parts of Indonesia. IOD index is calculated from the difference of SST anomalies in the Indian Ocean near Africa (50-70E; 10N-10S) and the SST anomalies in the Indian Ocean east of the island of Sumatra (90-110E; 10N-10S) [10,11]. In the period of the 2015/2016 El Niño, positive phase of IOD also took place in the Indian Ocean since mid-August 2015 to mid-November 2015. The peak condition occurred at the end of September 2015 with an intensity of 1.17°C as shown in the yellow graph on Figure 1.

![Figure 1. Niño3.4 SST index (red color chart) and IOD (yellow color chart) in the period January 2015 - June 2016.](image-url)
The positive phase of IOD index becomes a drought indicator for the west region of Indonesia because the convergence centers were formed near Africa thus blocking the supply of clouds from the Indian Ocean to Indonesia. Normally, in the western Indian Ocean, the temperature of the sea surface is cooling, but warm in parts of the eastern hemisphere which is characterized by a fairly equal distribution of sea surface temperature around the equator [10, 11].

Figure 2 (left) shows the variation of SST anomalies in the equatorial Pacific Ocean. It suggested that since April 2015, the tendency of sea surface temperature in eastern Pacific Ocean and central parts always seemed warmer than the normal temperature (climatological, 1981-2010). The warm temperatures continued to rise, the dominance of positive SST anomalies 2°C -3°C means that warmer sea surface temperature 2°C -3°C normally occurred around July 2015 to February 2016. Even at around position 100-160W looks around November-December 2015 was a peak with SST more than 3°C from the normal temperature. Figure 2 (right) shows the variations of SLP anomalies in the Pacific Ocean. Since the period of July 2015 to April 2016, the pressure above sea surface in the western Pacific Ocean continued to increase. The highest SLP was about 140-160E, to reach over 2hPa which was higher than normal conditions (1981-2010). While in the center and eastern of the Pacific Ocean, the surface pressure is lower than normal (up to 2hPa).

Figure 2. SST anomalies (left) and SLP anomalies (right) in the Pacific Ocean during the period July 2014 to December 2016.

The pressure difference will then cause a zonal wind movement, due to the nature of the air to move from high to low air pressure. The condition caused air from the western Pacific Ocean moved towards the central and eastern Pacific Ocean. It was also the cause of convective clouds over the Indonesian territory shifted to the middle and east pacific that reduced rainfall in the territory of Indonesia. Figure 3 (left) shows the zonal wind anomaly pattern in the Pacific Ocean. It can be seen on Figure 3 (left) around March 2015 to March 2016, in the central and eastern Pacific Ocean around 140-120W in the dominance of a positive anomaly of 2-6 m/s, which means winds are blowing hard around 2-6 m/s stronger than normal.

The shift of the convection center from its normal conditions in the Pacific Ocean caused an increase in water vapor that will lead to high rainfall in the central and eastern Pacific Ocean region. This was supported by the fact that the lower OLR data was about 20-40 W / m2 compared to normal (1981-2010) in the region, as shown on Figure 3 (right).
Figure 3. Zonal wind anomalies (left) and a nominal OLR (right) in the Pacific Ocean during the period July 2014 to December 2016.

Rainfall data near real time with the new high-resolution GSMaP is available since March 2014, so there is a long period of limited data for the determination of normal / climatological precipitation that is needed to determine how much reduction in rainfall that occurs due to climatic anomalies such as El Niño them. Therefore, this study used the rainfall data from IRI from the climatology period of 1979-2000. Based on those data, during the period of transition from the rainy season to the dry season (MAM 2015, Figure 4), in which El Niño was in weak intensity, the rainfall in most parts of Indonesia are still in normal condition.

Figure 4. The spatial pattern of precipitation anomalies (mm/season) in El Niño 2015-2016.

Even in southern part of Sumatra, Java, Kalimantan and southern parts of western and central Sulawesi, the rainfall tends to be greater about 10-30 mm than the normal average, as shown on Figure 4. While the strong El Niño intensity underway in the Pacific Ocean, it seems to
have a significant impact on the drought in almost uniformly in all parts of Indonesia. This condition was called the dry season (JJA 2015, Figure 4), in which the negative anomalies reached 200-400 mm of rainfall index. As for the transition period from the dry season to the wet season (SON 2015, Figure 4), it suggested the increasingly dry conditions and widespread in region of Indonesia. At the same time, the rainfall decreased to reach about 400-600 mm compared to normal. During this period, the El Niño reached the peak where SST anomalies also reached 2.48 °C in November 2015, in conjunction with the positive phase of IOD phenomenon that occurred in the Indian Ocean.

In the rainy period (DJF 2016, Figure 4), the visible pattern of rainfall in most parts of Indonesia were back to normal even tend to be higher than the average, except in East Nusa Tenggara, North Sulawesi and Maluku which seemed still dry. The transition from the rainy season to the dry season (MAM 2016, Figure 4) was coinciding with the period of moderate El Niño intensity with SST anomalies amounted to 1.44 °C in mid-March 2016. The El Niño continued to get weaker in intensity with SST anomaly of 0.59 and then ended up being neutral by mid-May 2016. During the 2016 MAM period, the rainfall in Indonesia was generally around 20-40 mm higher than normal, except in Nusa Tenggara, North Sulawesi and parts of Papua, which was still in dry as suggested by rainfall was lower than normal, about 200 mm on average. In some parts of Sumatra, Bali, East Kalimantan and part of Papua, rainfall was in normal category. The results supported previous report [22] based on GPCP data finding the Asian monsoon rainfall anomalies associated with the 2015/2016 El Niño. The station and satellite records confirm the extremely deficient rainfall over Indonesia and the Philippines. During the period JJA 2015 to DJF 2016, it was generally a negative rainfall anomaly between 45 to 90 mm/month in the region.

Based on GSMaP rainfall data for the period 2015/2016, the spatial patterns of El Niño accumulation per-season rainfall occurred in Indonesia were obtained (Figure 5). Figure 5 shows the transition from rainy season to dry season (MAM 2015) where during that period, a weak El Niño intensity, the cumulative rainfall in most parts of Indonesia ranging from 00-1500 mm, lasted . The Asian monsoon still gives influence as seen in the transition. Even though its influence which brings a little mass of water vapour, Asian monsoon was also visible in the south in which small rainfall less than 300 mm was around Nusa Tenggara. The accumulation of heavy rainfall over 1800 mm happened in the waters west of Sumatra, south Palopo (Central Sulawesi), the waters north of Nabire (Papua Barat) and partly on the mainland of center Papua.

During the dry season in the period of El Niño with strong intensity, rainfall reduced significantly throughout the territory of Indonesia. The accumulated rainfall ranging from 300-900 mm that is less than 300 mm/season occurred in the whole areas south of the equator, except Papua. Areas in the northern part of the equator have an accumulated rainfall ranging from 300-600 mm. It can be seen that the reduced rainfall occurred not only because of the Asian monsoon influence but also because of stronger El Niño anomalies. El Niño anomalies are caused by the decline of STT in most of the Indonesian waters, and the shifting center of low pressure in the Pacific Ocean due to the weakening easterlies winds. The results supported previous report suggesting a strong relationship between drought and ENSO during the dry season (JJA) because the ENSO phenomenon affects the condition of SST in Indonesian waters [23]. Likewise, the studies of SST on some parts of Indonesia have a negative correlation with the ENSO events during the dry season (JJA) [12]. At the time, SST Pacific Ocean warms the central part of SST conditions in Indonesian waters so that it is cooler than the normal conditions. This condition resulted in the weakening of the southeast monsoon winds and east-west zonal winds that are the source of convection in Indonesian territory. Besides, SST addition also inhibits the evapotranspiration process which is the source of water vapour for the process of cloud occurrence.

During the transition from dry season to wet season (SON 2015), there normally should be an increase in rainfall before the rainy season due to the influence of south-west monsoon. However, the rain did not occur in the waters north of Bali and Nusa Tenggara because of the dry conditions in the Indonesian territory south of the equator. It shows the result of south easterly winds influence is still dominant in the area. However, in Papua, part of Sumatraand Kalimantan and Papua (between 300-
600 mm) are still higher than the highlands in Papua and Aceh reaching 1500 mm. Accumulated rainfall is generally less in the south of equator during this period due to the combined effects of El Niño anomaly in the Pacific Ocean and IOD positive phase in the Indian Ocean.

Figure 5. The spatial pattern of accumulated precipitation (mm) in El Niño 2015-2016 in Indonesia.

In the rainy period (DJF 2016), the visible pattern of rainfall in most parts of Indonesia was back to normal where the accumulation ranging from 600-1500 mm, except in East Nusa Tenggara, North Sulawesi, Maluku, was still dry with accumulated rainfall of less than 300 mm. In that period, El Niño still had a strong intensity but IOD had normal phase. The strengthening of monsoon wind Asia was more dominant in parts of Indonesia so that it would support the process of convection in most parts of Indonesia. The presence of wet air masses was brought into the territory of Indonesia. These results are in line with previous studies [13] which reported that the geographical aspects had an effect on the rainfall anomaly pattern. Based on data from the model output, the peak period of the rainy season (DJF) has relationship with El Niño and positive rainfall anomalies in Java.

However, during the transition from the rainy season to the dry season (MAM 2016) the moderate intensity of El Niño continued to weaken and became neutral. During the period of MAM 2016, the rainfall in all parts of Indonesia ranged between 600-1800 mm except in Papua highlands (over 1800 mm), Bali, Nusa Tenggara which were dry less than 300 mm as shown in Figure 5.

This research also analyzed the distribution of rainfall and OLR in zonal (E-W) and meridional (N-S) in Indonesian region. Zonal distribution was done by daily average rainfall / OLR data processing based on latitude vs time, and the distribution was done meridional with daily data processing of rainfall / OLR daily based on longitude vs time. The results of data processing for daily rainfall
distribution and daily OLR are zonal and meridional as shown in Figures 6 and Figures 7, respectively.

Figure 6 shows the pattern of zonal distribution of rainfall indicating that in the El Niño period with weak intensity to moderate while IOD is still in neutral condition (early March - early June 2015). Indonesian territory is dominated by daily rainfall with very light intensity, less than 5 mm especially the area around 102.5E-130E, while in the west (90-102.5E) and east (130-150E) visible rainfall intensity varies from very light to light (5-20 mm). However, in mid to late June mild the mild and moderate intensity of rainfall predominates in Indonesia especially in the east (125-150E).

During a strong intensity of El Niño accompanied by positive phase IOD, from early July to October, the drought-stricken Indonesian region was expanding and its longer period was indicated by the dominance of very mild daily rainfall intensity of less than 5 mm, except in the west (90-100E) that varied from very light to light (5-20 mm). At the peak of the strong El Niño around mid-November 2015 and subsequently entering moderate and weakening around the end of March 2016, the areas experienced severe drought where the decreaseing of rainfall intensity less than 5 mm mainly occurred around 115E -130E because IOD entered the neutral phase.

While in the west (90-115E) and eastern (130-150E), the intensity of rainfall dominated by light intensity is 5-20 mm as shown in Figure 6 (left). Based on the OLR data, during the study period the relationship is close where the obtained OLR pattern is very similar to the rainfall pattern which has opposite value. Figure 6 (right) shows that during the period of rainfall with a very light intensity of less than 5 mm in the location, the high OLR value was between 230-280 W/m2. While the areas with greater rainfall or with light intensity of 5-20 mm rainfall had smaller OLR value dominated less than 210 W/m2.

Based on the results of meridional distribution, data processing for rainfall (Figure 7, left) during the weak and moderate El Niño period (March-June), the dominant pattern of daily rainfall with a very light intensity of less than 5 mm occurred in the north of the equator, especially 2N-12N and south of equator especially 8S-12S. However, when El Niño took place with strong intensity and with positive phase IOD (July-December), the southern areas of the equator suffered from severe drought where the dominance of daily rainfall intensity was very light less than 5 mm. As for the area around 6N-2S, the rainfall intensity varied from very light (<5 mm) to light (2-20 mm), but the daily rainfall to the north (6N-12N) with moderate intensity (20-50 mm) was higher. Furthermore, during the period of El Niño to moderate and weaker with IOD entering the neutral phase, the rainfall with a very light intensity of less than 5 mm was predominantly in the north of the equator while in the south of the
equator it varied from very mild to light intensity. The daily distribution of rainfall occurred during El Niño 2015/2016 in Indonesian territory which was in line with the distribution of OLR over Indonesian territory. In the meridional distribution, the smaller the rainfall in the region, the greater the value of OLR (Figure 7 right).

Based on the analysis of zonal and meridional distribution of rainfall and OLR, the relationship (both negative correlation) between the two parameters was significant, because OLR can describe the distribution of convective areas indicating their thickness and the number of cloud cover. In this study, a pattern that shows smaller OLR and greater rainfall occurred in the area was obtained. This result is line with research [24] that OLR is negatively correlated with rainfall, and also research [25] suggests that OLR is negatively correlated with the ITCZ (Inter Tropical Convergence Zone).

4. Conclusion

Based on the analysis of SST anomalies in the Niño 3.5, it shows that El Niño phenomenon occurred in the Pacific Ocean and El Niño intensity was strong (positive anomalies> 1.5°C) since the beginning of July 2015 until early March 2016, and reached its peak with a positive anomaly 2.48 °C in mid-November 2015. In mid-August to mid-November 2015, the data analysis shows that the IOD phenomenon in the Indian Ocean also has a positive phase. The analysis shows that SST and winds in the Pacific Ocean and the Indian Ocean significantly affect rainfall patterns in Indonesia. During El Niño 2015/2016 with strong intensity, especially the period of 2015, JJA precipitation declined and reached 200-400 mm / season in parts of Indonesia except for Aceh and North Sumatra which are partially in normal conditions. In the transitional period, (SON) coincided with the lasting period of positive IOD phase. It has led to increasingly severe drought and widespread in Indonesia. The worst drought areas occurred mainly in the southern part of the equator. The rainfall of 400-600 mm / season is lower than normal conditions. The merger of two global phenomena in the Pacific Ocean and the Indian Ocean exacerbated drought in Indonesia. The rainfall data have good GSMaP which can be used as an alternative in the study on the impact of El Niño in Indonesia spatially.

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