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Impacts of El Niño 2015 and the Indian Ocean Dipole 2016 on Rainfall in the Pameungpeuk and Cilacap Regions

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Abstract. El Niño and the Indian Ocean Dipole (IOD) are oceanographic phenomena which occur in the tropical Pacific Ocean and the Indian Ocean due to air–sea interactions. These phenomena affect climate variability both regionally and globally. This study was conducted to understand the impacts of El Niño 2015 and IOD 2016 events on rainfall in the Pameungpeuk and Cilacap regions. The data used consists of the NIÑO3.4 index, IOD index, daily rainfall from 1987–2016, daily sea surface temperature from 1987–2016, daily sea surface height from 1994–2016 and pentad sea surface current from 2007–2016. The method used in this research was a descriptive analysis. The results have shown that rainfall in Pameungpeuk and Cilacap was influenced by El Niño 2015 and negative IOD 2016. During El Niño 2015 a decrease in rainfall occurred, whereas during negative IOD 2016 rainfall increased. Rainfall anomalies in the east season and the second transition season during El Niño 2015 in Pameungpeuk reached −107 mm and −374 mm, meanwhile in Cilacap rainfall anomalies reached −111 mm and −218 mm. Conversely, rainfall anomalies during negative IOD 2016 reached 109 mm and 360 mm in Pameungpeuk, and in Cilacap reached 293 mm and 365 mm. Changes in rainfall in Pameungpeuk and Cilacap during El Niño 2015 and negative IOD 2016 events were closely related to the weakening and strengthening of convections in the southern waters of Java.

Keywords: anomaly, rainfall, El Niño, IOD, convection.

Abstrak. *El Niño dan Indian Ocean Dipole (IOD) adalah fenomena oseanografi yang terjadi di samudera Pasifik dan samudera Hindia tropis akibat interaksi antara atmosfer dan laut. Fenomena ini mempengaruhi variabilitas iklim baik regional maupun global. Penelitian ini dilakukan untuk mengetahui dampak kejadian El Niño 2015 and IOD 2016 terhadap curah hujan di wilayah Pameungpeuk dan Cilacap. Data yang digunakan terdiri dari indeks NIÑO3.4, indkes IOD, curah hujan harian dari tahun 1987–2016, suhu permukaan laut harian dari tahun 1987–2016, tinggi muka laut harian dari tahun 1994–2016 dan arus permukaan laut lima harian dari tahun 2007–2016. Metode yang digunakan dalam penelitian ini adalah analisis diskriptif. Hasil penelitian menunjukkan bahwa curah hujan di Pameungpeuk dan Cilacap dipengaruhi oleh kejadian El Niño 2015 dan IOD fase negatif 2016. Selama El Niño 2015 terjadi penurunan curah hujan, sedangkan selam IOD fase negatif 2016 intensitas curah hujan meningkat. Anomali curah pada saat musim timur dan musim peralihan kedua selama El Niño 2015 di Pameungpeuk mencapai −107 mm dan −374 mm, sementara di Cilacap mencapai −111 mm dan −218 mm. Sebaliknya, anomaly curah hujan selama IOD fase negatif 2016 mencapai 109 mm dan 360 mm di Pameungpeuk, dan di Cilacap mencapai 293 mm dan 365 mm. Perubahan curah hujan di wilayah Pameungpeuk dan Cilacap selama kejadian El Niño 2015 dan IOD fase negatif 2016 berkaitan erat dengan pelemahan dan penguatan konveksi di perairan selatan Jawa.*

Kata kunci: *anomali, curah hujan, El Niño, IOD, konveksi.*

1. Introduction

El Niño and the Indian Ocean Dipole (IOD) are oceanographic events that occur in the Pacific and Indian Oceans due to air–sea interactions. El Niño starts with the weakening of the trade wind when there is low air pressure in the east and high air pressure in the west of the tropical Pacific Ocean (Philander, 1990). Meanwhile, the IOD is characterised by sea surface temperature anomalies between the western and southeastern parts of the tropical Indian Ocean (Saji *et al*., 1999). An IOD event has two phases: positive and negative.

Positive IOD events are characterised by the cooling of the sea surface temperature in the southeastern equatorial Indian Ocean and the warming of the sea surface temperature in the western equatorial Indian Ocean. This warming causes convective clouds which are situated over the eastern Indian Ocean warm pool to shift to the west. Conversely, negative IOD events are characterised by the warming of the sea surface temperature in the southeastern equatorial Indian Ocean and the cooling of sea surface temperature in the western equatorial Indian Ocean. This warming causes convective clouds which are situated over this region to become stronger.

El Niño and IOD events cause changes in climate variability both regionally and globally. Changes in climate variability in turn cause various hydro-meteorological disasters in many countries. The position of the Indonesian Maritime Continent, located between these oceans, means it is highly vulnerable to El Niño and IOD events. El Niño events have caused drought disasters in Indonesia (Hendon, 2003; Davey *et al*., 2011; WMO, 2014). In contrast, negative IOD events have led to an increase in rainfall intensity in Indonesia (Guan *et al*., 2003).

Research about the impact of El Niño on agricultural products in Indonesia has been undertaken by several researchers. Agriculture is one of the most vulnerable sectors to El Niño events (Rojas *et al*., 2014). Deviation of climatic elements at planting time affects the growth period until harvest which causes the production value to be low (Wardoyo, 1999). About 18 provinces including the national food barns (West Java, Central Java, East Java, North Sumatra and NTT) are affected by El Niño events (Tabor *et al*., 2015).

El Niño events contribute to a decline in rice production (Xiangzheng *et al*., 2010; Naylor *et al*., 2001). El Niño 1997/1998 caused a loss of about 3 million tons of rice in Java (D'Arrigo & Wilson, 2008). In 2015, drought disasters and decline in agricultural production in Indonesia constituted one of the world's most costly natural disasters; this is estimated to have caused a loss of 16 billion USD (Done & Holland, 2016). El Niño 1997/1998 had significant implications in the social and economic sectors (Kishore *et al*., 2000).

Agriculture is a driving sector and buffers the concept of development in the south of Garut Regency in the future (Suminar *et al*., 2007). The coastal region of Garut Regency has a base economy in the agricultural sector (Sudarya *et al*., 2013). Meanwhile, the role of the agricultural sector in Cilacap Regency is very strategic because it contributes to the fulfilment of basic needs for the people of the regency especially and the people of Central Java in general (BPS, 2014).

Rainfall in the Indonesia Maritime Continent region, especially in South Sumatra and West Java, is influenced by IOD events (Liong *et al*., 2003). IOD 1997 caused severe rainfall in eastern Africa and droughts in Indonesia (Saji *et al*., 1999; Webster *et al*., 1999). Meanwhile, IOD events influence many countries bordering the Indian Ocean, with severe droughts in countries surrounding Indonesia during a positive IOD event (Weller & Cai, 2014).

Considering the strategic role of the agricultural sector but also its vulnerability to climate anomalies, it is necessary to identify the effects of El Niño and IOD events on rainfall in these regions. The region of Pameungpeuk in Garut Regency and Cilacap Regency, which are located in the south of Java, bordering the Indian Ocean, are important to study. The aim of this study is to investigate the impacts of El Niño 2015 and IOD 2016 on rainfall in Pameungpeuk and Cilacap.

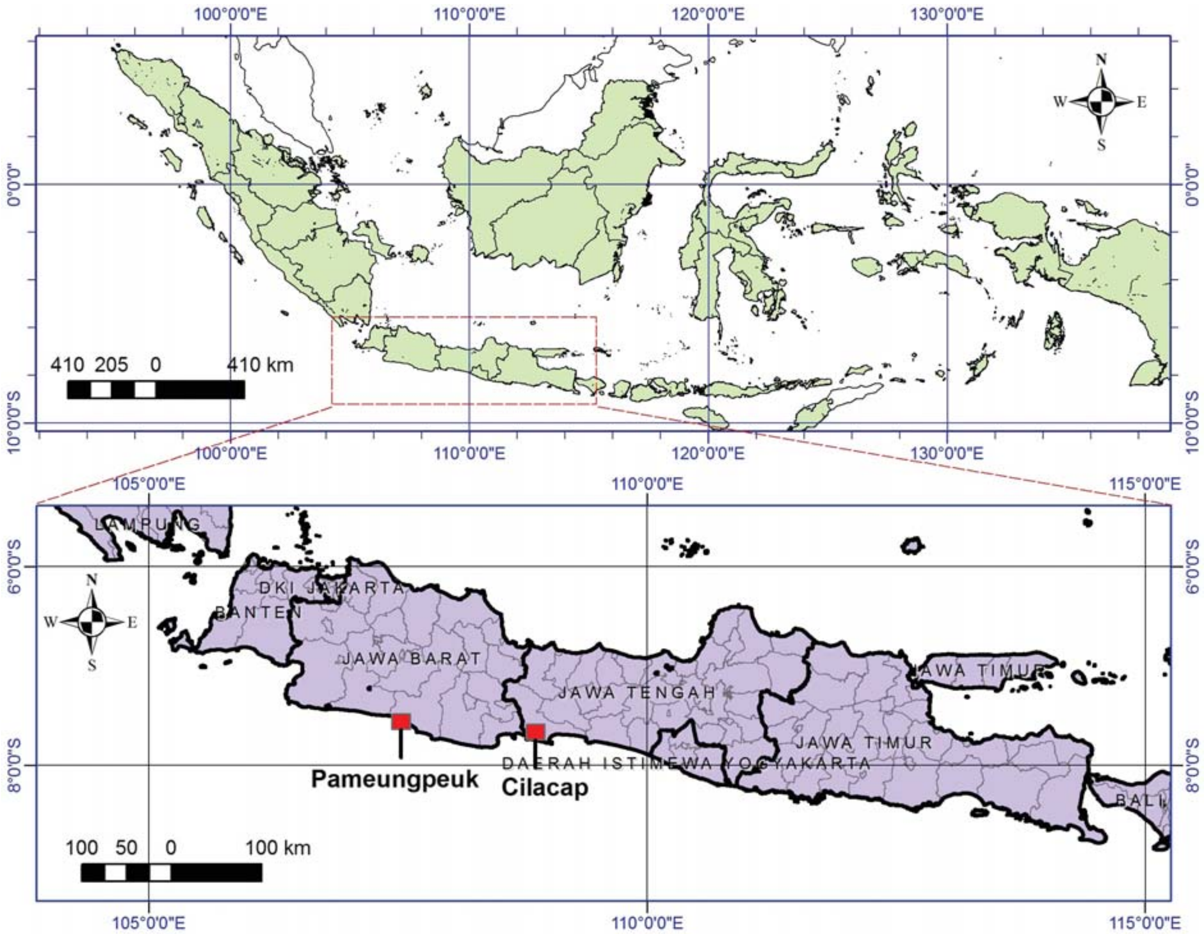

Figure 1. Research location.

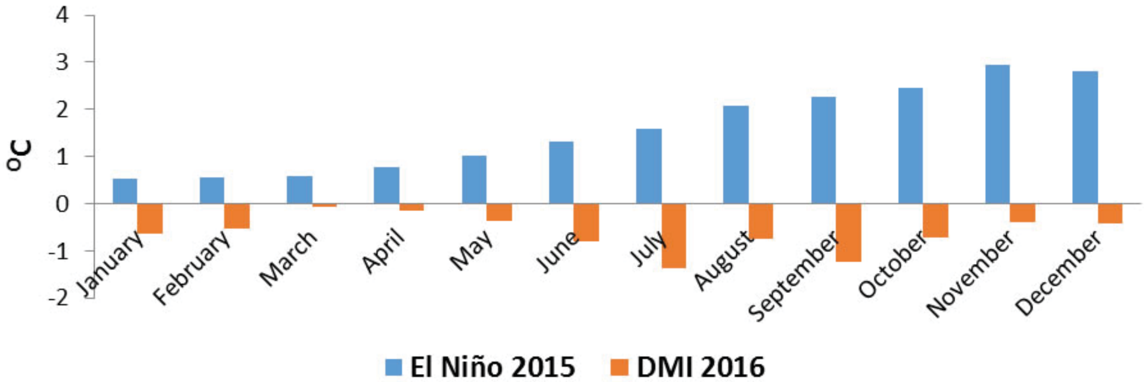

Figure 2. NIÑO3.4 and IOD indexes.

2. Research Method

The research sites were Pameungpeuk and Cilacap, which are shown in Figure 1. The locations of the study are indicated by red squares. The data used consisted of the NIÑO3.4 index, IOD index, monthly rainfall from 1987–2016, daily sea surface temperature from 1987–2016, sea level height from 1994–2016 and pentad sea surface current from 2007–2016. The NIÑO3.4 index data was obtained from CPC NCEP, the IOD index data was obtained from JAMSTEC, the sea surface temperature and sea surface current data were obtained from NASA PODAAC and the sea level height data was obtained from AVISO. The rainfall data was obtained from the Meteorology Station BMKG

Cilacap and the Technology Test Center and Space and Atmospheric Observation in Garut, LAPAN.

The method used in this research is a descriptive analysis. Daily and pentad data are processed into monthly data. The impacts of El Niño 2015 and IOD 2016 on rainfall are determined by their anomalous values. The value of rainfall anomaly during El Niño 2015 and IOD 2016 are calculated using equations 1 and 2:

$$CH_A = CH_i - \overline{\overline{CH}} \quad (1)$$

$$\overline{\overline{CH}} = \frac{\sum_{i=1}^{n} CH}{n} \quad (2)$$

where is rainfall anomaly, is the climatological rainfall, is rainfall at time *i* and *n* is the amount of data. In the study, the correlation coefficient between rainfall anomaly in the NIÑO3.4 and IOD indexes was calculated. To determine whether there is a significant correlation between these two variables, a significance test was carried out using the t-test method.

The results analysis based on the index values of NIÑO3.4 2015 and IOD 2016 is shown in Figure 2. Based on the index values, it is known that in 2015 there was a strong El Niño event with anomalies of up to 2.95 ^{O}C and in 2016 there was a negative IOD event with anomalies of up to 1.2 ^{O}C. The strong impacts of El Niño in the south of Java occur between July and November (Supari *et al*, 2016). Therefore, analysis was done from June to November 2015 representing the year of the El Niño and June to November 2016 representing the year of the IOD.

3. Results and Discussion

The monthly variation of rainfall in Cilacap and Pameungpeuk is shown in Figure 3. The intensity of rainfall in Cilacap and Pameungpeuk is quite high, with an annual average of more than 270 mm. The type of rainfall in this region exhibits a monsoonal pattern with one maximum and one minimum value. The highest amount of rainfall occurred in November and the lowest occurred in August. The average amount of rainfall in the east season and the second transition season in Pameungpeuk reaches 115 mm and 374 mm respectively, while in Cilacap it reaches 161 mm and 346 mm respectively.

Rainfall anomaly in the period June–November 2015 in Pameungpeuk and Cilacap is shown in Figure 4. The intensity of rainfall decreases during El Niño events, which is indicated by negative anomaly. The smallest decrease in rainfall intensity occurred in August in both regions, but the largest decline occurred in October in Cilacap, and in November in Pameungpeuk. This result is consistent with Supari *et al*. (2016), who state that the impact of El Niño 2015 on monthly precipitation in Cilacap was strongest in October. Rainfall anomaly during the east season and the second transition season in Pameungpeuk reached −107 mm and −374 mm respectively, and in Cilacap reached −111 mm and 218 mm respectively.

Rainfall anomaly in the period June–November 2016 in Pameungpeuk and Cilacap is shown in Figure 5. In contrast to El Niño 2015, there was an increase in rainfall intensity during negative IOD 2016. The largest increase occurred in September in Pameungpeuk, and in October in Cilacap. Anomalies of rainfall during the east season and the second transition season in Pameungpeuk reached 109 mm and 360 mm respectively; meanwhile in Cilacap they reached 293 mm and 365 mm respectively.

The correlation coefficient between rainfall anomaly in Pameungpeuk with the NIÑO3.4 index was −0.72, and with the IOD index was −0.81. Meanwhile, the correlation coefficient between rainfall anomaly in Cilacap with the NIÑO3.4 index was −0.63, and was −0.75 with the IOD index. The same result was stated by Fadholi (2013), where the value of the correlation coefficient between the IOD index and rainfall anomaly was higher than that of the Niño 3.4 index.

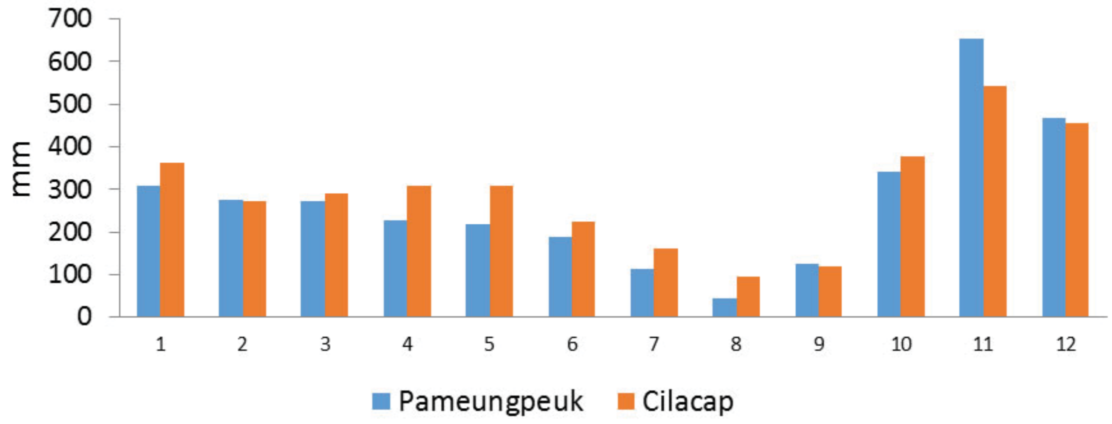

Figure 3. Monthly variation of rainfall.

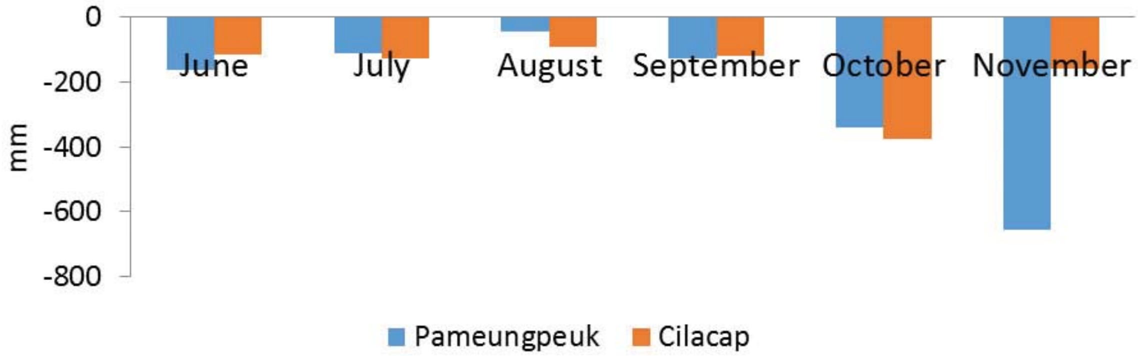

Figure 4. Rainfall anomaly during June–November 2015.

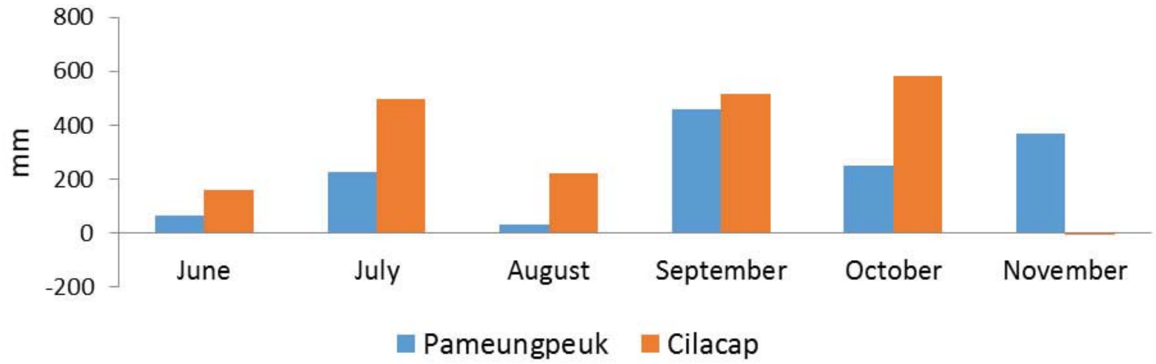

Figure 5. Rainfall anomaly from June–November 2016.

The result of the significance test on the value of the correlation coefficient of rainfall anomaly in Pameungpeuk, using the t-test method, was obtained with −4.82 against the NIÑO3.4 index and −6.42 against the IOD index. The value of the significance test, using the t-test method, in Cilacap was −3.84 against the NIÑO3.4 index and −5.28 against the IOD index. Meanwhile, the value of t-table at alpha = 0.05 was −2.07, so the test value of significance is greater than the t-table. This suggests that the phenomena of El Niño and IOD have a strong influence on the intensity of rainfall in Pameungpeuk and in Cilacap.

Based on the results, it is known that rainfall intensity in the Pameungpeuk and Cilacap regions were affected by the El Niño 2015 and negative IOD 2016 events. Rainfall intensity in these regions declined during El Niño 2015, but increased during negative

IOD 2016. The significant decline and increase of rainfall intensity occurred between the east season and the second transition season. The average rainfall anomaly from June to November 2015 was more than −150 mm, but from June to November 2016 it was more than 150 mm. The maximum and minimum rainfall anomalies occurred during the second transition season.

Several other studies have also shown similar results. This result is in agreement with a study conducted by Kirono *et al*. (2016), which stated that the annual rainfall dropped clearly during the 2015 El Niño event. In a study about food production centres in Java it was found that, especially in West Java, East Java and South Sumatra, the impact of El Niño is very significant to rainfall during the second seasons (Pramudia & Las, 2000). Rainfall anomaly in the western and eastern parts of Indonesia during negative IOD events increased by more than 100 mm/month, while it decreased by more than 100 mm/month during El Niño events (Nur'utami & Hidayat, 2016). El Niño 2015 has caused the territory of Indonesia, the Philippines and the Pacific Island countries to experience drought from July to December 2015 (VAM, 2015).

Changes in rainfall intensity during El Niño 2015 and negative IOD 2016 in both areas are closely related to the weakening and strengthening of deep convection. The convection process is influenced by changes in the oceanic conditions of southern Java, especially the sea surface temperature. The sea surface temperature of the Indonesian waters that are located in the tropical region plays a crucial role in strong convection processes (Qu *et al*., 2005; Sprintall *et al*., 2014). During El Niño events, there is a shift of the warm pool from the western part of the tropical Pacific Ocean to the centre and the east.

A shift in the warm pool will cause a decrease in sea level in the western Pacific Ocean and a rise in the east [see BOM AU (2008)]. The effect of El Niño events on the condition of the southern waters of Java is closely linked to the Indonesian Throughflow system. There are three main routes of the Indonesian Throughflow to the Indian Ocean: through the Lombok Strait, the Ombai Strait and the Timor Gap (Sprintall *et al*., 2009). The Indonesian Throughflow transport is weakened at the time of El Niño and strengthened at the time of La Niña (Meyers, 1996; Mihardja *et al*., 2001, as cited in Ningsih, 2003; Safitri *et al*., 2012).

The sea surface current pattern in the southern waters of Java during the east season and the second transition season of 2015 are shown in Figure 6. From June to November 2015, the sea surface current moved westward. During the southeast monsoon, between June and November, in the southern waters of Java there was an upwelling process (Wyrtki, 1962; Susanto & Marra, 2005; Sachoemar & Hendiarti, 2006). Upwelling is a process involving the rising of the water mass from the lower layer of about 100–300 metres to the surface layer (Bowden, 1983). Because the water mass comes from the lower layers, the sea surface temperature in the upwelling area is colder than that of the surrounding region.

The strengthening of upwelling during El Niño 2015 was accompanied by a decrease in sea level, as shown in Figure 7. The average decrease was very small, where the sea surface height anomalies during the east season were only about −0.5 cm, and in the second transition season reached about −6.5 cm. The decrease in the sea surface height of the coastal waters was greater than the decrease offshore. The largest decline occurred on the south coast of East Java during the second transition season, where the anomaly reached −7 cm.

The weakening of the Indonesian Throughflow transport during El Niño events causes sea levels in the southern waters of Java to decline. This decrease in sea levels leads to a shallowing process of the thermocline depth. In some El Niño events, the shallowing of the thermocline depth in the southern waters of Java reaches between 20 and 60 metres (Susanto *et al*., 2001). The shallowing of the thermocline depth causes upwelling in the southern waters of Java to be stronger than under normal conditions.

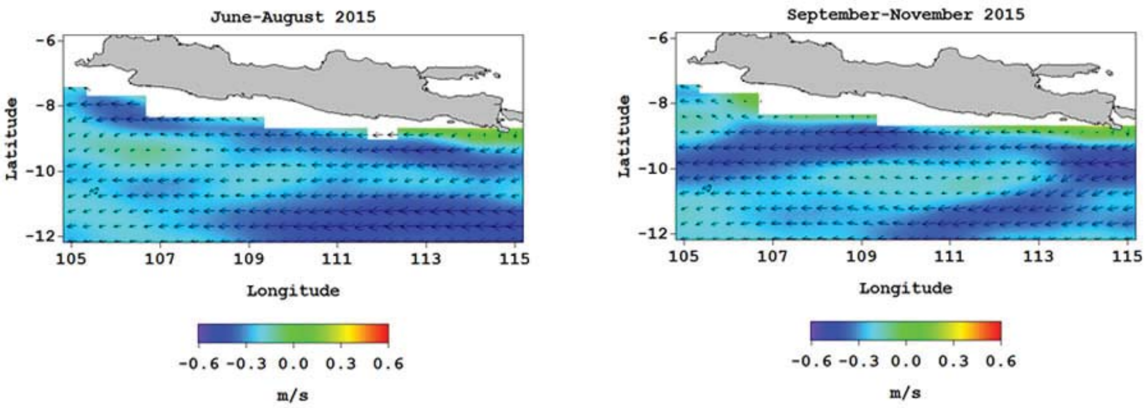

Figure 6. Pattern of surface current from June–November 2015.

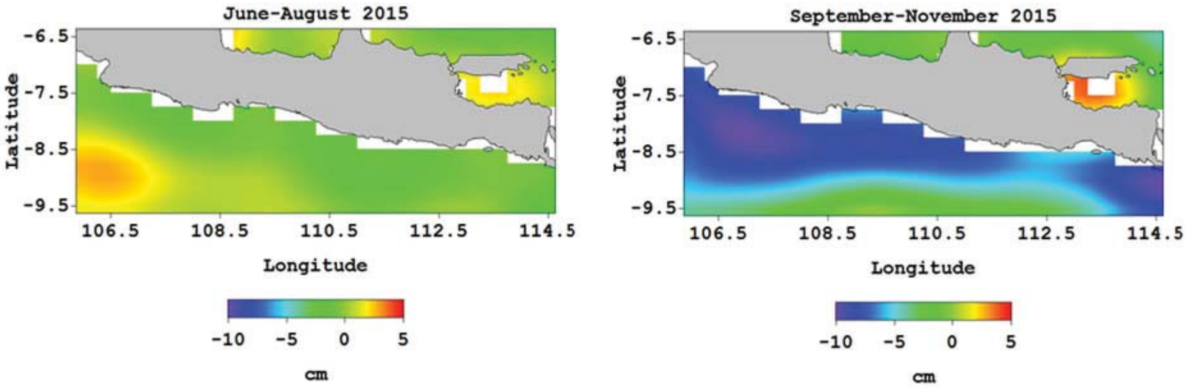

Figure 7. Anomaly of sea surface height from June–November 2015.

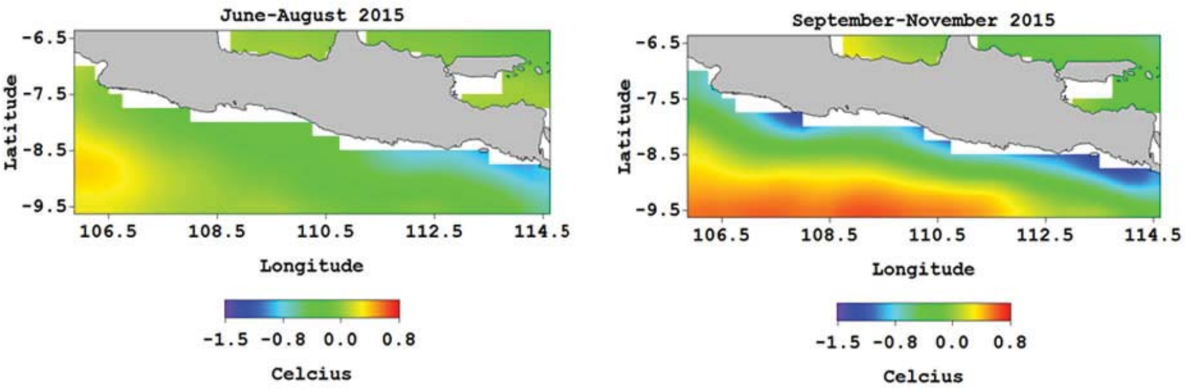

Figure 8. Anomaly of sea surface temperature from June–November 2015.

The strengthening of upwelling will cause a decrease in sea surface temperature. The distribution of sea surface temperature anomalies in the southern waters of Java during the east season and the second transition season during El Niño 2015 is shown in Figure 8. During El Niño 2015, the sea surface temperature in the southern waters of Java was colder than under normal conditions, which is characterised by negative anomaly. The average sea surface temperature anomaly during the east season about was −0.33 ^{O}C, and in the second transition season was about −0.25 ^{O}C.

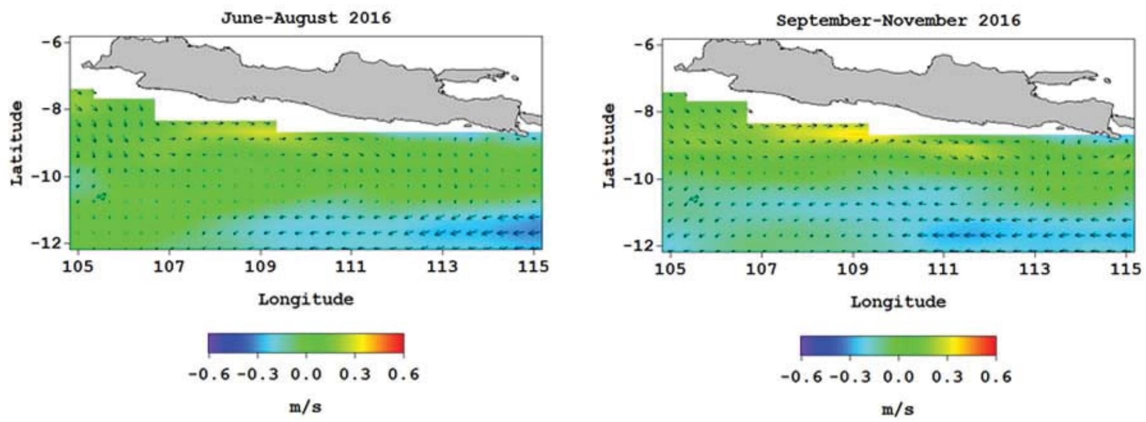

Figure 9. Pattern of sea surface current from June–November 2016.

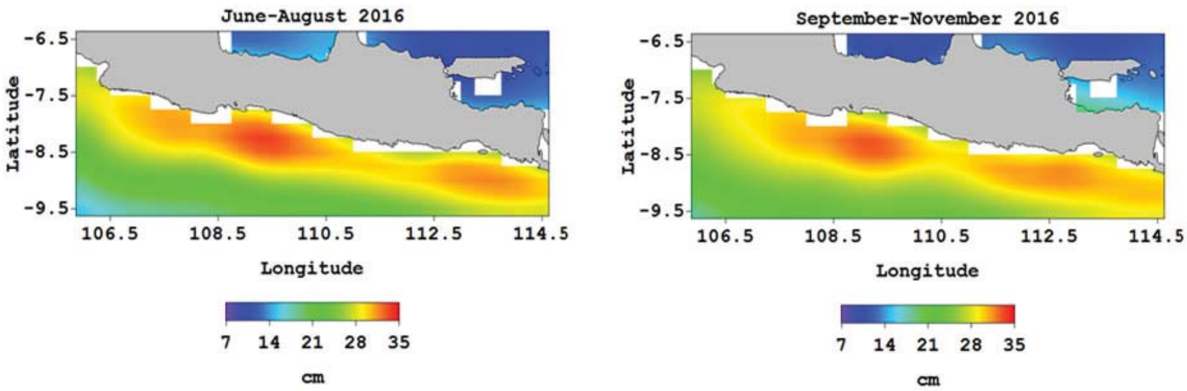

Figure 10. Anomaly of sea surface height from June–November 2016

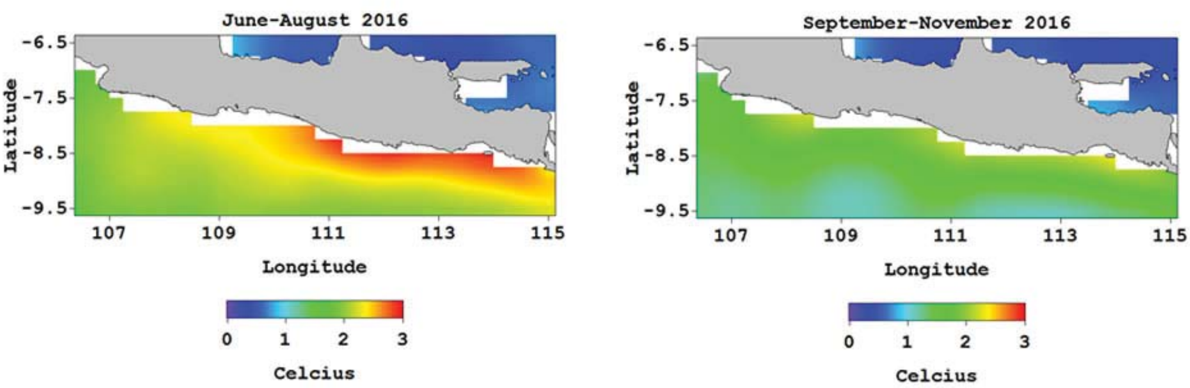

Figure 11. Anomaly of sea surface temperature from June–November 2016

The smallest decrease in sea surface temperature occurred on the south coast of East Java during the second transition season, where the anomaly reached −0.82 °C. The cooling of the sea surface temperature in the southern waters of Java leads to a decrease in the convection process, so cumulus clouds around the region were not formed. During El Niño events, there is a strong convection increase above the central and eastern regions of the tropical Pacific Ocean and a decline above the Indonesian Maritime Continent (Olchev *et al.*, 2015). This mechanism caused the amount of rainfall in Cilacap and Pameungpeuk to decrease during El Niño 2015.

During negative IOD 2016, the convection process over the Indonesian region increased [see JAMSTEC (2008)]. The increase of the convection process was due to changes in the dynamics of the surface current in the southern waters of Java. The pattern of sea surface current in the southern waters of Java from June to November 2015 is shown in Figure 9. On the south coast of Java up to 9.7^{O} S, the sea surface current moved eastward. This current is part of the Equatorial Countercurrent, which is derived from the western part of Sumatra. Frictions between the Equatorial Countercurrent and the South Equatorial Current in the southern waters of the Java caused convergence. This convergence process caused downwelling. Similar results were stated by Yoga et al (2014), where, at the time of negative IOD 2010, a downwelling process occurred in the southern waters of Java.

Sea surface height anomaly from June to November 2016 is shown in Figure 10. During negative IOD 2016, the sea surface height in the southern waters of Java increased. The sea surface height anomaly at the time of the east season reached 27.9 cm, and reached 28.5 cm during the second transition season. The largest increase occurred in the southern waters of East Java during the second transition season, which reached 29.4 cm.

Anomaly of sea surface temperature in the southern waters of Java during the east season and the second transition season during negative IOD 2016 is shown in Figure 11. In contrast to El Niño 2015, the sea surface temperature in southern waters of Java increased during negative IOD 2016. According to Martono (2016), the effect of IOD events on the fluctuation of the sea surface temperature in the Indonesian waters was stronger than that of ENSO. The increase in the sea surface temperature in the east season reached 2.24 ^{O}C, and dropped to 1.56 ^{O}C during the second transition season. The largest rise in sea surface temperature occurred on the south coast of Central Java to East Java in the east season, where it reached 2.61 ^{O}C. Rises in sea surface temperature cause a stronger convection process. The increase in the amount of rainfall in the western part of Sumatra and southern Java during negative IOD events is closely related to the occurrence of a strong convection process, so cumulus clouds were formed (Lee, 2015).

4. Conclusion and Recommendation

The results show that the intensity of monthly rainfall in the Pameungpeuk and Cilacap regions were affected by El Niño 2015 and negative IOD 2016. Rainfall intensity in these regions decreased during El Niño 2015 and increased during negative IOD 2016. Average rainfall anomalies from June to November 2015 reached −240 mm in Pameungpeuk, and reached −165 mm in Cilacap. Meanwhile, the average rainfall anomaly from June to November 2016 reached 329 mm in Cilacap, and reached 234 mm in Pameungpeuk. Changes in rainfall intensity during El Niño 2015 and negative IOD 2016 are closely related to the weakening and strengthening of the convection process. The convection process is strongly influenced by the condition of the southern waters of Java. At the time of El Niño 2015 there was a strengthening of the process of upwelling, so the sea surface temperature in the southern waters of Java was colder than under normal conditions. This condition causes convection in the region to weaken. Conversely, during negative IOD 2016, a downwelling process occurred, which caused the sea surface temperature to become warmer, so the convection process above this region became stronger.

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