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Research Paper

On the Influence of Enso And IOD on Rainfall Variability Over The Musi Basin, South Sumatra

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Abstract
The southern Sumatera region experiences one rainy season and one dry season in a year associated with seasonal change in monsoonal winds. The peak of rainy season is occurring in November-December-January during the northwest monsoon season, while the dry season comes in June-July-August during the southeast monsoon season. This study is designed to evaluate possible influence of the coupled ocean-atmospheric modes in the tropical Indo-Pacific region, namely the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) on the rainfall variability over the catchment area of the Music Basin, South Sumatera. The ENSO and IOD occurrences were reflected by the variability of sea surface temperature (SST) in the tropical Pacific and Indian Ocean, respectively. During El Niño and/or positive IOD episode, negative SST anomalies cover the eastern tropical Indian Ocean and western tropical Pacific including the Indonesian seas, leading to suppress convective activities that result in reduce precipitation over the maritime continent. The situation is reversed during La Niña and/or negative IOD event. The results revealed that the high topography area (e.g. Bukit Barisan) was shown to be instrumental to the pattern of rainfall variability. During the 2010 negative IOD co-occurring with La Niña event, the rainfall was significantly increase over the region. This excess rainfall was associated with warm SST anomaly over the eastern tropical Indian Ocean and the Indonesian seas. On the other hand, extreme drought event tends to occur during the 2015 positive IOD simultaneously with the occurrence of the El Niño events Investigation on the SST patterns revealed that cold SST anomalies covered the Indonesian seas during the peak phase of the 2015 positive IOD and El Niño event.

Keywords
ENSO, Indian Ocean Dipole, Musi Basin, rainfall variability, sea surface temperature

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1. INTRODUCTION

Indonesia is an archipelagic country on the equatorial region, lying between two oceans and two continents. It is causing Indonesia has a complex atmospheric and oceanic circulation and dynamics. Seasonal surface temperature contrast between land and sea leads to season change on the surface winds so-called monsoonal wind pattern. Change on the surface wind patterns has an influence on the ocean dynamics and circulation, in particular in the Indonesian waters. These wind and ocean circulation systems closely link to the surface evaporation in ocean that impacts rainfall pattern in the area (Aldrian and Susanto, 2003; Schott and McCreary, 2001).

On the interannual timescale, the coupled ocean-atmosphere modes in the tropical Indo-Pacific region (e.g. ENSO and Indian Ocean Dipole) have important impact on the rainfall over the maritime continent. During El Niño periods, the trade winds are weaken or even reversed. As a consequence, the sea surface temperature (SST) in the eastern equatorial Pacific Ocean are getting warmer, while that in the western part is getting colder. The convection zone moves eastward from the western to the central tropical Pacific Ocean. This eastward movement of the convective zone has caused reduce rainfall over the western Pacific, including the maritime continent. The situation is reversed during La Niña event (McPhaden, 2004; Philander, 1983; Rasmusson and Carpenter, 1982; Wyrtki, 1975). Usually, the El Niño/La Niña events develop in boreal summer, peaked in boreal fall to winter, and terminated in boreal spring of the following year (Philander, 1983; Rasmusson and Carpenter, 1982; Wyrtki, 1975).

Similar coupled ocean-atmosphere phenomenon is occurring in the tropical Indian Ocean, so-called the Indian Ocean Dipole (IOD) (Iskandar et al., 2015; Murtugudde et al., 2000; Saji et al., 1999; Webster et al., 1999). A positive IOD (pIOD) event is characterized by unusually cold (warm) SST in the southeastern (western) tropical Indian Ocean associated with the southeasterly winds anomalies along the southern coast of Sumatera and Java, and easterly winds anomalies along the equatorial Indian Ocean. During pIOD event, the convection activities are occurring over the central and western tropical Indian Ocean collocated with the warm SST. As a result, the eastern Africa and the Indian continent experienced heavy rainfall, while the eastern Indian Ocean rim country, including Indonesia, experienced severe drought (McPhaden, 2004; Wyrtki, 1975). Previous studies had confirmed that the IOD events have significant impact on the climate variability in the South and East Asia, Australia and other regions (Cai et al., 2009; Hamada et al., 2012; Iskandar et al., 2010; Saji and Yamagata, 2003; Vinayachandran et al., 2002; Yamagata et al., 2013).

This study was designed to evaluate possible impact of the ENSO and IOD on the rainfall variability over Musi Basin. The analysis was focused on the two extreme climate events in 2006 and 2015, namely the negative IOD/La Niña event and the positive IOD/El Niño event, respectively. The dynamics of rainfall variability was evaluated by comparing the rainfall data with the SST and surface winds variability. In addition, possible influence of the ENSO and IOD on the rainfall variability is investigated by correlating the rainfall data with the Niño3.4 index and the Dipole Mode Index (DMI) over a period of January 2000 to December 2015, respectively.

2. EXPERIMENTAL SECTION

Combined observational and reanalysis data sets were used in this study. Monthly rainfall data having horizontal resolution of 0.25° x 0.25° derived from the Tropical Rainfall Measuring Mission (TRMM) satellite were used in this study covering a period of January 2000 to December 2014. In addition, to evaluate the dynamics underlying the rainfall variability, this study also used monthly National Oceanic and Atmospheric Administration (NOAA) Optimum Interpolation SST (OI-SST) based on the Advanced Very High Resolution Radiometer (AVHRR) satellite data with spatial resolution of 0.25° x 0.25°. Possible influences of the ENSO and IOD events on the rainfall variability were analyzed by correlating the monthly rainfall data with monthly DMI data derived from the KNMI Climate Explorer and the Niño3.4 index derived from NOAA. Note that the climatological fields were calculated over the period of January 2000 – December 2015. The anomaly is defined as the deviation from monthly climatological fields.

The correlation analysis is conducted to evaluate the possible correlation between the rainfall variability over the Musi basin and the SST variation, IOD event as well as the ENSO. The coefficient correlation is calculated by:

$$r = \frac{1}{N-1} + \sum_{N-1}^{N} \frac{(x-\overline{x})(y-\overline{y})}{SxSy} \qquad (1)$$

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. where Sx dan Sy are standard deviation of each variables, x and y. The value of correlation coefficient (r) will be -1 ≤ r ≤ 1. Both variables will have good correlation if r = +1 or r = -1. The value r = +1 indicates that the point data (xi,yi) is lying on the same point and have significant correlation. Note that r = -1 means that both data is out of phase, which is 180°. Meanwhile, r = 0 means that the point data on graph is random and didn't have correlation or have bad correlation.

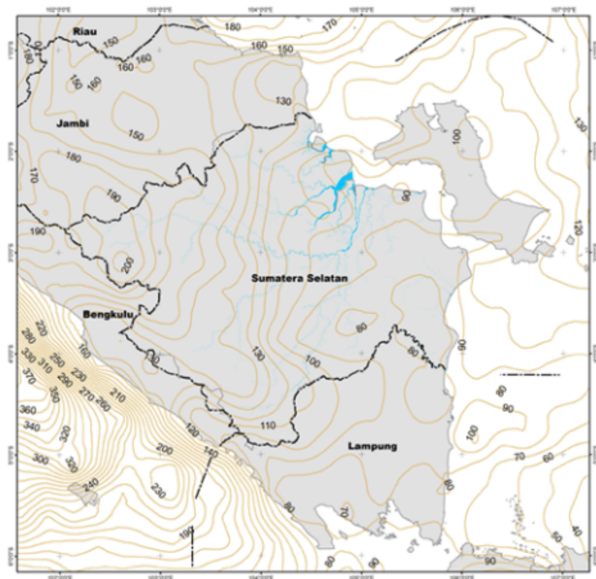

Figure 1. Monthly climatology of rainfall during dry season (August) derived over the period of January 2000 – December 2015

3. RESULTS AND DISCUSSION

Spatial distribution of the monthly climatology of the rainfall data from the TRMM satellite during August (dry season) is shown in Figure 1, it is shown that most of area of the South Sumatera has rainfall intensity < 100 mm/day). However, along the Bukit Barisan (southwest of south Sumatra) long term mean of the rainfall data is about 130 – 200 mm/day. This may indicates that area along the Bukit Barisan still have a good potential of rainfall even in the dry season.

The SST pattern during the dry season in August shows that the SST in the southern part of the South China Sea is higher than that in the Java Sea (Figure 2). It is suggested that the SST pattern is closely related to the southeast monsoon winds and the ocean circulation in the western part of the Indonesia seas (Iskandar et al., 2010; Schott and McCreary, 2001). During this season, southeasterly winds cause upwelling in the Java Sea and in the southeastern Indian Ocean off south Java and Sumatera resulting cold SST leading to reduce convective activities in the region.

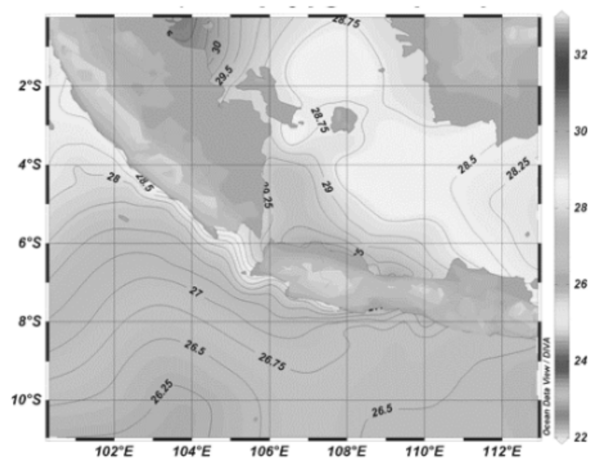

Figure 2. Monthly climatology of the sea surface temperature during dry season (August) derived from the NOAA-OISST

Figure 3. Same as Figure 1, except for rainy season (December)

On the other hand, during rainy season in December (Figure 3), the monthly climatology of rainfall data shows that the maximum intensity of rainfall occurs along the area of Bukit Barisan with maximum monthly rainfall exceeding 350 mm/day. The rainfall intensity is decreasing toward northeastern coast of south Sumatra. It should be noted that the rainfall intensity in the west of Bukit Barisan region is slightly higher than that in the eastern region. In addition, the rainfall intensity over the sea is higher than that over the land, suggesting the convective activities over the sea is higher that that over the land Luo et al. (2012); REASONa et al. (2000); Vinayachandran et al. (2002); Wolter and Timlin (1998); Yamagata et al. (2013).

The monthly climatology of SST during December is presented in Figure 4. Overall, the observed SST during northwest monsoon (December) is higher than that observed during

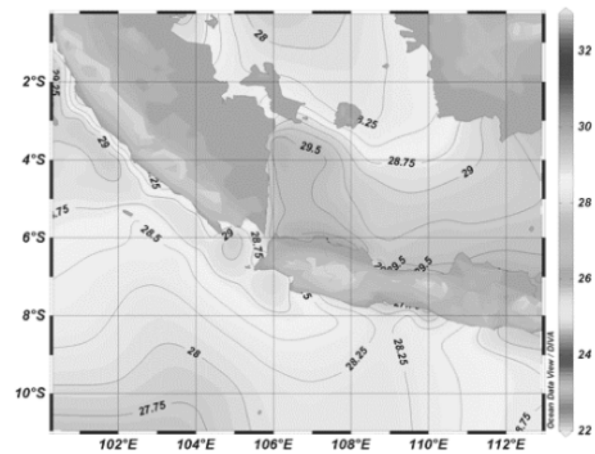

Figure 4. Same as in Figure 2, except for the rainy season (December)

southeast monsoon (August) (Vinayachandran et al., 2002). During the northwest monsoon, the surface winds blow toward the southeast deriving the surface flow from the South China Sea to the Java Sea (Yan et al., 2010). In addition, the northwesterly winds along the southern coast Sumatra and Java derive onshore Ekman transport causing downwelling along the coast. As a result, the SST along the coast is getting warmer.

Comparing the dry and rainy seasons, it is found that the catchment area along the Bukit Barisan has significant contribution on the rainfall distribution in the South Sumatra (Figure 1 and 3). During the dry season (August) rainfall distributions on the western part is higher than that on the eastern part, where the highest rainfall shifted to the western side of the Bukit Barisan toward the Indian Ocean. The situation is reversed during the rainy season.

The spatial correlation between the rainfall data and averaged SST in the entire area of south Sumatra is presented in Figure 5. It is shown that area along the Bukit Barisan has negative correlation with maximum correlation of r = -0.5. It is suggested that the topography of the Bukit Barisan is highly contributing to the rainfall distribution. The high topography will affect the pattern, direction dan wind velocity, which carry out water vapor from the evaporation area.

Based on the results above, we choose the location showing highest correlation as a sampling area of the monthly climatology and monthly time series of the rainfall (Figure 6a). At the sampling location, it is shown that the maximum rainfall is observed in December with monthly rainfall of 389 mm/day, while the minimum rainfall is 140 mm/day and it is observed in July-August (Figure 6b).

The seasonal pattern of the rainfall is affected by monsoons system, in which the maximum rainfall is occurring during the northwest monsoon, while the minimum rainfall is occurring

Figure 5. The spatial correlation coefficients between the monthly rainfall data and the averaged SST around the South Sumatra area

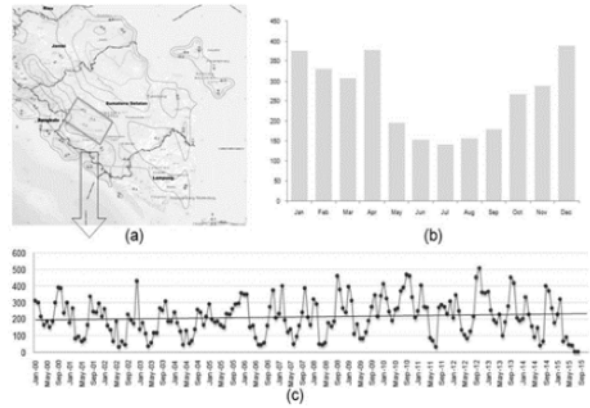

Figure 6. (a) Location of sampling area indicated by a box, (b) monthly climatology of the rainfall averaged over the sampling area, and (c) time series of the rainfall averaged over the sampling area for a period of January 2000 – December 2015

during the southeast monsoon. The time series of monthly rainfall indicates an increasing trend. The linear trend analysis shows that the rainfall has an increasing trend of about 2.18 mm/year (Figure 6.c).

In order to evaluate possible impact of the ENSO and IOD on the rainfall variability over the study area, we first show the time series of the DMI, Niño3.4 index and the rainfall anomaly over the study area (Figure 7). It is shown that there were several positive (negative) IOD events indicated by positive (negative) DMI occurring during January 2000 – December 2015 (Figure 6a). The strongest positive IOD event was observed in 2006. On the other hand, during the study period, we observed several El Niño signals and two strong La Niña signals (Figure 6b). We focused our analysis on the 2010 La Niña – negative IOD and 2015 El Niño – positive IOD events. During 2010, the La Niña signal was observed in the tropical Pacific Ocean, while the negative IOD event took place in the tropical Indian Ocean (Figure 7a-b). As a result, positive rainfall anomaly was observed throughout the year at the sampling area (Figure 6c).

In order to evaluate spatio-temporal evolution of the SST, surface winds and rainfall variability during the 2010 La Niña – negative IOD event, Figure 8 shows the monthly anomaly of SST, surface winds and rainfall from September to December 2010. It is shown that positive SST anomaly was observed in the Indonesian seas region in September to October 2010, while negative SST anomaly was observed in the central and western tropical Indian Ocean showing a typical negative IOD pattern (McPhaden, 2004; Saji and Yamagata, 2003; Wyrtki, 1975). This positive SST anomaly was associated with the northeasterly wind anomaly that derived downwelling along the southern coast of Sumatra and Java (Figure 8a-d) (Cai et al., 2009). Meanwhile, in the tropical Pacific Ocean, extremely cold SST anomaly was observed in the central and eastern tropical Pacific. This SST pattern is a typical pattern of the La Niña event (Philander, 1983; Rasmusson and Carpenter, 1982).

As shown by earlier studies, the SST patterns were associated with the rainfall distributions (Philander, 1983; Rasmusson and Carpenter, 1982). Positive rainfall anomaly was observed over a region with warm SST anomaly, while negative rainfall anomaly was co-located with the cold SST anomaly (Figure. 8e-h). Previous study has demonstrated that during La Niña event, there were upward air motions over the region with warm SST anomaly leading to enhance convective activities. Meanwhile, downward air motions were observed over the region of cold SST anomaly suppressing convective activities (Rasmusson and Carpenter, 1982). This is the reason why heavy rainfall was observed in the cactment area of the Musi Basin during 2010.

On the other hand, the South Sumatra region experienced extreme drought during 2015. This dry condition was associated with reduced rainfall intensity from March to the end of 2015 (Figure 7c). It is shown that during 2015 strong El Niño signal was observed in the tropical Pacific Ocean (Figure 7b) and also positive IOD signals appeared in the tropical Indian Ocean (Figure 7a). The combined impact of strong El Niño and positive IOD events significantly reduced rainfall intensity in the South Sumatra.

In order to have a spatio-temporal view of the ocean-atmosphere evolution during the 2015 El Niño-positive IOD event, monthly SST anomaly, surface wind anomaly and rainfall anomaly are

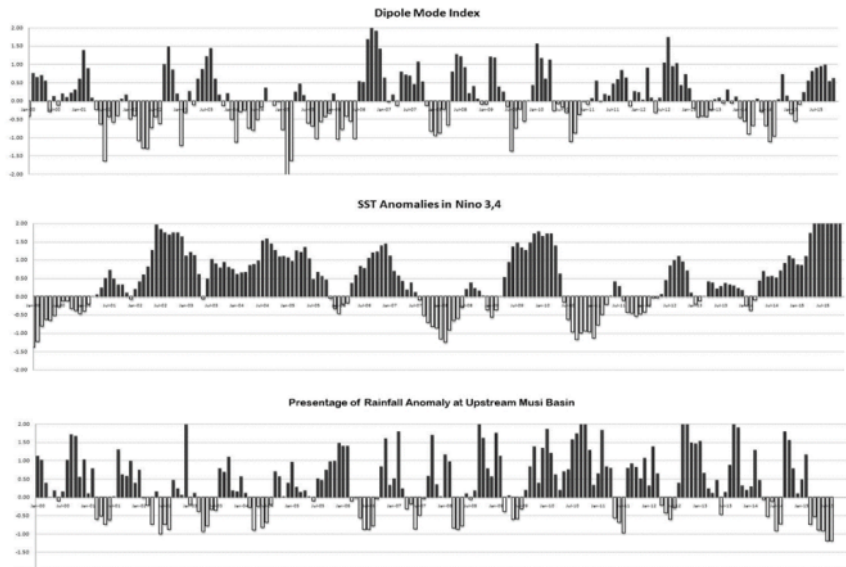

Figure 7. Time series of (a) Dipole Mode Index, (b) Niño3.4 index, and (c) rainfall anomaly over the sampling area during January 2000 – December 2015

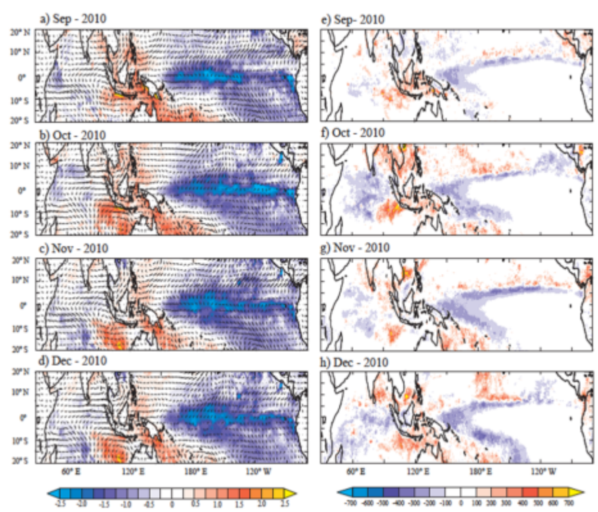

Figure 8. Ocean-atmosphere evolutions associated with the 2010 La Niña-negative IOD event, represented by the SST anomaly (shaded in °C), surface wind anomaly (vector in m/s) in the left panel (a-d) and rainfall anomaly (mm/month) in the right panel (e-h) from September to December 2010

presented in Figure 9 Only maps for a period of September to December 2015 are shown to capture the peak phase of the both events.

In September and October, strong southeasterly and easterly wind anomalies were observed along the southern coast of Java and Sumatera and along the equator, respectively (Figure 9a-b). These wind anomalies were favorable for upwelling events lowering SST. However, only SST in the interior Indonesian seas was anomalously negative, suggesting that the air-sea flux was more dominant in controlling SST during this period. The anomalous winds were weakened in November and even reverse direction as westerly wind anomalies along the equator in December (Figure 9c-d). The SST in the interior Indonesian seas was getting warmer in November and December. Meanwhile, in the interior Indian Ocean a basin-wide warming has occurred from October and peaked in November.

In the tropical Pacific, a robust El Niño SST pattern was observed in which the SST in the eastern tropical Pacific was getting warmer than normal (Figure 9e-h). The trade winds were weakened in September even reversed direction in the western basin. The warming SST peaked in December associated with strong westerly winds anomaly along the equator.

As expected, the rainfall anomalies pattern closely related to the SST and wind anomalies pattern. During September – October 2015, Indonesia has experienced severe drought event associated with negative SST anomalies observed mainly within the interior Indonesian seas (Figure 9e-g). The peak of drought even was observed in September-October. As the SST was getting warmer, the rainfall has also increased in Novem-

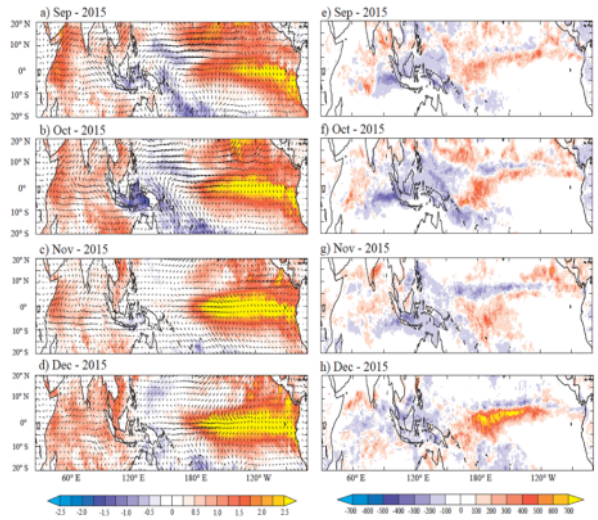

Figure 9. Same as Figure. 8 except for the 2015 El Niño-positive IOD event

ber – December. Interestingly, the northern part of Sumatera has a unique feature, which was opposite to the southern part. While the southern Sumatera still experienced negative rainfall anomaly, the northern part of the Sumatra still receive substantial amount of the precipitation in October-November 2015. Therefore, it can be confirmed that low rainfall intensity in the catchment area of Musi Basin during this period is linked to the coupled ocean-atmosphere mode in the Indo-Pacific region.

4. CONCLUSIONS

The rainfall variation of the South Sumatra region reveals seasonal pattern with maximum intensity is occurring during December and minimum intensity is observed in July – August. This seasonal rainfall variability is significantly correlated with the SST around the South Sumatra region. The maximum correlation (r = -0.5) was observed in the catchment area of the Musi Basin, which is along the Bukit Barisan. On the interannual time-scale, the rainfall variability is significantly affected by the IOD and ENSO events. During the positive IOD event followed by the El Niño event, the rainfall intensity is significantly decreased leading to severe drought condition over the South Sumatra. Meanwhile, during the negative IOD event followed by the La Niña event, there is significant increase in the rainfall variability over the South Sumatra.

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