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Impact of La Niña and La Niña Modoki on Indonesia rainfall variability

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Abstract. La Niña events are indicated by cooling SST in central and eastern equatorial Pacific. While La Niña Modoki occurrences are indicated by cooling SST in central Pacific and warming SST in western and eastern equatorial Pacific. These two events are influencing rainfall variability in several regions including Indonesia. The objective of this study is to analyse the impact of La Niña and La Niña Modoki on Indonesian rainfall variability. We found the Nino 3.4 index is highly correlated (r = -0.95) with Indonesian rainfall. Positive rainfall anomalies up to 200 mm/month occurred mostly in Indonesian region during La Niña events, but in DJF several areas of Sumatera, Kalimantan and eastern Indonesia tend to have negative rainfall. During La Niña Modoki events, positive rainfall anomaly (up to 50 mm/month) occurred in Sumatera Island, Kalimantan, Java and eastern Indonesia in DJF and up to 175 mm/month occurred only in Java Island in MAM season. La Niña events have strong cooling SST in central and eastern equatorial Pacific (-1.5°C) in DJF. While La Niña Modoki events warming SST occurred in western and eastern equatorial Pacific (0.75°C) and cooling SST in central Pacific (-0.75°C) in DJF and MAM. Walker circulation in La Niña Modoki events (on DJF and MAM) showed strong convergence in eastern Pacific, and weak convergence in western Pacific (Indonesia).

1. Introduction

Indonesia is located between two oceans (Indian and Pacific) and two continents (Asia and Australia). Because of this position, Indonesia has dynamic and complex climate variability. Climate variability that possibly occur in Indonesia, namely La Niña and La Niña Modoki. La Niña refers to ENSO events that cooling SST only occurs in the central and eastern equatorial pacific while La Niña Modoki cooling SST occurs in central equatorial Pacific and warming SST in the eastern and western equatorial Pacific [1].

La Niña events can be seen through a negative Nino 3.4 index and positive Southern Oscillation Index (SOI) whereas La Niña Modoki events can be seen through a negative ENSO Modoki Index (EMI). Nino 3.4 index can be calculated by using Sea Surface Temperature (SST) deviations in the central equatorial Pacific that called the Nino 3.4 region (5 N - 5 S, 120 W - 170 W) [2]. SOI can be calculated by using the difference SST region of Tahiti and Darwin [3]. Variability of SST Nino 3.4 region affects 50% of rainfall variability in Indonesia [4]. ENSO Modoki Index determined through calculation of EMI = [SSTA] A - 0.5 × ([SSTA] B + [SSTA] C) [1]. A region represented by the 165E-140W and 10s-10N, B 110W-70W and 15S-5N, area C 125E-145˚E and 10S -20˚N [1].

La Niña Modoki is an inter-ENSO variations. It also affected the rainfall variability in some areas [5]. Cai and Cowan [5], examines the impact of La Niña Modoki on Australian autumn rainfall variability. La Niña Modoki lead to rainfall increase extending on northwestern Australia to the northern Murray-Darling Basin, whereas the conventional La Niña lead to increase rainfall occurs only in the Eastern Australia region [5]. Based on the research, we need to understand the impact of La Niña and La Niña Modoki events in Indonesian rainfall variability. This research is expected to provide spatial information about the impact of these events to the Indonesian rainfall variability.

2. Methodology

2.1. Time Series Analysis
Time series analysis used to identify La Niña and La Niña Modoki years. Identification of La Niña based on Nino 3.4 index while La Niña Modoki based on ENSO Modoki Index (EMI). La Niña and La Niña Modoki occurs when Nino 3.4 and EMI show negative value, respectively. Time series data of Nino 3.4 and EMI used in this research are from 1981 to 2010.

2.2. Composite Analysis
Determining seasonal anomalies characteristic of rainfall, Sea Surface Temperature (SST), and wind in Indonesia region during La Niña and La Niña Modoki is done by composite analysis. Rainfall data used for this analysis is CHRPS from 1981 to 2010 with resolution 0.05° x 0.05°, while SST and wind used ECMWF data. Formula used for composite analysis described in equation 1.

$$\text{Composite} = \frac{X_{i1} + X_{i2} + \cdots + X_{in}}{n} \quad (1)$$

Where X_i is rainfall data of given season and n is amount of events.

2.3. Correlation Analysis
Correlation analysis was used to understand the relation between rainfall and two climate variability, La Niña and La Niña Modoki. We used time series and spatial correlation to understand the relation between rainfall and climate variability in long term period and in spatially. Time series correlation between all Indonesia rainfall and climate variability index (Nino 3.4, SOI, and EMI) are done using detrended annual (all month) and seasonal data from 1981 to 2010 through a 13-years sliding window. Spatial correlation calculated using linear cross-correlation at lag 0.

3. Result and Discussion

3.1. Correlation between SOI, Nino 3.4 Index and ENSO Modoki Index with Indonesian Rainfall
The rainfall data used for this correlation is average of spatial rainfall data in all Indonesian region. Correlation between SOI, EMI and Nino 3.4 index with Indonesian rainfall is shown in figure 1. La Niña events were indicated by positive value of SOI and negative value of Nino 3.4 index, while La Niña Modoki events were indicated by negative value of EMI.

Correlation of SOI and Nino 3.4 index with Indonesian rainfall have same fluctuations patterns but have different position. SOI (Nino 3.4) had a positive (negative) correlation in each season. During JJA and SON, both SOI and Nino 3.4 had high correlation reach 0.8 and -0.8, respectively. Whereas, during DJF and MAM, there were some periods that have low correlation. EMI had negative correlation with Indonesian rainfall in all season except MAM. During 1991-1993, EMI had positive correlation with Indonesian rainfall. All the indices had different pattern on DJF and MAM. So for further analysis, we focused only on that season (DJF and MAM).

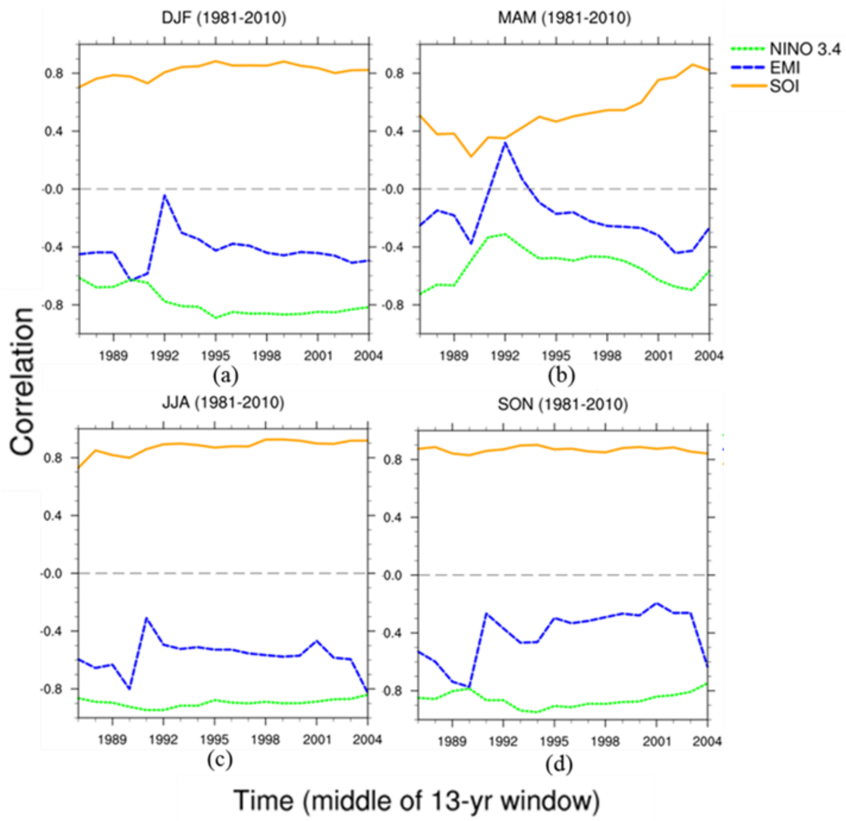

Figure 1. Correlation between SOI, Nino 3.4, and EMI with Indonesian rainfall using detrended trough a 13-years sliding window.

3.2. Spatial Correaltion between Nino 3.4 Index and ENSO Modoki Index with Indonesian Rainfall

Spatial correlation between EMI and Nino 3.4 index with Indonesian rainfall data over 30 years showed different spatial pattern (figure 2). Nino 3.4 had negative correlation with rainfall almost in all Indonesia region except west Kalimantan, Lampung, West Jawa and North Papua (figure 2a). Strong negative correlation (r = -0.9) occurred in East Kalimantan and North Sulawesi and Maluku. According to Aldrian and Susanto (2003), North Sulawesi and Maluku also had strong ENSO influence [6]. On MAM season, the coefficient correlation between Nino 3.4 and rainfall had same pattern with coefficient correlation on DJF, but the correlation was lower.

ENSO Modoki Index (EMI) had a weak negative correlation with Indonesian rainfall on every season (r = -0.3). Spatial extent of region with negative correlation on DJF was wider than MAM. On DJF negative correlation spread on some area such as Sulawesi, North and South Sumatra, East Kalimantan, Sulawesi, Bali, Java, and NTT. On MAM positive correlation was dominated in Kalimantan and Papua.

Generally, Nino 3.4 have stronger influence to rainfall in Indonesia than EMI. It can be seen from the value of coefficient correlation. According to Boer et al. [7], Indonesian rainfall anomalies has a strongest relation with SST anomalies in the Nino 3.4 region (170˚-120˚BB, 5˚LU-5LS) [7]. It is evident that Nino 3.4 has a stronger correlation with Indonesian rainfall than EMI.

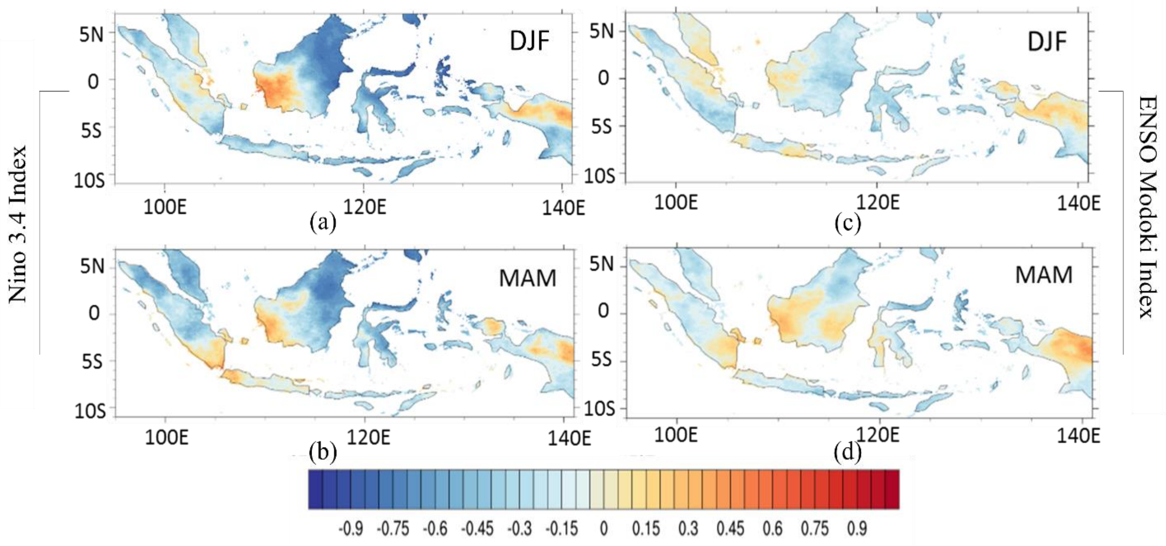

Figure 2. Spatial correlation between Nino 3.4 Index and ENSO Modoki Index with Indonesian rainfall.

3.3. *Identifying La Nina and La Nina Modoki years*

The occurrence of La Niña and La Niña Modoki in past year can be seen from time series data of Nino 3.4 and EMI, respectively. Negative value of Nino 3.4 and EMI indicated that La Niña and La Niña Modoki had occurred. Figure 3 shown La Niña and La Niña Modoki events during 30 years. There were a few times of La Niña and La Niña Modoki events. La Niña occurred in 1985, 1988, 1999, 2007 and 2010 while La Niña Modoki occurred in 1983, 1989, 2000, and 2008. La Niña and La Niña Modoki from 1981 to 2010 occurred five and four time, respectively. The five events of La Niña and and four events of La Niña Modoki in that time will be used to make a composite rainfall anomalies, SST anomalies and Walker circulation anomalies.

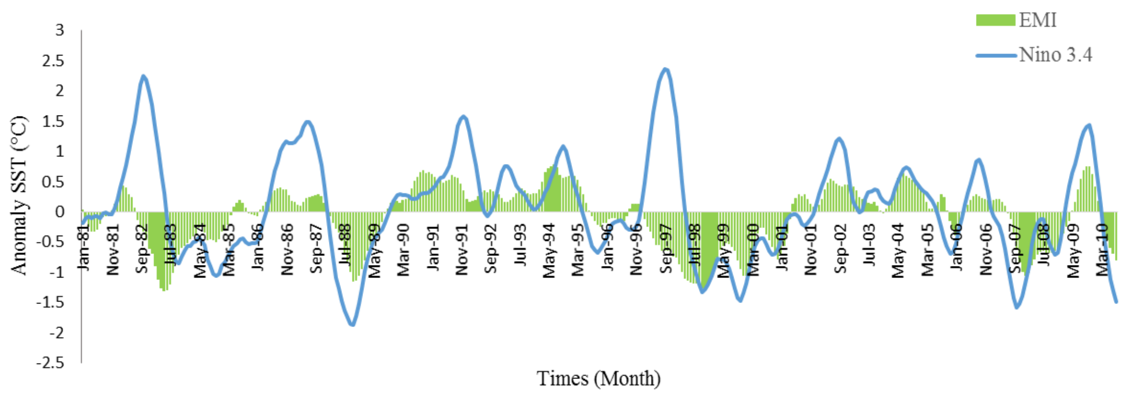

Figure 3. ENSO Modoki and Nino 3.4 Index (1981-2010).

3.4. *Sea Surface Temperature, Zonal and Meridional Wind Anomalies during La Nina and La Nina Modoki*

Indonesia rainfall anomalies are influenced by the SST (sea surface temperature) in the Pacific regions. When La Niña and La Niña Modoki occurred, SST conditions in Pacific has a different pattern than usual. SST conditions can be used as an index to determine the amount of water vapour in the atmosphere [8]. figure 4 shows a composite SST anomalies that is overlaid with the Wind (Zonal and Meridional) at altitude 850 hPa in the Pacific region during the La Niña and La Niña Modoki events. SST anomalies pattern had strong impact on rainfall variability [9]. When SST colder than normal, it can influence the increasing of surface pressure and surface wind divergence. After that it will reduce amount of rainfall [4]. SST Nino 3.4 region affected 50% on rainfall variability in Indonesian [4].

SST anomalies in equatorial pacific during La Niña and La Niña Modoki are different. SST anomalies during La Niña events on DJF is warming up to 1.25˚C, while in central and Eastern Pacific is cooling up to -1.5˚C. The wind in equatorial moved from east to west. During La Niña Modoki events, western (eastern) equatorial Pacific is warming up to 0.25˚C (0.5°C), while in the central equatorial Pacific cooling up to -0.75˚C. Generally, wind moved from central to west and east equatorial Pacific.

SST Anomalies during La Niña (Left) and La Niña Modoki (Right)

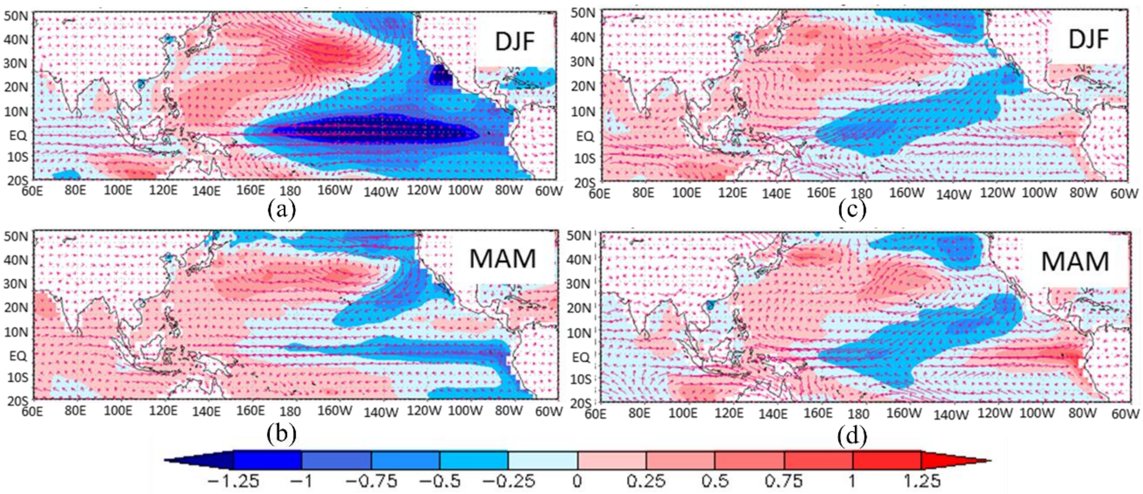

Figure 4. Composite anomalies sea surface temperature (°C), wind (u and v; m/s) level (850 hPa) during La Niña (a-b) and La Niña Modoki (c-d).

SST anomalies in western equatorial Pacific on MAM season during La Niña events (figure 4b) is warming up to 0.25˚C while in the central and eastern equatorial Pacific is cooling up to -1˚C. Wind movement was centered to the north of eastern Pacific. Conditions of SST anomalies in western equatorial Pacific during La Niña Modoki events on MAM season (figure 4d) is warming up to 0.75˚C, in the central equatorial Pacific is cooling up to -0.75˚C, and the eastern equatorial Pacific approach the American continent warming again up to 1°C. Wind moved from central to west and east equatorial Pacific.

3.5. Walker Circulation and Zonal Wind during La Niña and La Niña Modoki

Vertical wind profiles or Walker circulation is atmospheric circulation that occurs as a result of the encouragement of sea surface temperature gradient along the equator. The character of this circulation is determined by the interaction between oceans and atmosphere of the tropical areas [10]. Formation of Walker circulation is prevalent in the Pacific region with maximum formation in the upper atmosphere (300-200 hPa) [10]. Strengthening of this circulation are closely related and consistent with cooling and warming SST in the the Pacific [10].

Walker circulation can be analysed through the mean zonal wind (vector) and vertical velocity (contour) at latitude 5˚LU-5LS and at the height of 1000-100 hPa. Figure 5 shown a composite Walker circulation anomalies during La Niña and La Niña Modoki events. Negative value of vertical velocity indicated the convection while positive value of vertical velocity indicated the subsidence. Walker circulation conditions during La Niña on DJF season (figure 5a) shown that many convection occurred in parts of Indonesia, while the Pacific region has a significant subsidence. During La Niña Modoki, convection occurs in Indonesia and eastern Pacific, while the subsidence occurs in the central Pacific region (figure 5c).

Walker circulation during La Niña events on MAM season (figure 5b) showed that Indonesia has a convection but not very strong, while central Pacific region has low subsidence. During La Niña Modoki events on MAM season (figure 5d), there was convection in eastern and western Pacific. The convection in eastern was stronger than in western.

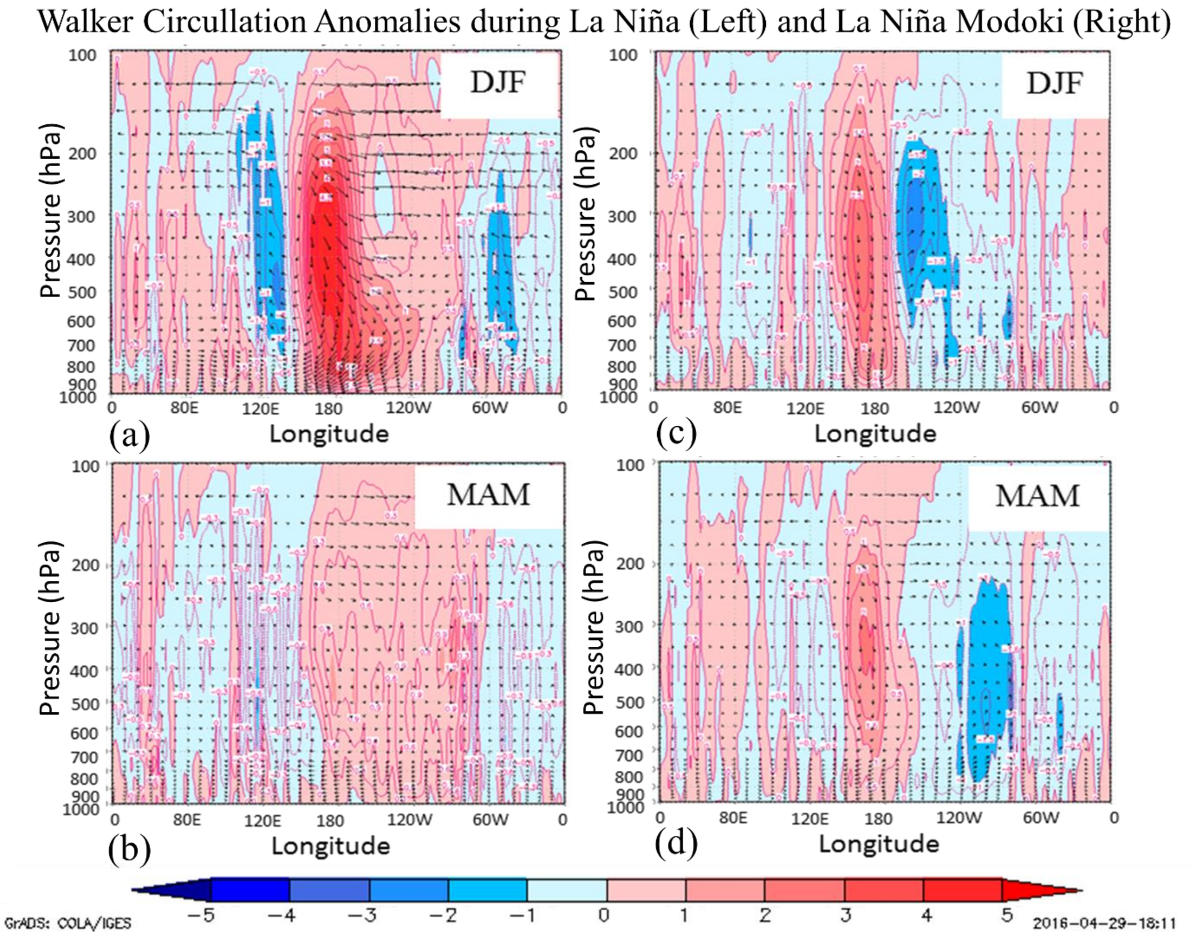

Figure 5. Composite seasonal Walker circulation anomalies using zonal wind (u; m/s) and vertical velocity (ϖ; 10-2Pa/s) level 1000-100 hPa during La Niña (a-b) and La Niña Modoki (c-d).

3.6. Rainfall Anomalies During La Nina and La Nina Modoki

La Niña and La Niña Modoki caused different impact to rainfall anomalies in Indonesia. Rainfall anomalies indicate standard deviation of rainfall that occurred during La Niña and La Niña Modoki events. The monthly spatial data of Indonesian rainfall are used to composite analysis. Based on the result on figure 6, the range of rainfall anomalies was high that was around -250 mm/month to 250 mm/month.

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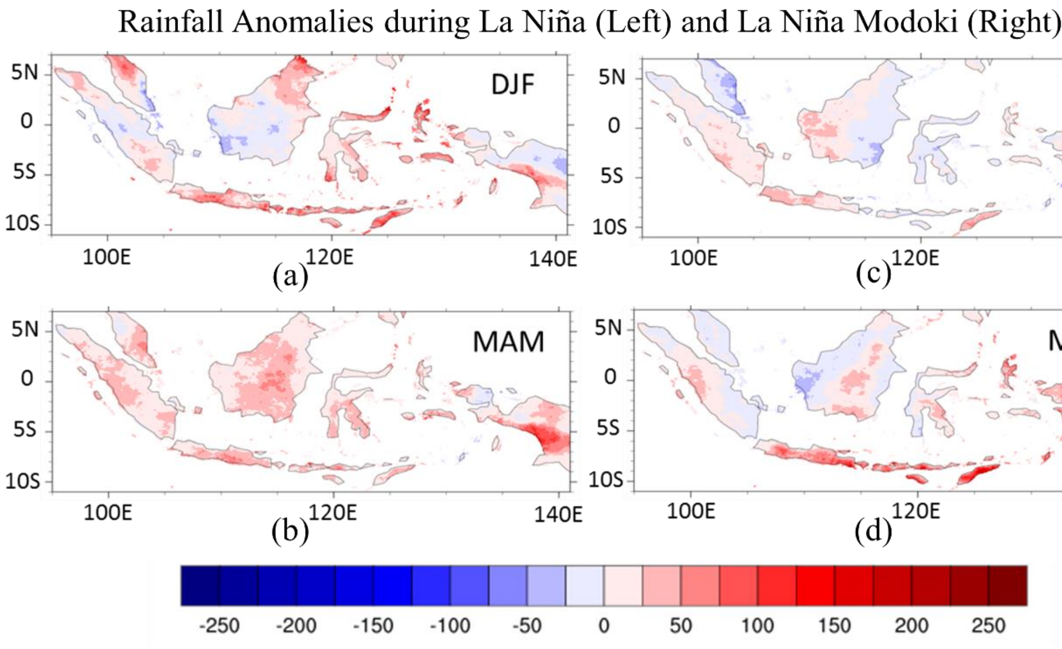

Figure 6. Composite Indonesian rainfall anomalies La Nina (a-b) and La Nina Modoki (c-d).

Positive rainfall anomalies during La Niña events on DJF season (figure 6a) is up to 150 mm/month that occurred in Sulawesi, Maluku, and southern part of Indonesia, while negative rainfall anomalies up to -75 mm/month occurred in some part of Sumatera Island, Kalimantan and eastern Indonesia. During La Niña Modoki (figure 6c) positive rainfall anomalies up to 50 mm/month occurred in part of Sumatera Island, Java, Kalimantan and eastern Indonesia. While negative rainfall anomalies up to -75 mm/month occurred in parts of Borneo, eastern Indonesia and Sulawesi Island.

La Niña events on MAM season (figure 6b) affected positive rainfall anomalies up to 175 mm/month that occurred in all of Indonesia regions. Condition of rainfall anomalies during La Niña Modoki events (figure 6d) on MAM season showed that Java Island has a strongest positive anomaly up to 175 mm/month. La Niña Modoki also causing negative rainfall anomalies up to -75 mm/month in part of Sumatera Island and eastern Indonesia.

4. Conclusion

Nino 3.4 and EMI have negative correlation in every season except on MAM, while SOI has positive correlation in all season except on MAM. Spatially, Nino 3.4 index has strong negative correlation (r = -0.95) with Indonesian rainfall, while EMI have weak correlation (r = -0.3).

SST anomalies during La Niña events indicate that cooling SST occurred in the central and eastern equatorial Pacific up to -1.5˚C in every season. In La Niña Modoki events, warming SST occurred in the western and eastern equatorial Pacific up to 0.75˚C and cooling in the central equatorial Pacific up to -0.75˚C in both seasons. Walker circulation anomalies that occurred during La Niña events on DJF season have strong convection in the western equatorial Pacific, but during MAM season experience weak convection. La Niña Modoki caused strong convection in the eastern Pacific and weak convection in the western Pacific (Indonesia) during DJF and MAM season. La Niña caused positive rainfall anomalies in Indonesia up to 200 mm/month on DJF and MAM, but on DJF season some areas such as Sumatera Island, Kalimantan and eastern Indonesia had negative rainfall anomalies. La Niña Modoki during DJF caused weak positive rainfall anomalies (50 mm/month) in some are of Sumatera Island, Borneo, Java and eastern Indonesia, and caused a strong positive anomaly up to 175 mm/month only in Java Island during MAM season.

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