Lestari et al. 2019 J. Geomate

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International Journal of GEOMATE, Sept., 2019 Vol.17, Issue 61, pp. 156 - 162
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2019.61.8256
Special Issue on Science, Engineering & Environment

IMPACT OF 2016 WEAK LA NIÑA MODOKI EVENT OVER THE INDONESIAN REGION

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*Corresponding Author, Received: 19 Nov. 2018, Revised: 31 Dec. 2018, Accepted: 26 Jan. 2019

ABSTRACT: After an extreme 2015/16 El Niño phenomenon, the Pacific Ocean witnessed a La Niña Modoki event, while a strong negative IOD simultaneously took place in the Indian Ocean. The event was weaker in intensity and shorter time, compared to the similar case in 1998/99. Using the combined monthly sea surface temperature (SST) derived from the Optimum Interpolation Sea Surface Temperature (OISST) version 2, the atmospheric reanalysis data from the National Center for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) and the precipitation data from the Tropical Rainfall Measuring Mission (TRMM), the dynamics and possible impact of this event were investigated. The 2016 La Niña Modoki initially developed in boreal summer, subsequently matured in autumn, and abruptly terminated in winter. This short-lived La Niña Modoki was associated with a unique SST anomalies pattern in the Indo-Pacific region. Strengthened easterly winds in the central tropical Pacific Ocean was associated with a warming SST over the western Pacific Ocean and triggered convergence in the lower atmosphere causing upward motion and enhanced convective process over the Indonesian region. As a consequent, most of the Indonesian region experienced excess precipitation during boreal summer, except in the northern part of the Sumatra Island.

Keywords: Atmosphere Circulation, Indonesian Region, La Niña Modoki, Precipitation

1. INTRODUCTION

El Niño-Southern Oscillation (ENSO) Modoki is one type of the interannual climate variability that has intensively discussed in recent years [1–3]. ENSO Modoki is associated with typical warming sea surface temperature (SST) anomalies in the central tropical Pacific Ocean (TPO) with cooling SST anomalies both side in the western and eastern TPO [1].

After a super El Niño in 2015/16 [4,5], TPO witnessed a unique cooling SST anomaly. This pronounced phenomenon was similar to that occurred after an extreme 1997/98 El Niño. We expected that the phenomenon was also associated with a new flavor of coupled ocean-atmosphere interaction, so-called La Niña Modoki, which is referred to the cooling phase of ENSO Modoki. The previous study has found that La Niña Modoki has affected climate variability in some region [6]. It caused excess rainfall extending from northwestern Australia to the northern Murray-Darling Basin, as consequence of shifting convection process more westward in the TPO. La Niña Modoki was also increased above normal precipitation anomalies leading severe flooding in the Southeast Asia region during boreal autumn [7].

Considering the geographic position of the Indonesian region, climate variability in this area has strongly influenced by the climate modes took place in the TPO [8]. Therefore, this study is designed to investigate the 2016 La Niña Modoki event and evaluate its possible impact on precipitation over the Indonesian region. Although several La Niña Modoki events have occurred several times, this study focused only on the 2016 La Niña Modoki event by comparing with a strongest La Niña Modoki event occurring during the three decades, namely 1998/99 La Niña Modoki events.

2. DATA AND METHODS

The monthly SST data used in this study are obtained from the National Oceanographic and Atmospheric Administration (NOAA) Optimum Interpolation Sea Surface Temperature (OISST) Version 2 with a horizontal resolution of 0.25° × 0.25°. This data are available from September 1981 to February 2018.

The low-level winds data at 850 MB are from the National Center for Atmospheric Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) Reanalysis [9]. The data covers a period from January 1948 to June 2018 with a horizontal resolution of 2.5° × 2.5°.

The monthly precipitation data are from the Tropical Rainfall Measurement Mission (TRMM), in which only data over land are used in this study. The data have a horizontal resolution of 0.25° in both longitude and latitude and cover a period from January 1999 to April 2018.

To evaluate the evolution and possible impact of the climate mode on the Indonesian region, we first calculate the anomalies of each data. Anomalies of all variables are defined by subtracting the monthly climatology from the monthly data. Note that the monthly climatology for SST and precipitation were calculated based on the period of January 2001–December 2015, while for the low-level winds was calculated based on the period of January 1948– December 2013. In order to analyze the seasonal variation, we calculate the seasonal mean by running 3-month-average data; March to May (MAM) season, June to August (JJA) season, September to November (SON) season, and December to February (DJF) season, respectively for all data.

Furthermore, to identify the La Niña Modoki event, El Niño Modoki Index (EMI) was used in this study. The EMI was defined as average SST anomalies over the central TPO (165°E to 140°W, 10°S to 10°N) minus SST anomalies in the eastern (110°W to 70°W, 15°S to 15°N), and western (125°E to 145°E, 10°S to 20°N) TPO regions [1]. Following Ashok et al. (2007), the negative index below one standard deviation for at least three consecutive seasons (from summer to winter season) is categorized as La Niña Modoki event.

3. RESULTS AND DISCUSSION

3.1 Evolution of the 2016 La Niña Modoki Event

Figure 1 shows the time series of the EMI from January to December 1998-99 (red solid line) and 2016-17 (blue dashed line). Based on the EMI, it can be seen that the 2016 La Niña Modoki event had shorter-lived time and weaker intensity compared to 1998/99 La Niña Modoki. The EMI revealed that evolution of 1998/99 La Niña Modoki event started in boreal spring (April 1998), reached its peak in boreal summer and autumn (August and October 1998) with a maximum intensity about –1.6°C and terminated in boreal spring (April 1999). Meanwhile, 2016 La Niña Modoki event started to develop with a relatively weak intensity in early boreal summer (June 2016). Then, it reached its peak at the end of autumn (November 2017) with a maximum intensity of about –0.9°C. After reaching its peak, the intensity of the 2016 La Niña Modoki was weakened and abruptly terminated in the early winter season (December 2016). Considering the intensity during the evolution and peak of the EMI, 2016 La Niña Modoki can be categorized as a weak La Niña Modoki event.

The seasonal evolution of SST and low-level winds anomalies of the 2016 La Niña Modoki is illustrated in Fig. 2e-h. The initial development of this event can be identified by the gradual cooling of SST anomalies firstly observed in the eastern to the central TPO (80°W to 165°W) just after the termination of the 2015/16 super El Niño event (Fig. 2f). During boreal summer 2016, the easterly winds anomalies were also developed in western TPO. As a result, the cooling intensity of SST anomalies was strengthened and extended more westward near the dateline during boreal autumn. Meanwhile, in the western TPO and the Indonesian waters covered by positive SST anomalies.

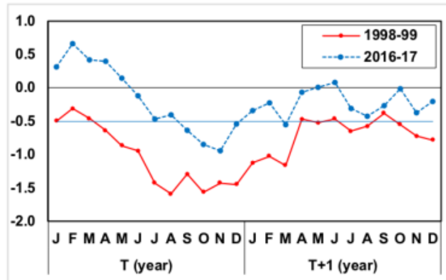

Fig. 1 Times series of EMI for 1998/99 (red solid line) and 2016 (blue dashed line) La Niña Modoki events.

It was shown that the cold SST anomalies were centered at 150°W to 170°W with a maximum intensity of about –2.5°C. At the same time, strong easterly winds anomalies over the western TPO, which are the peculiar features during La Niña Modoki event, can be observed during the mature phase of the 2016 La Niña Modoki. The easterly winds anomalies were observed along the western half of the equatorial Pacific Ocean, while the westerly winds anomalies were found in the eastern TPO and northwesterly winds anomalies were blowing along the southeastern coast of the TPO. As a consequence, a warmer than normal SST anomalies were observed in the vicinity of the Indonesian region and in the southeastern TPO, while colder than normal SST anomalies only observed in the eastern half of the equatorial region of the Pacific Ocean. Furthermore, the cold SST anomalies pattern was abruptly decayed in boreal winter, leaving just a little part of cold SST anomalies near the dateline with very weak intensity.

3.2 Comparison with 1998/99 La Niña Modoki Event

During 2015/16, the TPO witnessed a super El Niño [4,10], which terminated at the end of boreal spring 2016 [11,12]. Following the termination of super El Niño, however, the TPO did not experience a strong La Niña Modoki event as it did in 1998 just after an extreme El Niño in 1997.

Figure 2 presents the distinct SST anomalies patterns during 1998/99 and 2016/17. The spatial distribution of SST anomalies in 2016/17 revealed a weak La Niña Modoki event. The colder SST anomalies observed in the central TPO, although with weak intensity and shorter live time.

Meanwhile, a strong La Niña Modoki event existed in the TPO during 1998/99. The strong 1998/99 La Niña Modoki event revealed contrast winds and SST anomalies patterns with those observed during the 2016 La Niña Modoki event. Stronger than normal easterly winds anomalies were observed from the eastern to the western equatorial Pacific Ocean during the peak phase of the event. As a result, cold tongue (cold SST anomalies) was extended to the west in contrast to that observed in 2016 La Niña Modoki event. Furthermore, narrower warm SST anomalies compared to that of 2016 event covered the Indonesian region and far western TPO region. These distinct winds and SST anomalies patterns result in the different response of the precipitation over the Indonesian region. We will discuss the mechanism in the following sub-section.

It also can be seen that the tropical Indian Ocean (TIO) also witnessed strong negative Indian Ocean Dipole (IOD), both in 1998 and 2016 [12]. A strong negative IOD triggered strong convective process over the Indonesian region causing heavy rainfall in this region.

During boreal summer 1998, strong northwesterly winds anomalies blowing from northwestern TIO to Indonesian region. The colder SST anomalies in the central TPO also triggered strong westerly winds anomalies blowing to Indonesian region. Associated with this condition, there was convergent zone over the Indonesian region and divergent zone over the western TIO and central-western TPO at the low-level atmosphere (Fig. 3b). The vertical motion anomalies in Fig. 4b confirmed this response.

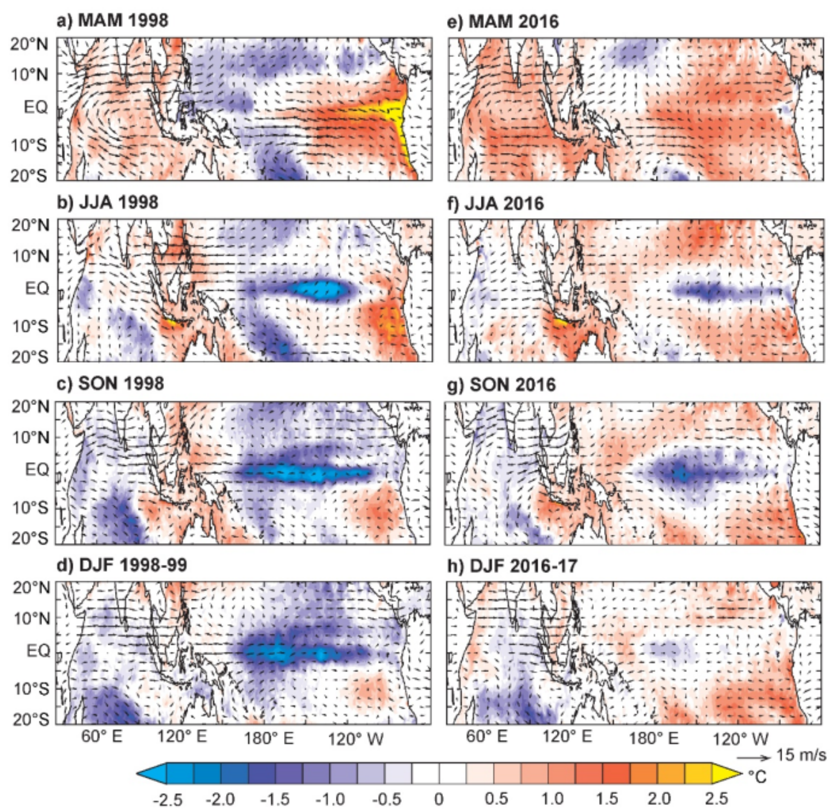

Fig. 2 Seasonally averaged of SST anomalies (*shaded*; °C) and winds anomalies (*vector*; m/s) during 1998-99 (left) and 2016-17 (right) in (a,e) boreal spring (MAM), (b,f) boreal summer (JJA), (c,g) boreal autumn (SON), and (d,h) boreal winter (DJF), respectively.

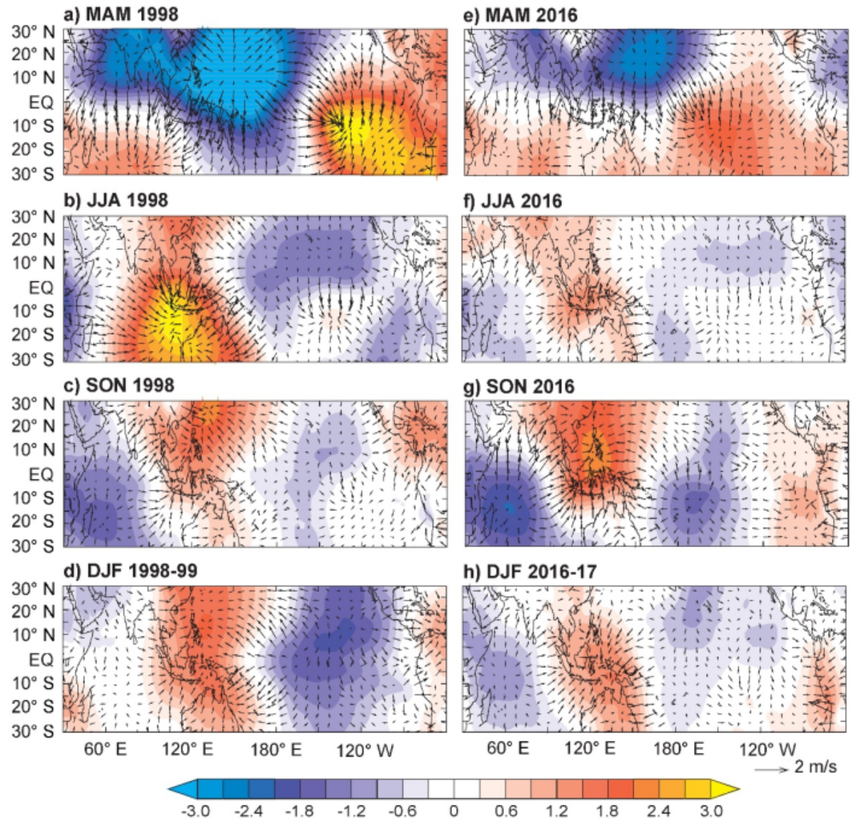

Fig. 3 Same as Fig. 2, but for velocity potential anomalies (*shaded*; 10^5 m^{-2} s^{-1}) and convergent/divergent winds anomalies (*vector*; m/s) at 850 mb.

There were two-cell of Walker circulation that has developed. Strong descending motion dominated over central to western TPO (165°W - 135°E) with stronger ascending motion in the eastern TIO (90°E - 120°E) and weaker ascending motion in the eastern to central TPO (90°W - 150°W) consistent with SST anomalies pattern. The different response is shown during boreal summer 2016, the convergence zone covered narrow area and moved more westward to the central part of Indonesian region compared to those occurring during 1998 event. As a result, the intensity of Walker circulation anomalies is also weaker. However, convergence zone over the Indonesian region triggered ascending atmospheric motion and increased convective activities causing excess precipitation in this area.

3.3 Impact of the 2016 La Niña Modoki on the Indonesian Climate

In general, the Indonesian region experienced excess precipitation during 2016 La Niña Modoki as shown in Fig. 5d-f. During boreal summer, the above normal precipitation observed almost all of the Indonesian region, except the northern part of Sumatra Island. The maximum precipitation with intensity above 100 mm/month covered the area of central Java and the southern Papua Island. In the autumn season, the coverage area of the 2016 La Niña Modoki impact shifted to the central-eastern Indonesian region. The northern-eastern part of Kalimantan Island also experienced more surplus precipitation compared to that during the boreal summer. It associated by strong convergent winds anomalies that dominated over the northeastern TPO (110°E - 135°E) as shown in Fig. 3g. It also confirmed by vertical motion anomalies in Fig. 4g. The strong ascending motion that existed in this area increased water vapor and convective activities. As result, more surplus precipitation observed in this area.

Interestingly, it is also shown that deficit precipitation also existed over the central to the northern part of Sumatra and over the northeastern part of Kalimantan Islands during the autumn season. Note that these areas were surrounded by cold SST anomalies indicating a strong couple of ocean-atmosphere interaction. Finally, the impact of 2016 La Niña Modoki was terminated during the winter season, with small areas of the Indonesian region still covered by above normal precipitation.

Figure 5 also shows the distinct pattern of distribution precipitation during two La Niña Modoki events (i.e 1998/99 La Niña Modoki and 2016 La Niña Modoki). It can be seen that the intensity and the coverage area of precipitation during boreal summer 1998 were higher and wider than during the same season in 2016. Above normal precipitation anomalies with a maximum intensity of about 100 mm/month observed most of all Indonesian region during summer 1998. It associated by stronger convergent winds that existed in southeastern of TPO (90°E - 120°E). During the autumn season, however, the intensity of above normal precipitation in 2016 La Niña Modoki became higher compared to 1998/99 La Niña Modoki. The coverage area of above normal precipitation during autumn 1998 also became narrower Furthermore, during the winter season the impact of that event decayed.

4. CONCLUSIONS

Based on the spatial distribution of sea surface temperature anomalies, the evolution of a unique cooling pattern in the central tropical Pacific Ocean during 2016/17 can be identified as a weak La Niña Modoki. It also was confirmed by El Niño Modoki index, which revealed negative values below one standard deviation for three consecutive seasons (from summer 2016 to winter 2016). The event initially developed in the early boreal summer (June 2016). Then, it matured at the end of the autumn season (November 2016) and abruptly terminated in the early winter season (December 2017).

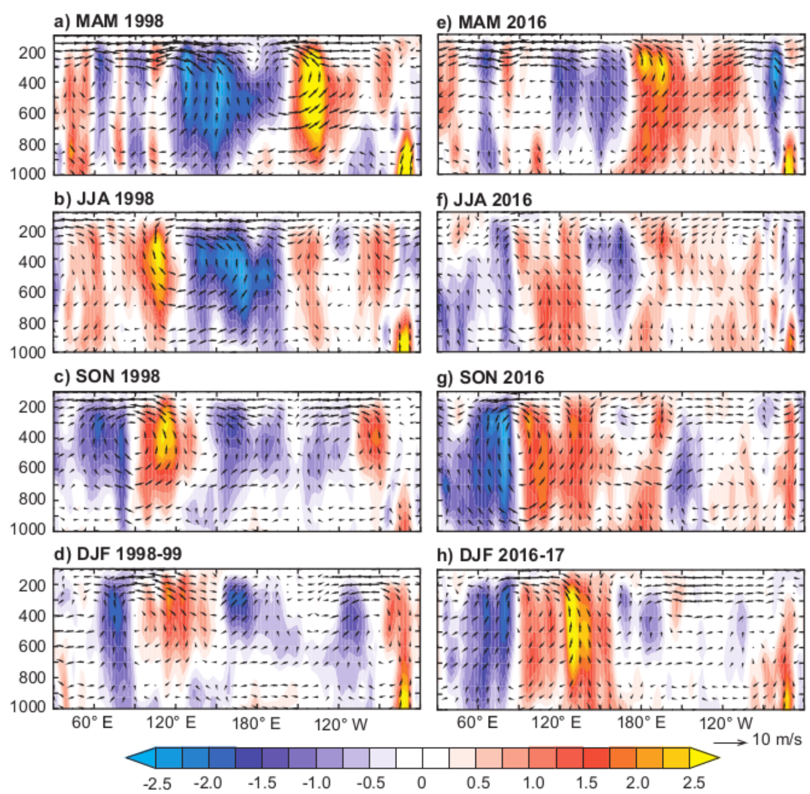

Fig. 4 Same as Fig. 2, but for seasonally Walker circulation (*vector*; m/s) and vertical velocity (*shaded*) in the tropical Indian-Pacific Ocean.

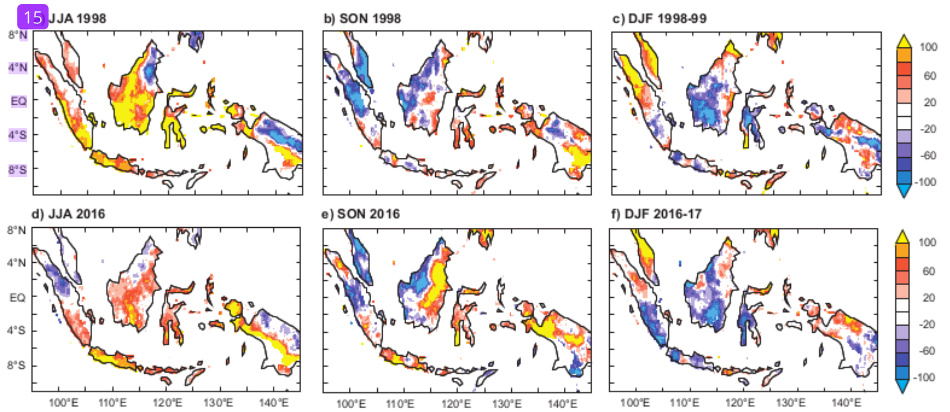

Fig. 5 Seasonally averaged of precipitation anomalies (mm/month) during boreal summer until boreal winter.

The onset of 2016 La Niña Modoki was linked to strong easterly winds anomalies observed in the western tropical Pacific Ocean and stronger than normal northwesterly winds anomalies found in the southeastern tropical Pacific Ocean. As a result, there were cooling SST anomalies in the eastern to central tropical Pacific Ocean. During the peak of this event, the cooling sea surface temperature anomalies were extended more westward near the dateline, with maximum sea surface temperature anomalies centered around 150°W to 170°W. Meanwhile, in the southeastern tropical Pacific Ocean and western part of the tropical Pacific Ocean warm sea surface temperature anomalies were observed. This cooling (warming) sea surface temperature triggered divergence (convergence) zone and descending (ascending) atmospheric motion, and suppressed (enhanced) convective process in the central tropical Pacific Ocean (Indonesian) region. As a consequence, the Indonesian region experienced excess precipitation, except the northern part of Sumatra and north-western Kalimantan Islands. The maximum precipitation above 100 mm/month observed over central Java, northeastern Kalimantan, and northern Papua Island.

This study suggests that it is important to fully understand the dynamic and the possible impact of this event on Indonesian region. Accordingly, the next step toward evaluating this phenomenon by using long-term data is underway.

5. ACKNOWLEDGMENTS

This research is supported by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia through the PMDSU Scholarship for the first author. The last author was supported by a grant of the *Penelitian Berbasis Kompetensi 2018*.

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Lestari et al. 2019 J. Geomate

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