Impacts of the MJO on Rainfall at Different Seasons in Indonesia

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Abstract. The Madden-Julian Oscillation (MJO) is the dominant mode of intraseasonal variability of rainfall in Indonesia, but its signal is often obscured in individual station data, where effects are most directly felt at the local level. This study aims to investigate the general impacts of MJO on rainfall at different seasons in Indonesia, particularly during boreal summer. Impacts of the MJO on daily rainfall anomaly during the four climatic seasons: DJF, MAM, JJA, and SON in Indonesia have been evaluated using in-situ data from 86 stations during 1981 - 2012 and remote sensing data using GPM IMERGV06 from 2001 - 2019. The greatest impact of the MJO on rainfall over Indonesia occurs during the DJF and MAM seasons (austral summer), with the magnitude varying across regions. Enhanced rainfall generally occurs over the western parts of Indonesia on phases 2 to 4, central parts of Indonesia on phase 4, and eastern parts of Indonesia on phases 4 to 5. Conversely, suppressed rainfall generally occurs over the western parts of Indonesia on phases 5 to 8, central parts of Indonesia on phases 6 to 8, and eastern parts of Indonesia on phases 1 to 2 and 6 to 8. In addition, the MJO influence during the JJA and SON seasons are slightly less, in terms of intensity, than during the DJF and MAM seasons, which is likely due to the northward shift of ITCZ and, hence, the intraseasonal oscillation convective envelope during boreal summer. Generally, enhanced rainfall occurs over the western and northern parts of Indonesia on phases 2 to 3, and suppressed rainfall on phases 6 to 7. The results indicate that convectively active MJO may increase the possibility of daily extreme rainfall in particular regions in Indonesia at different seasons.

1. Introduction

One of the most intriguing planetary-scale phenomena for this century is probably the Madden-Julian Oscillation (MJO). Since its early detection by Madden and Julian in 1971, many studies have been attempted to delineate its distinct feature, structure, behaviour and teleconnection with other local to planetary-scale phenomenon based on observed data and model. Accordingly, it is said to be the most dominant mode of intraseasonal variability across the tropics and a baroclinic disturbance in circulation that is coupled to large-scale variations in convection [1,2]. The MJO is an intraseasonal tropical oscillation which has a periodicity of 30 - 90 days as a result of an interaction between ocean and atmosphere [3].
Through examination of spectral character of tropical convection, Hendon and Salby [4] found that the MJO convective signal propagates eastward along the equator at about 5 m/s, and is primarily confined to the Eastern Hemisphere, although its circulation signal influences the global tropics (Figure 1). Further, they suggested that a prevailing diurnal component interferes with the 35-95 day signal in convection in three centers of global climatological convection -- South America, Africa, and Maritime Continent. This finding is coherent with Neale and Slingo [5] which stated that the atmospheric convection in the Maritime Continent has a globally significant role as a heat source for global circulation and in modulating large-scale intraseasonal variability such as the MJO [6]. In particular, it has been suggested that changes in the diurnal precipitation cycle account for most of the variation in precipitation with the passage of the MJO, and that the strength of the diurnal cycle modulates the MJO [7].

![Figure 1. The MJO rain forcing during the boreal winter and summer with 30-60 days periodicity which has dominant eastward propagation along the equator [8]](image)

The MJO is the dominant mode of intraseasonal variability of rainfall in Indonesia, but its signal is often obscured in individual station data, where effects are most directly felt at the local level. The MJO impact on local level can be influenced by several factors such as topography [9,10] and its interaction with diurnal cycle [7].

MJO signals are observed to be strong and peak in boreal winter (December – March) in the western Pacific [11]. There are many previous studies to discuss the MJO impacts during boreal winter in the Tropics and particularly, in Indonesia. For examples, MJO increases rainfall by up to 5 mm/day
on phases 2 to 4 and decreases rainfall on phases 6 to 8 in Indonesia [9]. Active MJO phases increase extreme precipitation events by ~15 - 20% in the tropics [12]. MJO increases the probability of extreme precipitation by up to 30-50% on phases 2 to 4, while decreases the extreme precipitation probability by ~10 - 20% on phases 6 to 8 over Southeast Asia [13]. Most recently, the probability of extreme precipitation events over the western and central parts of Indonesia increases (decreases) by up to 70% (40%) when MJO active (inactive). While, in the eastern part of Indonesia, the probability of extreme precipitation events increases (decreases) by up to 50% (40%) when MJO active (inactive) [14].

Despite of many studies investigate the impact of MJO during boreal winter (November - April) in Indonesia, the impact of MJO during boreal summer (May - October) in Indonesia has not been discussed intensively. This is due to the weaker MJO signals during boreal summer than during boreal winter. However, although the MJO signals are weaker, the impact can be significant due to local and topographic effects [9]. Therefore, this study aims to investigate the general impacts of MJO on rainfall at different seasons in Indonesia, particularly during boreal summer.

2. Data and Methods

In this study, impacts of the MJO on daily rainfall in Indonesia during four climatic seasons: December to February (DJF), March to May (MAM), June to August (JJA), and September to November (SON)) have been evaluated using in-situ data from 86 BMKG stations (Figure 2) during 1983 - 2012 (30 years) and remote sensing data using GPM IMERGV06 [15] with spatial resolution of 0.1° from 2001 - 2019 (19 years). From 86 stations, there are 10 stations that have about 10 - 15 % of empty data. All stations data has passed through the quality control procedures and homogeneity test as described in Supari et al. [16].

Figure 2. The distribution of station locations used in the study.

The MJO events are defined based on an all-season real-time multivariate MJO index (RMM) which categorized MJO events into phases and amplitudes [17]. The MJO has eight phases, where each phase of MJO indicates the location of the MJO convective center. The MJO propagates eastward starting at phase 1 (west Africa), phase 2 and 3 (the Indian Ocean), phase 4 and 5 (Maritime Continent), and phase 6 to 8 (over the western Pacific). In addition, the MJO amplitude indicates the strength of MJO convection where the strong MJO has amplitude ≥ 1 and the weak MJO has amplitude < 1.
The flowchart of the method used in this study is depicted in Figure 3. First, the annual climatology of daily precipitation (precipitation seasonality) is calculated from the daily precipitation time series. Second, the low-pass filter is applied to the precipitation seasonality to generate the low frequency signal of the precipitation seasonality. The original precipitation is then subtracted by the low frequency signal of the precipitation seasonality to derive the rainfall anomaly. The subtraction of low frequency signal of precipitation seasonality intends to maintain the daily variation (high frequency signal) of the original precipitation and to remove the seasonality from the original precipitation. Next, for each station and grid, the rainfall anomaly was categorized into 8 strong MJO phases (amplitude $\geq 1$) and 1 weak MJO phase (amplitude $< 1$). The mean value of rainfall anomaly of weak MJO phase is considered as the normal value which is close to 0 mm/day. Finally, for each strong MJO phase, the mean value of rainfall anomaly is subtracted by the normal value to derive a single value of rainfall anomaly for each station and grid. This process was conducted for different seasons (DJF, MAM, JJA and SON).

Figure 3. Flowchart of the method used in this study.

3. Results and Discussions

The rainfall anomaly for each MJO phase during boreal winter are given in Figure 4 (DJF) and Figure 5 (MAM). In general, there is a synchronous spatial pattern of MJO impact on rainfall anomaly between station and GPM data. The magnitude of rainfall anomalies of station data are varying across regions. This is likely due to the local effect from each station such as topographic and diurnal cycle effect. During DJF and MAM, enhanced inland rainfall generally occurs over the western parts of Indonesia on phases 2 to 4, central parts of Indonesia on phase 4, and eastern parts of Indonesia on phases 4 to 5. Conversely, suppressed inland rainfall generally occurs over the western parts of Indonesia on phases 5 to 8, central parts of Indonesia on phases 6 to 8, and eastern parts of Indonesia on phases 1 to 2 and 6 to 8. This results support the previous studies [9,13,14].

Specifically, the spatial pattern of rainfall anomalies over the eastern and northeastern parts of Kalimantan Island is the “reverse” of its surrounding, particularly on MJO phases 1 to 3 and 5 to 6. For example, during MJO phases 1 to 3, the eastern and northeastern Kalimantan have negative rainfall anomalies while its surrounding have positive rainfall anomalies. This “reverse” phenomena maybe due to the interaction between MJO and diurnal cycle, however, further investigation is needed for future research.
Figure 4. (Left panel) Rainfall anomalies for each MJO phase from station data during DJF. Black (Red) boxes indicate the region with dominant positive (negative) rainfall anomalies. (Right panel) Rainfall anomalies for each MJO phase from GPM IMERGv06 data during DJF.

Figure 5. (Left panel) Rainfall anomalies for each MJO phase from station data during MAM. Black (Red) boxes indicate the region with dominant positive (negative) rainfall anomalies. (Right panel) Rainfall anomalies for each MJO phase from GPM IMERGv06 data during MAM.
During boreal summer, the MJO influence on rainfall during the JJA (Figure 6) and SON (Figure 7) are slightly less, in terms of intensity, than during the DJF and MAM seasons. This is likely due to the northward shift of Intertropical Convergence Zone (ITCZ) and hence, the intraseasonal oscillation convective envelope. This result is inline with a recent study which indicated that the amplitude of rainfall diurnal cycle reduces by about 35% during the boreal summer compared to the boreal winter, particularly over the major islands and adjacent oceans in the Maritime Continent [18]. During JJA, the station data show that the clearly impact of MJO on rainfall are positive anomaly on phases 2 to 3 and negative anomaly on phases 6 to 7 over Indonesia region. However, specifically, the intensity is higher over the northern parts of Indonesia, particularly Kalimantan Island as being shown by the GPM data (Figure 6). In addition, positive (negative) rainfall anomalies are also observed on phase 1 (8) in the western (eastern) part of Indonesia.

During SON, the impacts of MJO on rainfall are slightly similar to during JJA with the glimpse of higher intensity over the northern parts of Indonesia compared to the southern parts, which can be seen during phases 1 to 3 and 5 to 7 (Figure 7). During these phases, the highest intensities were observed over Kalimantan and Sumatra Islands, followed by Java Island. The “reverse” rainfall anomaly phenomena in Kalimantan also looks pretty clear during SON, but unclear during JJA (except during phases 1 to 2). This may lead to the effect of seasonal circulation that influence this phenomena. These results indicate that convectively active MJO may increase the possibility of daily extreme rainfall events in particular regions in Indonesia even during boreal summer (JJA and SON). However, the quantification of probability changes of extreme rainfall events is not part of this study and remains for further investigation.

Figure 6. (Left panel) Rainfall anomalies for each MJO phase from station data during JJA. Black (Red) boxes indicate the region with dominant positive (negative) rainfall anomalies. (Right panel) Rainfall anomalies for each MJO phase from GPM IMERGv06 data during JJA.
4. Conclusions

Impacts of the MJO on daily rainfall in Indonesia during four climatic seasons: DJF, MAM, JJA and SON have been evaluated using in-situ data from 86 BMKG stations and remote sensing data using GPM IMERGV06. There is generally a synchronous spatial pattern of MJO impact on rainfall anomaly between station and GPM data. During DJF and MAM, enhanced inland rainfall generally occurs over the western parts of Indonesia on phases 2 to 4, central parts of Indonesia on phase 4, and eastern parts of Indonesia on phases 4 to 5. Conversely, suppressed inland rainfall generally occurs over the western parts of Indonesia on phases 5 to 8, central parts of Indonesia on phases 6 to 8, and eastern parts of Indonesia on phases 1 to 2 and 6 to 8. The magnitude of rainfall anomalies of station data are varying across regions. During JJA and SON, the intensity of rainfall anomalies are slightly less than during DJF and MAM. This is likely due to the northward shift of ITCZ which also results in the glimpse of higher intensity over the northern parts compared to the southern parts of Indonesia. Enhanced rainfall occurs over the western and northern parts of Indonesia on phases 2 to 3, and suppressed rainfall on phases 6 to 7. The “reverse” rainfall anomaly phenomena in Kalimantan Island was observed during DJF, MAM and SON, but not clearly seen during JJA. The results indicate that convectively active MJO may increase the possibility of daily extreme rainfall in particular regions in Indonesia at different seasons.

Acknowledgments

Authors wishing to acknowledge assistance or encouragement from BMKG colleagues at Global Atmospheric Watch at Bariri, Central Sulawesi; Center for Research and Development, Center for Climate Change Information. This research project is financially supported by Center for Research and Development of BMKG.
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