Characteristics of the Extreme Rainfall over Indonesian Equatorial Region based on the Madden-Julian Oscillation Index Data Analysis

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Abstract. Indonesia Maritime Continent (IMC) is one the most important region at the equator which affected by many atmospheric phenomena, especially Madden-Julian Oscillation and Monsoon. Asian Winter Monsoon causes the increasing of rainfall in several places in Indonesia in December-January-February (DJF), and since MJO related to a propagation of convective cloud, somehow it affects the rainfall variability in equator, especially over Indonesia. Interaction of both phenomena simultaneously bring rainfall is increasing in Indonesia, especially in Western Part of Indonesia. Therefore, a research about the impact of MJO in rainfall especially in Bandung and other cities over Indonesia is important. This study aims to investigate impacts of MJO events on the rainfall variability in Bandung and other cities focusing when Asian Winter Monsoon (December-January-February/DJF) for period of DJF 2002/03 – DJF 2012/13 passing over Indonesia. The results show that from 10 MJO events in period DJF 2002/03 – DJF 2012/13, the event increased the rainfall continuously in phase 3, phase 4, and phase 5. In phase 3, the increasing happened in every station except Supadio in Pontianak with the total precipitation > 30 mm/day. The condition of rainfall in phase 4 fluctuates in every station, but with the dominant increasing in Equator. In phase 5, the decreasing of rainfall happened in North of the Equator and Equator, while in South of Equator, the rainfall in Cengkareng Station in Jakarta increased about 20% but decreased about -42% in Bandung Station.

1. Introduction
The geographical condition of the Indonesian Maritime Continent has resulted in Indonesia’s territory having a very strong potential for convective activity [1]. Therefore, various atmospheric phenomena occur in Indonesia [2]. Atmospheric phenomena, including the MJO and Monsoon phenomena, affect the variability of Indonesian rainfall. Monsoons are changes in annual trade flows associated with variability in rainfall in each monsoon region [3]. The Asian-Australian Monsoon classification by [4] states that increased rainfall in Indonesia generally occurs during the Asian Winter Monsoon (DJF).

Whereas MJO is associated with the formation of convective clouds at the equator and has an intraseason pattern [5-7], thus it affecting the variability of rainfall around tropical regions including...
Indonesia[8,9]. The western region of Indonesia is bordered by the Indian Ocean where connectivity is very intensive, so it has a direct response to the MJO phenomenon. Studies on MJO in the Indonesian Maritime Continent have been carried out [1,10,11] to the effect of MJO on cases of extreme rainfall in Jakarta [12,13]. The results of these studies show varied results regarding the impact of MJO on rainfall, including in the western region of Indonesia. [8] and [14] agree that the "complex" Indonesian territory has resulted in the absence of a specific pattern regarding the state of rainfall in the Indonesian region during active MJO. Therefore, this study is intended as a further study to understand the impact of active MJO on rainfall in the western part of Indonesia during the Asian Winter Monsoon.

This study aims to analyze rainfall patterns in the western part of Indonesia using the rainfall data from BMKG station which is represented by rainfall in Cut Nyak Dien and Polonia Stations for the northern region, rainfall for Kototabang and Supadio Stations for the Equator region, and rainfall at Cengkareng and Bandung stations for the southern region; to identify MJO events in the DJF period 2002/03 to DJF 2012/13 in phases 3, 4 and 5; and analyze the influence of MJO in each phase on rainfall in the western region of Indonesia.

2. Data and Method
The data used includes rainfall data from TRMM satellite precipitation and BMKG observation rainfall represented by 6 stations: Cut Nyak Dien and Polonia Stations representing the North, Kototabang and Supadio Stations representing the Equator region, and Cengkareng and Bandung Stations representing the Southern region. It is estimated that rainfall patterns in the Equator region have an equatorial pattern, therefore zonal wind data from Equatorial Atmospheric Radar / EAR (Kototabang, 0.2°S, 100.32°E), RMM index data, Outgoing Longwave Radiation (OLR) data, and rainfall data are used.

While the used methodology of this study is analysing of regional rainfall characteristic which divided into the Northern part of Equatorial region, near the Equatorial region, and the Southern part of the Equatorial region, respectively. Then, analysing of Monsoon in the Equator region, and identification of MJO events using the RMM index and analysis of OLR anomaly using the Hovmoller diagram, before finally analysing of the influence of MJO on rainfall data (based on observation data and spatial data). The lower threshold used for spatial results is 5 mm/day, which is the lower limit of light rainfall according to BMKG (2014).

3. Results and Discussion
3.1. Precipitation Pattern Analysis
As shown in Figure 1, the rainfall in the North region shows that some areas have a monsoonal pattern, as shown in the results of the FFT of the Polonia Station rainfall. Others tend to have an equatorial pattern, as shown by composite and FFT results at Cut Nyak Dien Station. However, the average monthly rainfall in the Cut Nyak Dien region ranges from 250-350 mm, which indicates rainfall in the DJF period in the region. Moreover, the 12-month oscillation peak (monsoonal) seen in the rainfall at Cut Nyak Dien station, which shows the Cut Nyak Dien region is also affected by the Monsoon phenomenon.

Generally, based on composite results, the rainfall of the Equator region tends to have rainfall characteristics in the equatorial pattern. Aside the results of the FFT showing a 12-month (monsoonal) oscillation pattern, the monsoon effect in the Equator region can also be identified through the results of zonal wind wavelets in Kototabang as shown in Figure 2. Whereas the South region shows a clear monsoonal pattern so that the southern region can be said to be influenced by an annual oscillation pattern such as the monsoon as shown in Figure 3.
Figure 1. The Composite and FFT of Rainfall over the Northern part of the Equatorial Region of Indonesia for Cut Nyak Dien (represented as (a) and (b)), and Polonia (represented as (c), and (d), respectively)
Figure 2. As the same as Fig. 1, but for near Equatorial line for Kototabang (represented as (a) and (b)), and Supadio (represented as (c), and (d), respectively)
3.2. Analysis of Monsoonal Pattern using Wind Data from EAR over Western part of Indonesia

The monsoonal pattern in the Western Region of Indonesia is shown by the results of wavelet analysis on both wind zonal and meridional wind data in the Lower Level Troposphere (~ 850 hPa) and in the Upper Troposphere (~ 200 hPa). The result, (Figure 4) shows that there is a 12 monthly dominant oscillation pattern in each wavelet result.

**Figure 3.** As the same as Fig. 1, but for Southern of Equatorial line for Cengkareng (represented as (a) and (b)), and Bandung (represented as (c), and (d), respectively)
Figure 4. Wavelet plot of wind data taken from Equatorial Atmospheric Radar (EAR) at Kototabang, West Sumatera that showing the zonal and meridional wind of EAR for lower and upper atmosphere (represented as 850 and 200 hPa, respectively)
**MJO Identification**

An identification of overall MJO events using the RMM index time series for the period December 2002 - December 2013 is shown in Figure 5. There were 10 MJO events in the DJF 2002/03 - DJF 2012/13 period (Table 1).

![Image](image_url)

**Figure 5. Time Series of RMM Index started from 2003 to 2013**

**Table 1.** Active MJO events during Asian Winter Monsoon in DJF 2002/03 – DJF 2012/13

| MJO Periods | Phase 3 | Phase 4 | Phase 5 |
|-------------|---------|---------|---------|
|             | Date    | Duration | Date    | Duration | Date    | Duration |
| 1 DJF 2002/03 | 23 Dec - 27 Dec | 5 days | 28 Dec - 31 Dec | 4 days | - | - |
| 2 DJF 2003/04 | 7 Dec - 13 Dec | 7 days | 14 Dec - 16 Dec | 3 days | 17 Dec - 22 Dec | 6 days |
| 3 DJF 2003/04 | 27 Jan - 31 Jan | 5 days | 1 Feb - 7 Feb | 7 days | 8 Feb - 11 Feb | 4 days |
| 4 DJF 2005/06 | 11 Jan - 14 Jan | 5 days | 15 Jan - 17 Jan | 3 days | 18 Jan - 23 Jan | 6 days |
| 5 DJF 2006/07 | 17 Dec - 29 Dec | 13 days | 30 Dec - 1 Jan | 3 days | 2 Jan - 8 Jan | 7 days |
| 6 DJF 2007/08 | 18 Dec - 21 Dec | 4 days | 22 Dec - 26 Dec | 5 days | 27 Dec - 4 Jan | 9 days |
| 7 DJF 2007/08 | 1 Feb - 3 Feb | 3 days | 4 Feb - 8 Feb | 5 days | 9 Feb - 12 Feb | 4 days |
| 8 DJF 2011/12 | - | - | - | - | 20 Jan - 26 Jan | 7 days |
| 9 DJF 2012/13 | 31 Dec - 1 Jan | 2 days | 2 Jan - 6 Jan | 5 days | 7 Jan - 10 Jan | 4 days |
| 10 DJF 2012/13 | 15 Feb - 16 Feb | 2 days | 17 Feb - 22 Feb | 6 days | 23 Feb - 24 Feb | 2 days |
Contribution of Active MJO during Asian Winter Monsoon to Precipitation

Table 2. Rainfall during active MJO and Asian Winter Monsoon in DJF 2002/03 – DJF 2012/13

| Stations   | Precipitation during MJO | Phase 3 | Phase 4 | Phase 5 |
|------------|--------------------------|---------|---------|---------|
|            | Average Percentage (%)   | 77      | 70      | -38     |
| Cut Nyak Dien | Above normal             |       6 | 6       | 1       |
| Frequency  | Normal                    | 0       | 0       | 0       |
|            | Below normal              | 3       | 3       | 8       |
| Polonia    | Average Percentage (%)   | 26      | -19     | -84     |
| Frequency  | Above normal              | 4       | 3       | 0       |
|            | Normal                    | 0       | 0       | 0       |
|            | Below normal              | 4       | 5       | 7       |
| Kototabang | Average Percentage (%)   | 49      | 22      | -54     |
| Frequency  | Above normal              | 4       | 4       | 1       |
|            | Normal                    | 0       | 0       | 0       |
|            | Below normal              | 5       | 5       | 8       |
| Supadio    | Average Percentage (%)   | 2       | 47      | -50     |
| Frequency  | Above normal              | 3       | 5       | 1       |
|            | Normal                    | 2       | 1       | 1       |
|            | Below normal              | 4       | 3       | 7       |
| Cengkareng | Average Percentage (%)   | 63      | 16      | 20      |
| Frequency  | Above normal              | 3       | 5       | 5       |
|            | Normal                    | 0       | 0       | 1       |
|            | Below normal              | 6       | 4       | 3       |
| Bandung    | Average Percentage (%)   | 47      | 2       | -42     |
| Frequency  | Above normal              | 4       | 1       | 0       |
|            | Normal                    | 3       | 1       | 4       |
|            | Below normal              | 2       | 7       | 5       |

The Badan Meteorologi, Klimatologi dan Geofisika (BMKG) observation data showed an increase in rainfall in nearly all of the western part of Indonesia when MJO in phase 3. The rainfall then declined in phase 4 and phase 5.
Figure 6. Rainfall during active MJO and Asian Winter Monsoon in DJF 2002/03 – DJF 2012/13 in Northern part of the Equatorial region (a), Near the Equatorial region (b), and Southern part of the Equatorial region (c), respectively
In the Northern area, consistently, an increase in rainfall is seen in the Cut Nyak Dien region reaching 77% when MJO phase 3 with the frequent number of above normal rainfall events. It means that the probability of increasing rainfall in the Cut Nyak Dien region when MJO in phase 3 is greater is around 6/9 or 66%. Likewise with the Polonia region with an increase in rainfall of 26% but with a probability of increasing and decreasing rainfall ≈ 50%. In the Equatorial Area, phase 3 of MJO increases rainfall in the Kototabang area by 49% but with a probability of increasing and decreasing rainfall ≈ 50%, in the other hand rainfall in the Supadio region shows normal condition. In the Southern Region, increased rainfall also occurs in both the Cengkareng and Bandung regions, but with the different probability of increasing and decreasing rainfall. In Cengkareng, the probability of decreasing rainfall is 66%, whereas in Bandung probability of increasing rainfall is ≈ 50%.

During phase 4 of MJO, the increasing of rainfall in the Northern Region occurred in the Cut Nyak Dien area reaching 70%, however in the Polonia region it decreased by -19%. In the Equatorial Area, an increase in rainfall occurred at 22% in the Kototabang region and 47% in the Supadio region. However, the probability of increasing rainfall in the Equatorial Area is ≈ 50% in both the Kototabang and Supadio regions. In the Supadio region, the increase in rainfall in phase 4 was significant compared to phase 3 and phase 5. When MJO phase 4, in the Southern Region, the rainfall conditions tend to be normal (16% in the Cengkareng area and 2% in the Bandung area) with a probability of decreasing rainfall more often occurs at 77% in the Bandung area.

In phase 5, the consistency of decreasing rainfall tends to occur in the North and Equatorial Areas. In the South, an increase in rainfall of 20% is seen in Cengkareng with a probability of increasing rainfall ≈ 50%. Whereas in the Bandung region, there was a decrease in rainfall of -42% with a probability of a decrease in rainfall of ≈ 50%.

Overall, the spatial data of average precipitation (Figure 6) shows a similar pattern with the results of observations, namely an increase in rainfall in almost the entire West Indonesia when MJO in phase 3 then decreases in phase 4 and phase 5. Consistently, precipitation occurs in almost all regions in the western part of Indonesia during MJO phase 3. The ocean area appears to have greater precipitation than the land area. In the coastal region of Sumatra island bordering the Indian Ocean, precipitation ranges from 15 - 30 mm / day. Likewise, with the ocean area around the islands of Java and Kalimantan. Mainland in Java seems to have considerable precipitation around 10-30 mm / day compared to Sumatra and Kalimantan (5 - 25 mm / day). In phase 4, several regions in the western part of Indonesia began to show precipitation conditions <5 mm / day. In the Northern Region and the Equatorial Area shows precipitation ranges from 5-15 mm / day. Whereas in the South, precipitation reaches > 30 mm / day. while the Equator and North regions, ranging from 5 - 20 mm / day. In phase 5, the South Region experiences precipitation ranging from 5-20 mm / day, while the Northern Region and the Equatorial Region of the western region of Indonesia show precipitation <5 mm / day.

Active MJO tends not to occur during the Australian Summer Monsoon Season (JJA). Figure 7 shows that the active MJO event in the JJA 2003 - JJA 2013 period starts in the transition season I (MAM) and ends around the beginning of June.
**Figure 7.** Average rainfall during phase 3 (a), 4 (b), and 5 (c) during active MJO and Asian Winter Monsoon in DJF 2002/03 – DJF 2012/13

**Figure 8.** Average rainfall during phase 3 (a), 4 (b), and 5 (c) during active MJO and Australian Summer Monsoon in DJF 2002/03 – DJF 2012/13. *MJO inactive in early June*
4. Conclusion

Based on the results of the study, it can be concluded that of the 10 MJO events in the DJF 2002/03 - DJF 2012/13 period, rainfall increased when MJO phase 3, then it continued to decline in phase 4 and phase 5. The influence of Monsoon was seen through an increase in rainfall in the Western Region of Indonesia (it was seen during MJO phase 3, before entering the Western Region of Indonesia). The condition of rainfall varies when MJO phase 4 (currently in the Western Region of Indonesia), and tends to decrease when MJO phase 5 (after passing through the Western Region of Indonesia). In phase 3 there was an increase in rainfall (except Supadio area); in Cut Nyak Dien region by 78%, at Polonia Station at 25%, at Kototabang Station at 49%, at Cengkareng Station 63%, and at Bandung Station 47% with precipitation reaching > 30 mm / day. Rainfall in phase 4 shows quite fluctuating results. In the Northern Territory rainfall increased 70% in the Cut Nyak Dien area but decreased by -19% in the Polonia region. In the Equatorial Area, an increase in rainfall occurred at 22% in the Kototabang region and 47% in the Supadio region. In the Southern Region, the condition of rainfall tends to be normal around 16% in the Cengkareng area and 2% in the Bandung area. In phase 5, the decrease in rainfall is seen in the Northern Region (38% Cut Nyak Dien Station, Polonia Station -84%) and the Equatorial Area (Kototabang Station -54%, Supadio Station -50%). In the Southern Region, rainfall in Cengkareng Station increased by 20%, and at Bandung Station decreased by -42%. For further research, more BMKG data is needed to see the effect of MJO on rainfall. It is also needed the use of other variables (humidity and wind) to analyze air mass transport.

References

[1] Hidayat R, Kizu S. 2010 International Journal of Climatology 30 1816-1825.
[2] Hermawan E. 2011. “Peran MJO dalam membangkitkan Intensitas Monsun di Indonesia”. Seminar Nasional Sains Atmosfer dan Antariksa (SNSAA) 2011
[3] Ramage C. 1971 Monsoon Meteorology. International Geophysics Series, Vol. 15, San Diego: Academic Press.
[4] Prawirowardoyo S. 1996. Meteorologi. Bandung: Penerbit ITB, pp. 85-86
[5] Madden R A and Julian P R. 1971. Journal of the Atmospheric Sciences 28 702-708.
[6] Madden R A and Julian P R. 1972. Journal of the Atmospheric Sciences 29 1109-1123.
[7] Lau K M and Chan P H. 1985. Monthly Weather Review 113 1889–1909.
[8] Zhang C. 2005 Rev. Geophys. 43 RG2003.
[9] Zhang C. 2013 Bull. Am. Meteorol. Soc. 94 1849-1870.
[10] Kamimera H, Shuici M, Yamanaka M D and Syamsudin F. 2012. SOLA 8 111-114.
[11] Fujita M, Yoneyama K, Suichi M, Nasuno T. 2011. Journal of the Meteorological Society of Japan 89A 317-330.
[12] Trilaksono N J, Otsuka S and Yoden S. 2011. SOLA 7 193-196.
[13] Wu P, Arbain A A, Suichi M, Hamada J I, Hattori M, Syamsudin F and Yamanaka M D. 2013. SOLA 9 79-83.
[14] Peatman S C, Mathews A J and Stevens D P. 2014 Q. J. R. Meteorol. Soc. 140 814-825.