Relationship between extreme rainfall based on GSMaP data with Madden Julian Oscillation (MJO) in Bangka Island

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Abstract. The effect of MJO events on extreme rainfall events on Bangka Island needs to be spatially studied in more detail. The low quality of rain station data encourages the use of alternative data such as Global Satellite Mapping of Precipitation (GSMaP). This study aimed to analyze the influence of active MJO on extreme rainfall events using GSMaP data on Bangka Island. The methods used are extreme threshold of 95th, 98th and 99th percentile, the Spearman Rank correlation between extreme rainfall events and active MJO and its correlation significance test. The results showed that northern coast has the highest range of extreme threshold. The correlation significance test showed GSMaP grids that have a significant correlation with the MJO are in the north of the Island, especially coast area. MJO phases 3 and 5 have an impact on decreasing of extreme rainfall events which are known through the negative correlation values. From all the three extreme thresholds, it was only MJO phase 4 that increasing extreme rainfall events. Active MJO phase 4 causes Bangka Island as a convective area, while MJO phases 3 and 5 affect the formation of suppressed areas on Bangka Island.

1. Introduction

Many studies have examined the impact of MJO as a trigger for extreme rainfall in Indonesia, especially Bangka Island. However, most are only qualitatively and are case studies like a research by Saragih et al [1]. These MJO researches need to be studied further by counting the correlation between active MJO events and extreme rainfall events. However, the quality of station rainfall data that is still not good enough on temporally and spatially make it need to use alternative data [2]. One alternative rainfall data that is commonly used in Indonesia is GSMaP. GSMaP with a spatial resolution of 0.1° is very helpful for areas that do not have rainfall measurement data [3]. GSMaP's daily data which has reached 18 years period will be able to describe the correlation between MJO and extreme rainfall.

This study aimed to analyze the correlation of active MJO to fluctuations in extreme rainfall events on Bangka Island based on GSMaP data. This research was also conducted because previous research on the effect of MJO on rainfall in Bangka Island was only qualitatively and without analysis of extreme values.

2. Methodology

2.1. Study Area

The study area is Bangka Island, one of the main islands of the Bangka Belitung Islands Province. figure1 shows that geographically Bangka Island is located in the east of South Sumatra Province.
surrounded by Bangka Strait, South China Sea, Karimata Strait, Gelasa Strait, and Java Sea. Convective cloud development on Bangka Island due to weather disturbances could reach the Mesoscale Convective System scale [4].

![Figure 1. Bangka Island as study area](image)

2.2. Data
This study used one of GSMaP's daily rainfall products, GSMaP_MVK. This is one of GSMaP data type that usually used to analyze extreme rainfall. Although MVK was not calibrated with rain-gauge data, it was corrected by the Kalman filter method [5]. It was also usually used to analyze extreme rainfall [6]. GSMaP_MVK data from 2001 to 2018 were obtained from the Hokusai (ftp://rainmap@hokusai.eorc.jaxa.jp). Grid Analyzing and Display System (GrADS) was one of common applications to process GSMaP_MVK data. It could display the data as a map or extract the rainfall value.

In this study, although MJO had 8 phases, only MJO phase 3, 4 and 5 from 2001 to 2018 were used and analyzed, because that three phases were usually affect the extreme rainfall in western region of Indonesia [1]. Active MJO phase was determined by using the amplitude value of more than 1 [7]. The MJO amplitude data were obtained from the Japan Meteorological Agency which were defined from Empirical Orthogonal Functions (EOFs) of Outgoing Longwave Radiation (OLR) and average 850 and 200 hPa zonal wind [8]. MJO amplitude data can be downloaded from https://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/figs/olr0-sst1_1980-2010/rmm8.csv. Number of MJO event on phase 3, 4, and 5 were showed in table 1.

| MJO phase | Number of MJO event | Number of active MJO event |
|-----------|---------------------|---------------------------|
| 3         | 770                 | 445                       |
| 4         | 846                 | 495                       |
| 5         | 867                 | 535                       |

2.3. Method

2.3.1. Extreme Rainfall Threshold. The extreme rainfall in this study is defined as climatologically extreme daily rainfall. Therefore this study used the percentile method [9]. This study used 3 percentile
levels, they are 95th, 98th and 99th percentile which listed in equation 1. The three percentile levels are used because of variations in rainfall referring to research [10].

\[ P_{95,98,99} = \frac{i(n+1)}{100} \]  

where \( P \) = n-th percentile, \( i \) = percentile rank, and \( n \) = number of values.

2.3.2. Correlation. The testing of correlation between extreme rainfall events and MJO is using the Spearman Rank correlation equation [11]. This type of correlation is used because the data is an annual event so that it only produces 18 samples, small number (\( n < 30 \)) and does not meet the requirements for the calculation of Pearson correlation. The Spearman Rank correlation equation is shown in equation 2.

\[ \rho = 1 - \frac{6 \sum d_i^2}{n(n^2-1)} \]  

where \( \rho \) = Spearman Rank correlation, \( d \) = difference between two ranking (extreme rainfall event and MJO event), and \( n \) = number of observations.

2.3.3. Significance Test. The t test in equation 3 is done to get a GSMaP grid that has a significant correlation between extreme rainfall events and the MJO event [12]. The t test for correlation is preceded by determining the hypothesis. The null hypothesis (Ho) states that there is no relationship between extreme rainfall events and MJO, while the alternative hypothesis (Ha) states otherwise. Ho is accepted if the statistical test results are smaller than the critical value, and otherwise Ho is rejected (Ha is accepted) if the statistical test produces a value greater than the critical value.

\[ t_0 = \frac{\rho \sqrt{n-2}}{\sqrt{1-\rho^2}} \]  

where \( t_0 \) = statistical value, \( \rho \) = spearman rank’s correlation, and \( n \) = number of samples.

3. Result and Discussion

3.1. Extreme Rainfall Threshold
The GSMaP data mapping resulted in 137 grids. The spatial distribution of the extreme threshold of 95p (95th percentile) in Figure 2a shows the range between 36.1 - 51.6 mm, 98p (98th percentile) in Figure 2b shows the range between 48.3 - 67.3 mm, and 99p (99th percentile) in Figure 2c shows the range between 67, 3 - 87.8 mm. In general, the spatial distribution of extreme thresholds shows that the northern part of Bangka Island, especially the coastal area as the area with the highest threshold. This shows that the area is the wettest. These results are in accordance with the results of previous studies using both CHIRPS data [2] and field rainfall data [13]. The high range of extreme thresholds in north area, especially the coast, shows the amount of rainfall intensity that occurs or the frequency of heavy rainfall events that are more common than other regions. There are two main factors that cause these conditions, namely local and regional factors.

Local factors that cause high extreme thresholds on the northern coast of Bangka Island are due to diurnal cycles of convective cloud formation around the coast, one of which is characterized by land sea breeze [14]. In fact, Bergeman et al. [15] mentioned that the diurnal cycle of convective cloud formation contributing to the climatology of high rainfall around the coast. Coastal lands that still get the influence of sea activity have the potential for convective cloud formation from land sea breeze effect. Air mass with high water vapor that moving from sea to land could support the formation of clouds with a heavy rainfall content. Interaction between hilly areas in the north with the flow of Asian cold monsoon during the rainy season can be a cause of heavy rainfall in that region. When the Asian cold monsoon reaches its peak between December and February, high-speed monsoon flow in the lower layer can transform into a trans-equatorial monsoon flow from the northern earth across the equator to the southern earth [16].

High velocity of air flow in the lower layer of trans-equatorial monsoon flow carries a high moisture content. The interaction of wet air mass flow with hilly areas in the northern part of Bangka Island that
play role as barrier cause low-level convergence [17]. Compression of air masses due to low-level convergence has an impact on the formation of convective clouds that can cause heavy rainfall.

Figure 2. Spatial distribution of extreme threshold for 95th (a), 98th (b), and 99th (c) percentile

3.2. Correlation with MJO Event

3.2.1. Distribution of Coefficient Correlation. Spatial distribution of the Spearman rank correlation coefficient between GSMaP’s extreme rainfall and MJO events is not displayed. Correlation coefficient number between extreme rainfall 95p with MJO phase 3 ranged from -0.71 to 0.21. In extreme rainfall 98p, the correlation coefficient number with MJO phase 3 ranged from -0.55 to 0.23. In extreme rainfall 99p, the correlation coefficient ranged from -0.70 to 0.39. Grid distribution patterns with the high correlation coefficients are concentrated in the northern part of Bangka Island.

The correlation coefficient between MJO phase 4 with extreme rainfall 95p ranges between -0.04 to 0.59. Correlation coefficient with extreme rainfall 98p ranged from -0.18 to 0.66. Correlation coefficient with extreme rainfall 99p ranged from -0.25 to 0.61. The correlation coefficient between extreme rainfall events from the three percentiles with MJO phase 4 is dominated by positive values. The pattern of grid distribution with a high number of correlation coefficient is also concentrated in the northern part of Bangka Island.

Correlation coefficients between extreme rainfall 95p with MJO phase 5 ranged from -0.60 to 0.30. Correlation coefficient between extreme rainfall 98p with MJO phase 5 ranged from -0.52 to 0.36. Correlation coefficient between extreme rainfall 99p with MJO phase 5 ranged from -0.57 to 0.31. The distribution of correlation coefficients between extreme rainfall events and the MJO phase 5 again results the dominance of negative values such as the distribution of correlation coefficients with MJO phase 3.
3.2.2. Distribution of Significant Correlation. Results of the t test to find the grids with significant correlations are shown in figures 3 to 5. Figure 3 (a, b, and c) shows the spatial distribution of the GSMaP grid which has a significant correlation with the MJO phase 3. Figure 4 (a, b, and c) shows the spatial distribution of the GSMaP grid which has a significant correlation with MJO phase 4. Figures 5 (a, b, and c) show the spatial distribution of the GSMaP grid which has a significant correlation with the MJO phase 5.

Spatial distribution of the grid with a significant correlation between extreme rainfall 95p and MJO phase 3 is shown in Figure 3a. There are 23 grids with significant correlations, 20 grids are on the north coast (Bangka and West Bangka Regency) and 3 grids are on the southern coast (South Bangka Regency). At extreme rainfall 98th percentile, there are 8 grids with significant correlations, shown in Figure 3b. Three grids are in West Bangka Regency, 4 grids in Bangka Regency and 1 grid in South Bangka Regency. At the 99th percentile, there are 10 grids with a significant correlation shown in Figure 3c. Six grids are in West Bangka Regency and 4 grids in Bangka Regency. The grid with the most significant correlation was generated between extreme rainfall 95p with MJO phase 3.

Spatial distribution of the grid with a significant correlation between extreme rainfall 95p and MJO phase 4 is shown in Figure 4a. There are only 4 grids with significant correlation, 3 grids are on the north coast (Bangka Regency) and 1 grid on the southern coast (South Bangka Regency). At extreme rainfall 98p, there are 17 grids with significant correlations that shown in Figure 4b. Eight grids are in West Bangka Regency and 9 grids are in Bangka Regency.

At extreme rainfall 99p, there are 18 grids with significant correlation that shown in figure 4c. 8 grids are in West Bangka Regency, 9 grids in Bangka Regency, and 1 grid on the west coast of Central Bangka.
Regency. Mapping results show the grids with significant correlation are concentrated in the northern part of Bangka Island (Bangka and West Bangka Regency). Only one grid each located in Central Bangka and South Bangka Regency.

Figure 4. Spatial distribution of significant correlation grid between extreme threshold 95th (a), 98th (b), and 99th (c) percentile with MJO phase 4 events

Spatial distribution of the grid with significant correlation between extreme rainfall 95p with MJO phase 5 is shown in Figure 5a. There are 9 grids with significant correlation, 7 grids are in West Bangka Regency, 1 grid in Bangka Regency, and 1 grid in South Bangka Regency. At extreme rainfall 98p, there are only 4 grids with significant correlation, all of them are in West Bangka Regency (Figure 5b). At extreme rainfall 99p, there are only 4 grids with a significant correlation consisting of 3 grids in West Bangka Regency and 1 grid in Bangka Regency. Mapping results show the grids with significant correlation are concentrated in the northern part of Bangka Island, West Bangka Regency. Only one grid is located in Bangka and South Bangka Regency.
Chandrasekaran and Vissa [18] state in their research that active MJO phases influence Extreme Rainfall Events (ERE) frequency significantly by using Tropical Rainfall Measuring Mission (TRMM) precipitation data and 95th percentile based threshold. From the mapping of significant correlation between extreme rainfall events and MJO in this work, it is also shown that only MJO phase 4 has an impact on increasing extreme rainfall events from the three thresholds. This indicates that only MJO phase 4 has an impact on the formation of convective areas in Bangka Island and its surroundings, so that the formation of convective clouds with heavy rainfall is also increasing. In contrast, MJO phases 3 and 5 cause weakening of connectivity so that rainfall tends to decrease. The impact of the MJO phase 4 that obtained from the results of this study is also in accordance with the results of the study of Handayani et al. [19] in the West Sumatra region, where MJO phase 4 helped increases the accumulation of monthly rainfall.

The map of the significant correlation also shows that extreme rainfall events in the northern part of Bangka Island are sensitive to fluctuations of MJO phases 3, 4 and 5. MJO can also affect convective activity in the diurnal cycle, the formation of convective areas, and the strengthening of low-level westerly winds occur in Sumatra, especially Bangka Island [20]. When MJO phase 4 is active, interaction between wet air masses from the west with topographic roughness in the northern part of the island (figure 7) were formed. This strengthens the growth of convective clouds that have been initiated by convective areas. In contrast, the effects of MJO phases 3 and 5 form a suppressed area [21], although low-level westerly wind has occurred at a low speed [22]. This causes the Bangka Island, especially the northern part, has decrease convective cloud formation.

**Figure 5.** Spatial distribution of esignificant correlation grid between extreme threshold 95th (a), 98th (b), and 99th (c) percentile with MJO phase 5 events
Figure 6. Topography of Bangka Island shows the roughness of surface in northern part.

4. Conclusion

Based on spatial distribution of extreme rainfall threshold using GSMaP data, northern Bangka is the wettest area. Meteorological analysis found the existence of interaction between monsoon flow and topography in producing convective clouds. MJO phase 3 and 5 affect on suppressed area around Bangka Island, although low-level westerly wind has begun with low velocity. Therefore the extreme rainfall events from all percentiles calculation tend to decrease. It is showed by some grids of GSMaP that have significant negative correlation in all extreme rainfall events. The significant positive correlation between extreme rainfall events in all percentiles threshold with MJO phase 4 indicated that the increase of extreme rainfall event when MJO active occur more frequent. This relationship was formed because MJO phase 4 triggered low-level westerly wind and convective area in Bangka Island. MJO also influence the diurnal cycle by its interaction with the topography especially in North Bangka. It triggered the increasing of extreme rainfall event by producing more convective clouds. This study used GSMaP as substitution for field rainfall data. It has quite large on errors possibility as the different of remote sensing observation with surface measurement. It is suggested to use another alternative rainfall data such as rainfall estimation from weather radar product for the next study. This study also measured the effect of MJO to extreme rainfall event only by statistical calculation. This could make different results when using a longer or shorter period of data. Analysis of a more detailed process of the atmospheric must be done to get an explanation of the influence of MJO on extreme rainfall events.

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