Analysis of precipitation microstructure characteristic during Madden Julian Oscillation (MJO) using micro rain radar (MRR) and disdrometer in South Tangerang

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Abstract. Rain microstructure is a critical aspect to understand the dynamics and microphysics character of the clouds. It is characterized by the distribution of size, fall velocity and shape of raindrop. Raindrop size distribution (DSD) explains the detail of the microphysical process because it represents a process of rain to the surface. One of the phenomena that influence the rain patterns in Indonesia is Madden Julian Oscillation (MJO). Therefore, observing rain microstructure with its relation to MJO can determine the differences in rainfall characteristic and microphysical processes during active and inactive MJO period. The data used in this study are Micro Rain Radar (MRR), disdrometer, and real-time multivariate (RMM) index data. The period/date selection of active MJO event performed using RMM index method is more than 1 in phases 4 and 5 and otherwise for inactive MJO. Types of rain are divided into stratiform and convective rain based on disdrometer data. From that, there are 46 active and 52 inactive MJO events. Rain microstructure in this study focuses on DSD from disdrometer and micro rain radar data analyzed with liquid water content profile, fall velocity, reflectivity, and rain rate from MMR. Besides, there are parameters of DSD, which are the mass-weighted diameter (Dm) and total concentration (Nw), calculated using the moment and gamma distribution method. The result shows that DSD and other parameters are greater during inactive MJO period. It means that process of collision-coalescence, evaporation, and updraft is dominant during inactive MJO period.

Keywords: Micro Rain Radar, disdrometer, microstructure, microphysics, MJO

1. Introduction

Indonesia is a meeting area for various interactions of the atmosphere and the sea. The formation of phenomena has affect the weather system could be observed in terms of rainfall. One of the influential phenomena is the Madden Julian Oscillation (MJO) which can cause changes in rainfall patterns in Indonesia. Rainfall is an important parameter that influences the hydrological cycle.

The microstructure of rain is characterized by a distribution of the size, shape, and velocity of falling raindrops [1]. Understanding the microstructure of rain, such as the vertical structure of rain, is an essential aspect in understanding cloud dynamics and microphysics [2]. Raindrop Size Distribution
(DSD) profile can explain the microphysical process in more detail because DSD represents the rain process until it fall to the surface [3]. Rain microstructure is different between active and inactive MJO in Sumatera [4].

Technology makes measurements and observations of precipitation more accurate, such as measurements with the Micro Rain Radar (MRR) and disdrometer. Microstructure processing of raindrop size distribution data on MRR and disdrometer can explain microphysical processes of warm clouds in the tropics, either in general or specific periods MJO that can affect to rainfall anomalies.

The method identification of rainfall events in the MJO period is discussed in section 2. This chapter also discussing DSD and its parameter. Section 3 are divided into three subsections; the first subsection discusses the rainfall statistics, the second subsection contains a distribution of average raindrop size, the last section contains a vertical structure/average profile of rain parameter.

2. Data and Method

Data used in this study are MRR, disdrometer, and Real-Time Multivariate (RMM) index from March 2016-May 2019 in the Serpong area (6.3 ° S, 106.7 ° East) (figure 1). Temporal resolution of MRR and disdrometer is minutes. The variables used from MRR are DSD, Liquid Water Content (LWC), rain rate, reflectivity, and fall velocity, while from disdrometer are rain rate and DSD.

![Figure 1. The study area. The black point represents the coordinate point of Serpong (6.3°S, 106.7°East), South Tangerang.](image)

Data validation was done by comparing the results of the MRR rain intensity measurement with the AWS surface data and the disdrometer for same period in this study. The rainfall intensity of the three instruments was compared by the correlation method. The date of the rain event is taken from the disdrometer data and also provided that the rain rate in one day is 5 mm/day. Rainfall events can be divided into convective and stratiform rain [5]. This rule applies to at least ten consecutive rain events of data disdrometer. Stratiform rain occurs when the rain rate is more than 0.5 mm/hour, and the standard deviation is less than 1.5 mm/hour. Meanwhile, convective rain occurs when the rain rate is more than 1.5 mm/hour, and the standard deviation is more than 1.5 mm/hour.

The selection date of the event was done by grouping active and inactive MJOs in phases 4 and 5. Grouping active and inactive MJOs was based on the amplitude values of RMM1 and RMM2. The RMM amplitude value is categorized as active MJO if the amplitude is ≥ 1. DSD parameters such as mass-weighted diameter or mean diameter (Dm) in mm and intercept parameter or total concentration (Nw) in mm⁻¹ m⁻³, from the gamma distribution model [5], are processed by selecting time before, in the form of dates classified into rain events and MJO phases.

\[
M_x = \int_0^\infty N(D) D^x dD \\
Dm = \frac{M_4}{M_3} \\
Nw = \frac{4^6 \pi 10^{-3} M_3}{6 \pi \rho Dm^4}
\]

Where \(N(D)\) is the concentration of raindrops (mm⁻¹ m⁻³), \(D\) is the diameter (mm), \(\rho\) is the density of water which is 1 kg / m³. \(M_x\) is the moment method, the calculation of the moment method is an integral
of N (D) and D to the x, where x corresponds to the moment required in the data processing. Dm and Nw require third (M3) and fourth (M4) moments. The successful process of DSD parameters with moment and gamma methods, the results were compared in each condition. To strengthen analysis, we will be plotted vertical profile of Dm, Nw, LWC, rain rate, fall speed, and reflectivity with Contour Frequency Altitude of Diagram (CFAD).

3. Results

3.1 Rainfall Statistics Based on Active and Inactive MJO

The data correlation between MRR and the disdrometer is 0.72. MRR was used at an altitude of 500 m because the MRR height near the surface was very prone to be noise [6]. Meanwhile, the correlation between the disdrometer and the AWS BMKG is 0.80. It indicates that the data used is good for use in research.

It was found that the active and inactive MJOs were 84 and 137 events, respectively. From the MJO incidence and limited surface observation data available, rainfall events> 5 mm/day only amounted to 46 events for active MJO and 52 events for inactive MJO.

For total stratiform (convective) rain events totaled 36550 (8802) samples with rain rate 1.2 (37.82) mm/day. Rainfall events when active MJO has totaled 3477 (627) samples with rain rate 1.36 (27.64) mm/day while rain events when inactive MJO was totaled 5198 (1000) samples with rain rate 1.15 (41.58) mm/day. Not all events with one minute of rain were classified as stratiform or convective rain types. Therefore, this method [5] was suitable for using consider rains for ten consecutive data (minutes). If rain less than 10 minutes, was considered noise. This can be seen in the total number of rain samples are different from the sum event with rain has been successfully categorized, namely stratiform and convective. Besides, if the rain rate observed by the disdrometer is <0.1 mm/hour, then the data is considered noise [7].

Figure 2. (a) Diurnal cycle of rain in Serpong for the period March 2016-May 2019 (black line), active MJO (red line) and inactive MJO (blue line) from the disdrometer data, and (b) Reflectivity profile dated January 10, 2017, that stratiform and convective (yellow and black bar)

The peak of the diurnal rain cycle in Serpong, South Tangerang, occurs in the afternoon. This is due to the dominant evaporation process. In figure 2a, it can be seen when the active MJO, the peak of the diurnal cycle is a shift to 3.00 Local Time (LT). From all the data, it was found that the peak of rain occurred in the afternoon, precisely at 16.00 LT, which was similar to the situation when the inactive MJO. Convective rain was characterized by high reflectivity from the surface to a certain height (figure 2b).

3.2 Distribution of Average Raindrop Size Distribution

There is slightly different of average DSD during stratiform where active MJO had a higher concentration than inactive MJO (figure 3a). The average DSD in convective rain (figure 3b) shows that in inactive MJO, the concentration of raindrops is higher. The average DSD in accordance with the research of Marzuki [4] in Kototabang, West Sumatra.
Figure 3. Average DSD (a) stratiform rainfall events and (b) convective rain events from the disdrometer with 22 bin.

DSD parameters, Dm (figure 4a, b) in convective rain, the inactive MJO phase has a larger Dm distribution, but it is evenly distributed in the stratiform rain. For Nw (figure 4c, d), the active MJO phase was higher, indicating a greater concentration than inactive MJO.

Figure 4. Histogram of (a) Dm, (b) log_{10}Nw for convective and (c) Dm, (d) log_{10}Nw stratiform rain classified into the active and inactive MJO phases.

The mean value of the Dm-Nw parameter during stratiform (convective) rain is 1.14-1.26 mm (2.08-1.63 m⁻³ mm⁻¹) for active MJO and 1.18-1.15 mm (2.35-1.58 m⁻³ mm⁻¹) for inactive MJO. It can be seen that the Dm value of inactive MJO is greater than active MJO, and the concentration is the opposite. It indicates that raindrop size is bigger when the inactive MJO, so the concentration tends to be less. This due to the concept of diameter and concentration of a particle in the atmosphere. The larger diameter of the raindrops will tend to have a smaller concentration, and vice versa.

3.3 Vertical Structure / Average Profile of Rain Parameters

The DSD profile of the MRR data shows the same results as the previous discussion of the disdrometer data. In stratiform rain, the Dm profile is getting bigger to the surface, while the Nw profile is on the contrary, getting smaller on the surface. It shows that the larger diameter of the raindrops, has smaller the concentration. When inactive MJO, Dm is greater than active MJO and the opposite for Nw (figure 5). Although, there is a difference in Nw when inactive MJO-convective rain which is getting bigger to the surface (contrary to before). At the high-altitude, there is a smaller Dm. This indicates a decrease in the small grains that reach the surface. Solar radiation and high surface temperatures during the inactive
phase allow the evaporation process to occur at small raindrop sizes [8]. This reduction in the number of small raindrops is possible due to the evaporation and updraft processing. The drops will disappear due to the evaporation process, or resist the upward vertical force by the updraft process. As a result, the grains undergo a process of collision and coalescence, so the large raindrops will be increased.

![Figure 5](image)

**Figure 5.** The CFAD (a) Dm with stratiform-active MJO, (b) Dm with convective-active MJO, (c) log\(_{10}\)Nw with stratiform-active MJO, (d) log\(_{10}\)Nw with convective-active MJO, (e) Dm with stratiform-inactive MJO, (f) Dm with convective-inactive MJO, (g) log\(_{10}\)Nw with stratiform-inactive MJO, (h) log\(_{10}\)Nw with convective-inactive MJO, from the MRR. The red line is the mean value.

All results show that the values for convective rain and inactive MJO are greater than stratiform and active MJO. For convective rain, the higher the altitude, the LWC value decreases, meaning that on the surface, it is getting bigger because the resulting rain is getting heavier. Inactive MJO has a greater LWC, which means that the likelihood of rainfall and raindrops is higher than active MJO, which can be proven by its rain rate (figure 6).
Figure 6. The CFAD (a) LWC with stratiform-active MJO, (b) LWC with convective-active MJO, (c) rain rate with stratiform-active MJO, (d) rain rate with convective-active MJO, (e) LWC with stratiform-inactive MJO, (f) LWC with convective-inactive MJO, (g) rain rate with stratiform-inactive MJO, (h) rain rate with convective-inactive MJO, from the MRR. The red line is the mean value.

The rain rate on the surface is greater in the inactive MJO phase than the active MJO (figure 6). The higher the rain rate, the greater the increase in raindrop size, consistent with the Dm distribution. The value of LWC and rain rate for stratiform rain, before passing through the melting layer area has increased sharply, and after passing through the area, the value quickly decreasing and sharp. This is due to the presence of a brightband layer at an altitude of 4000-5000 meters. The altitude corresponds to the layer with a temperature of 0°C from the sounding data (figure 7), wherein this layer the ice phase will change into a liquid phase. The brightband layer is an indication of stratiform rain. In the brightband layer, the number of a drop has increased significantly, especially in small diameter drops, which is indicated by an increase in the total concentration (Nw) in figure 8.

Figure 7. The result (temperature to height) of radiosonde Soekarno-Hatta Station
Figure 8. The CFAD (a) reflectivity with stratiform-active MJO, (b) reflectivity with convective-active MJO, (c) fall velocity with stratiform-active MJO, (d) fall velocity with convective-active MJO, (e) reflectivity with stratiform-inactive MJO, (f) reflectivity with convective-inactive MJO, (g) fall velocity with stratiform-inactive MJO, (h) fall velocity with convective-inactive MJO, from the MRR. The yellow and red line is the mean value.

When inactive MJO, the reflectivity is higher than active MJO. The greater rain, the steeper slope of Z. The greater Z value has indicated the greater concentration of raindrop size \( Z = D^6 \) (figure 8). The reflectivity shows the amount of energy reflected from an object, such as a wave. According to the law of the Doppler effect, the closer the object gets make the greater frequency/energy being captured. Likewise, if the larger object size, that will have the greater energy. If the diameter of the raindrops gets bigger, the energy captured is also large, so that the reflectivity will be increased too. The correlation between reflectivity and diameter has indicated that raindrops are indeed larger when inactive MJO.

In figure 8, it can be seen that the fall velocity is greater in the inactive MJO phase than the active MJO. When inactive MJO, the greater falling speed is made possible by the dominant downdraft process. The collision and coalescence process is easier to occur, and the raindrops are carried down as larger raindrops. The updraft and downdraft increase the collision-coalescence processed by reducing the size of small raindrops on the surface [9].

Rain structures during inactive MJO are accompanied by strong vertical winds [4] and have greater reflectivity [10]. The relationship between the reflectivity profile and vertical wind has been carried out by Mori [11] that updraft reduces the concentration of small raindrops during inactive MJO.

The collision-coalescence process occurs when droplets meet in clouds of different sizes. Large drops will have a higher terminal velocity, resulting in an active collision-coalescence process between large and small drops. Small raindrops would be pushed upwards due to evaporation (convection process) and updraft. This collision-coalescence process will enlarge the raindrop so that the velocity of falling (gravity) that drops will be greater than the updraft. This causes by large raindrops fall to the surface. The larger raindrops, the faster they will fall to the surface (high falling speed). This also be seen also in the rain profile and Dm, which is getting bigger on the surface. This large raindrop makes the
reflectivity value even greater. This process can be seen in the parameters of the rain structure, DSD, and its parameters profile, which show MJO active more dominant and microphysical processing.

Figure 9. Linear regression between Z and R (a) stratiform and (b) convective from disdrometer

Reflectivity is an essential parameter of DSD which value is comparable to \(D^6\) (6\(^{th}\)-moment method). The Z-R equation can convert reflectivity data into rain rates, where the data usually contained in weather radar is reflectivity. This shows that the reflectivity value of inactive MJO is greater than active MJO (figure 9). It approves with a value of A is greater when inactive MJO, in spite the values of B are quite close to each other.

4. Conclusion
DSD during inactive MJO contains larger drop than active MJO. This is also indicated by the distribution and profiles of Dm, Nw, liquid water content profile, fall velocity, reflectivity, and rain rate. Cloud droplets with different sizes will experience a collision-coalescence process, so the drops get heavier and fall to the surface (falling speed increases) as large drops. Large raindrops will make the rain rate even bigger, so will the reflectivity, which gets a large wave reflection. In the inactive MJO phase, the microphysical processes (collision-coalescence, evaporation) and updrafts that play a role in producing large raindrops are more dominant than the active MJO phase.

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