Vertical structure of raindrop size distribution over West Sumatera from global precipitation measurement (GPM) observation

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Abstract. Vertical Structure of Raindrop Size Distribution (DSD) over West Sumatera (99.82 E – 100.82 E; 0.73 S – 0.27 N) was observed from Normal Scan (NS) of Global Precipitation Measurement (GPM) observation during December 2014 to June 2018. This observation was carried out for stratiform and convective rain. The vertical structure of DSD from GPM was described as two gamma distribution parameters, namely, mass-weighted mean diameter ($D_m$) and total raindrop concentration ($N_w$). In addition, the vertical structure of integral rainfall parameters was investigated from the vertical structure of radar reflectivity ($Z$). It was found that vertical structure of DSD from NS of GPM observation showed different value for both stratiform and convective rain, for the same rainfall intensity. The NS of GPM estimates larger (smaller) $D_m$ ($N_w$) for convective than stratiform rain. It indicates convective has more large drops than stratiform rain with lower of total drops number for the same rainfall intensity. Furthermore, the gradient of vertically downward from $D_m$ and $N_w$ is slightly larger during convective rain than during stratiform rain for all classes intensity. This indicates a more significant growth of raindrop in rain column during convective rain than during stratiform rain over West Sumatera.

Keywords: Raindrop Size Distribution, Global Precipitation Measurement, Normal Scan, gamma parameters, West Sumatera.

1. Introduction

Vertical Raindrops Size Distribution (DSD) describe the raindrops distribution from falling into the ground. Comprehensive study about vertical DSD is important in various field of technology. Vertical DSD is important in telecommunication system that estimates the attenuation from microwave in the atmosphere [1-2]. Thorough knowledge of vertical DSD is also important to design meteorology radar system that is installed in ground and satellite radar [3].

Vertical DSD is different for different rainfall type and rainfall intensity [4]. Generally, there are two main rainfall type that are stratiform rain and convective rain. Stratiform rain is formed from nimbostratus clouds while convective rain is formed from cumulus and cumulonimbus clouds [5]. Beside the different of cloud forming, these type of rainfalls have different microphysical process during falling that can be identified from vertical DSD.

There are some instrument to observe vertical structure of DSD that are meteorology radar [6], videosonde [7], and precipitation occurrence system [8]. Radar is common to observe vertical structure DSD in tropics that can use ground radar and satellite radar. Ground radar is powerful to
observe DSD near the ground height but the observation is limited in where that instrument installed. It weakness can be solved by satellite radar that is moving around the earth. The radar satellite which has DSD data is Global Precipitation Measurement (GPM). GPM was launched in February 2014 for covering previous precipitation measurement mission that is Tropical Rainfall Measurement Mission (TRMM) satellite.

The study of vertical structure of DSD in Indonesia especially at West Sumatera has been conducted from previous study [9 - 13] by using ground radar. GPM observation for vertical structure of DSD in Indonesia was not investigated. Thus, this work investigated vertical structure of DSD over West Sumatera from GPM observation. We observed vertical structure of DSD from stratiform and convective rain during January 2015 to June 2018.

2. Data and Methodology

This work investigated vertical structure of DSD from GPM observation for 0.5-degree around National Aeronautics and Space Observation station at Kototabang (0.23° S, 100.32° N), West Sumatera, Indonesia. The range of GPM data is 0.73° S – 0.27° N and 99.32° E – 101.32° E during January 2015 to August 2018. It was found 3886 data for stratiform rain and 10450 data for convective rain for this research observation.

GPM is a result from collaboration between Japan Aerospace Exploration Agency (JAXA) and National Institute of Communication Technology (NICT). GPM observation covers 80% of globe area (65° S – 65° N) with addition ka-band radar that was not exist on TRMM. The horizontal resolution of GPM observation is approximately 5 x 5 km.

GPM carries Dual-frequency Polarized Radar (DPR) with Ku-band Precipitation Radar (PR) (13.6 GHz) and Ka-band PR (35.5 GHz). GPM has three mode observation, namely Normal Scan (NS), Match Scan (MS), and High-sensitivity Scan (HS). NS from GPM has 176 range bin with 125 m vertical resolution and 49 angle beams scanning. MS has 176 range bin with 125 m vertical resolution and 25 angle beams scanning. NS has 88 range bin with 250 m vertical resolution and 24 angle beams scanning. NS showed good agreement with numerical and ground radar validation [14-16]. Thus, this research used NS from GPM observation to obtain more data observation.

GPM provides DSD data for an observation area in gamma parameters that was obtained from normalized gamma distribution. These parameters are mass-weighted mean diameter ($D_m$) and total drop concentration ($N_w$). The normalized gamma distribution for GPM DPR express as [17]:

$$N(D) = N_w f(\mu) \left(\frac{D}{D_m}\right)^\mu \exp \left[-(4 + \mu)\frac{D}{D_m}\right],$$

(1)

where $f(\mu)$ is function of shape parameter ($\mu$):

$$f(\mu) = \frac{6}{256} \frac{(4+\mu)^\mu}{\Gamma(\mu+4)}.$$  

(2)

Parameter $N_w$ is ratio between liquid water content ($W$) and parameter $D_m$, while parameter $D_m$ is the ratio for the fourth to third moment from DSD. The parameter $N_w$ expressed as:

$$N_w = \frac{256 \times 10^3 W}{\pi \rho_w D_m^4},$$

(3)

where $\rho_w$ is the density of water. This study was not calculating DSD parameters manually, its use the parameter $D_m$ and parameter $N_w$ that have been provided by GPM. In addition, this research use radar reflectivity ($Z$) data for looking characteristics rain type both stratiform and convective from GPM observation.
3. Result and Discussion

Figure 1 shows the vertical structure of reflectivity ($Z$) for stratiform and convective rain from NS of GPM observation. The data were observed for 5 rainfall classes category i.e. very light rain ($0.1 - 1$ mm/h), light rain ($1 - 2$ mm/h), moderate rain ($2 - 5$ mm/h), heavy rain ($5 - 10$ mm/h), and very heavy rain ($10 - 20$ mm/h). It shown the strong different pattern for both stratiform and convective rain above 4 km for all classes category. This altitude (4 km) is the height of melting layer that provides from International Telecommunication Union Recommendation (ITU-R) in tropics. Melting layer is indication of rain type, whether it is stratiform or convective. The melting layer height more than the value that was recommended from ITU-R is accordance with previous study at Kototabang [11,18-19].

![Figure 1](image)

Figure 1. Average reflectivity ($Z$) for (a) very light rain ($0.1 - 1$ mm/h), (b) light rain ($1 - 2$ mm/h), (c) moderate rain ($2 - 5$ mm/h), (d) heavy rain ($5 - 10$ mm/h), and (e) very heavy rain ($10 - 20$ mm/h) for stratiform and convective rain.

The value of $Z$ for stratiform rain shows significant increase and reach maximum number over 4 km that indicates a significant increase of large drops due to melting process of ice particle into water ($Z \approx D^6$). After all ice particles melt into water that was observed from maximum value of $Z$ which was known as bright band height (BBH). Furthermore, below BBH the $Z$ value of stratiform rain start to decrease due to decrease number of large drops that cause break up. Its feature was not shown in convective rain (Figure 1). It cause convective rain was come from cumulus or cumulonimbus clouds which do not through a melting process like stratiform rain. Thus, the classification of rain type from NS is conform with characteristics of stratiform and convective rain [4].

The average vertical profile of $Z$ over West Sumatera shown different pattern for all rain type and all classes intensity. The melting layer pattern was strongly observed for lower rain intensity (very light rain – light rain). It may be due to aggregation that is more dominant for this rain intensity. Furthermore, the more negative of gradient $Z$ for these intensity indicates not significant growth of large drops. For higher intensity (moderate rain – very heavy rain), the vertical profile of $Z$ shows
positive gradient that mean there are more growth number of large drops. In addition, in the rain column (below melting layer), convective rain shows higher number of Z for moderate to very heavy rain (Figure 1). This feature indicates that convective rain over West Sumatera has more number of large drops than stratiform rain in moderate rain to very heavy rain that consistent with previous study at Kototabang [20].

Figure 2. Average mass-weight mean diameter ($D_m$) for (a) very light rain ($0.1 – 1$ mm/h), (b) light rain ($1 – 2$ mm/h), (c) moderate rain ($2 – 5$ mm/h), (d) heavy rain ($5 – 10$ mm/h), and (e) very heavy rain ($10 – 20$ mm/h) for stratiform and convective rain.

Figure 3. Average total drop concentration ($dBN_w$) for (a) very light rain ($0.1 – 1$ mm/h), (b) light rain ($1 – 2$ mm/h), (c) moderate rain ($2 – 5$ mm/h), (d) heavy rain ($5 – 10$ mm/h), and (e) very heavy rain ($10 – 20$ mm/h) for stratiform and convective rain.
The different pattern of vertical Z profile from for both stratiform and convective rain affected to the value of DSD that was shown in the vertical gamma parameters. Figure 2 and 3 show the vertical structure of mass weight mean diameter ($D_m$) and total drop concentration ($N_w$) for stratiform and convective rain from NS of GPM observation. The data were observed for 5 rainfall classes category i.e. very light rain (0.1 – 1 mm/h), light rain (1 – 2 mm/h), moderate rain (2 – 5 mm/h), heavy rain (5 – 10 mm/h), and very heavy rain (10 – 20 mm/h).

Generally, the number of $D_m$ and $N_w$ is larger for higher rainfall intensity. The pattern of $D_m$ shows strong different for stratiform and convective rain (Figure 2). It is consistent with the pattern of Z that different both these rain type. The different was more observed with increasing of rainfall intensity. It is intended that convective rain has more number of large-size drops. It cause the higher $D_m$ has correlation with number of large-sized drops. Its pattern is conversely shown from parameter $N_w$, the number of $N_w$ was higher for stratiform rain than convective rain. It indicates stratiform rain has larger number of small drops and less number of total raindrops concentration than convective rains over West Sumatera from NS of GPM observation. This feature is different with previous study at Kototabang that found larger $D_m$ for stratiform than convective rain in lower rainfall intensity (< 10 mm/h) [20]. This difference is may be due to strong regional variability from DSD over land and sea that data were included in this research.

Generally, the number of $D_m$ ($N_w$) decrease (increase) with height for both stratiform and convective rain except for very heavy rain. Decreasing $D_m$ with increasing $N_w$ is correlated to evaporation and coalescence process [21]. Its pattern is similar with previous study for vertical structure of DSD at Kototabang that used Micro Rain Radar [10-13]. Furthermore, the gradient of vertically downward from $D_m$ and $N_w$ is slightly larger during convective rain than during stratiform rain for all classes intensity. This indicates a more significant growth of raindrop in rain column during convective rain than during stratiform rain.

4. Conclusion
Vertical structure of DSD over West Sumatera from NS of GPM observation showed different value for both stratiform and convective rain. The NS of GPM estimates larger (smaller) $D_m$ ($N_w$) for convective than stratiform rain. It indicates convective has more large drops than stratiform rain with lower of total drops number for same intensity. The number of $D_m$ ($N_w$) decrease (increase) with height for both stratiform and convective rain was denoted that evaporation and coalescence process in rain column is dominant. Furthermore, the gradient of vertically downward from $D_m$ and $N_w$ is slightly larger during convective rain than during stratiform rain for all classes intensity. This indicates a more significant growth of raindrop in rain column during convective rain than during stratiform rain.

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