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Precipitation microstructure in different Madden–Julian Oscillation phases over Sumatra

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ABSTRACT

Intraseasonal variations of precipitation and its microstructure are investigated using measurements of the Equatorial Atmospheric Radar (EAR) facilities at Kototabang, west Sumatra, Indonesia (0.20°S, 100.32°E, 864 m above sea level). Raindrop size distribution (DSD) observations are obtained from a 2D-Video Disdrometer (2DVD) with a near continuous record of operation over eight consecutive years (2003–2010). Precipitation types are classified using 1.3-GHz wind profiler observation, and are partitioned according to active and inactive convective phases of Madden–Julian Oscillation (MJO). It is found that precipitation systems during the inactive phase are more continental in nature than those during the active phase. Cloud propagation from brightness temperature data indicates that Sumatra receives the rainfall mainly from maritime clouds during the active phase, while it is mainly from the continental clouds (land-based convection) during the inactive phase. Other remarkable differences between active and inactive phase precipitation systems are also observed from the vertical structure of precipitation. The precipitation during the inactive phase has deeper storms, a higher reflectivity aloft, more lightning activity and less stratiform characteristics, as compared to the active phase. Assessment of cloud effective radius of the Moderate Resolution Imaging Spectroradiometer (MODIS) data also shows a slight difference in the cloud droplet between the active and the inactive MJO phases. Different convective storms in different MJO phases lead to different DSD characteristics and Z–R relationships. The DSD during the inactive phase tends to have a higher concentration of medium and large-size drops than the active counterpart, consistent with the previous study during the first campaign of Coupling Processes in the Equatorial Atmosphere project. Although the DSD parameters and coefficient of Z–R relationships fall within the range of tropical maritime precipitation, mass-weighted mean diameter (D_m) for the deep convective rains during the inactive phase are somewhat larger than that for maritime and closer to the continental cluster. Therefore, continental-like DSDs are somewhat dominant during the inactive phase, consistent with the intraseasonal variation of precipitation structure. The causative processes of the observed difference in the DSD for the two phases have also been discussed with the help of satellite and radar data. Evaporation and updraft associated with the intense convection during the inactive phase seem to eliminate the small-sized drops from the spectra. Finally, radar reflectivity during the inactive phase is larger than that during the active MJO phase, at the same rainfall rate. This condition can limit the accuracy of radar-derived rainfall estimates for the tropics when applying a single Z–R relation to the two MJO phases, particularly for deep convective rains.

1. Introduction

Rain microstructure, which is characterized by size distribution, shape and fall velocity of raindrop (e.g., Diederich et al., 2004; Thurai et al., 2009) has a broad list of applications in meteorology, hydrology, and related sciences. Long-term observation of raindrop size distribution (DSD) can be used to govern an equation between different rainfall variables such as the radar reflectivity factor (Z)–rainfall rate (R) relationship. The equation is important to convert radar reflectivity from the weather radar to rainfall rates.

The DSD varies not only within a specific storm but also across differing storms types (e.g., Ulbrich, 1983; Tokay and Short, 1996) and climatic regimes (e.g., Bringi et al., 2003) that leads to the variability of the Z–R relation. Such variability substantially limits the accuracy of radar-

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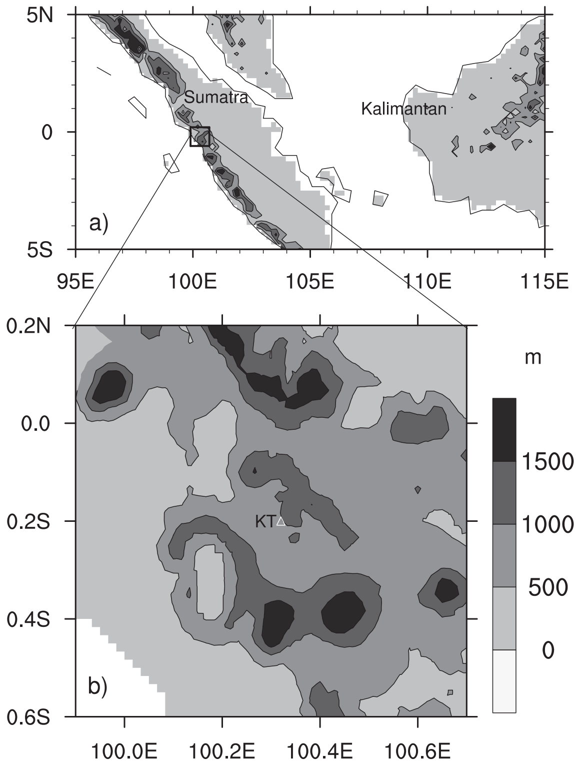

Fig. 1. Surface topography around Sumatra in meter unit (a) and Kototabang which was abbreviated by KT (b).

derived rainfall estimates and becomes one of the error sources of rainfall estimates for the radar (Maki et al., 2005). Therefore, study of DSD variability is important to improve the *Z–R* conversion accuracy. Attempts to understand the variability of DSD have received considerable attention by measurement of the DSD in various climatic regimes (e.g., Ulbrich, 1983; Tokay and Short, 1996; Bringi et al., 2003; Schönhuber et al., 2008; Marzuki et al., 2013a). However, there still exist some fundamental issues which are poorly understood particularly for the tropical region where the variations in precipitation occur due to a wide range of timescales. Furthermore, the DSD measurement of the tropical region is still sparse.

A phenomenon that substantially contributes to the variations of tropical precipitation is the Madden–Julian Oscillation (MJO). The MJO is characterized by intraseasonal variability (30–60 days) in a large-scale of zonal wind, surface pressure and temperature at different levels of the troposphere (Madden and Julian, 1971). Schematically, the MJO is known to be particularly developed over the tropical Indian Ocean and propagates eastward along the equator. Detailed reviews of the MJO can be found in Madden and Julian (1994) and Zhang (2005). Previous studies have suggested that the MJO influences the characteristics of the DSD. For example, Kozu et al. (2005) found a difference in the DSD of two phases of MJO during the first campaign of Coupling Processes in the Equatorial Atmosphere (CPEA) over the Indonesian Maritime Continent. Marzuki et al. (2010b) analyzed the same data as Kozu et al. (2005) but with a better rain classification. Both studies found that the DSD during the convectively inactive is broader than that during the active MJO phases, particularly for heavy rain ($R > 10$ mm h^{-1}). It is coincident with higher radar reflectivity during the inactive than during the active phases, at the same rainfall rate. The differences in the DSD between convectively inactive and active MJO suggest the difference in the process that forms and grows precipitation particles aloft. Morita et al. (2006) interestingly showed that the echo top heights are lower in the active phase of the MJO than those in the inactive periods. During active MJO, stratiform rain fractions in the total rain increase, while intense convection is suppressed. This is consistent with diabatic heating profile, lightning activities and ground temperature (e.g., Lin et al., 2004; Kozu et al., 2005; Morita et al., 2006). These conditions would cause the difference in physical processes affecting the DSD such as coalescence, break-up, evaporation, size sorting, updraft and downdraft which lead to difference in DSDs for each MJO phase.

Wheeler and Hendon (2004) defined eight MJO phases that correspond to the positions of the center of the convective activity along the tropics. Both Kozu et al. (2005) and Marzuki et al. (2010b) analyzed one month data that cover only one MJO cycle. Further advances must be made in order to improve our overall understanding on the natural variability of rain microstructure in response to the MJO. In this paper, the DSD data from disdrometer measurement with a near continuous record of operation over eight consecutive years (2003–2010) at Kototabang, west Sumatra (Fig. 1), are analyzed. Prior to the discussion of the DSD in Section 3, the data and method are introduced in Section 2. General features of precipitation and atmospheric circulation for each MJO phase are first discussed in Section 3. Section 4 addresses the discussion of the results, and Section 5 is a summary that includes recommendations for a future work.

2. Data and methods

2.1. Raindrop size distribution measurement

A 2D-Video Disdrometer (2DVD) was used to measure drop size, shape, and fall speed. The method to obtain the DSD from such drop data is explained in detail by Schönhuber et al. (2008). The 2DVD has been collecting samples of raindrop spectra almost continuously over eight years (2003–2010). The performance of our instrument can be found in Marzuki et al. (2013b). The 2DVD occasionally records spurious small drops especially in heavy rainfall that may be due to the mismatching problem between the front- and side-view camera images. Such problem can be reduced by re-matching the data from the standard matching software with the camera data (Marzuki et al., 2013b). However, the camera data are not available for the entire experimental period. Therefore, a threshold of drop fall speed was adopted to filter out the spurious drops using Gunn and Kinzer (GK) observation results (Gunn and Kinzer, 1949), as proposed by Tokay et al. (2001). We retained the drops within 65% of GK observations. The rainfall rate derived from the filtered data was in good agreement with that obtained by optical rain gauge (ORG) in which the best fit line of the two measurement was $R_{ORG} = 0.97\ R_{2DVD}$. The DSDs with integration time of 2 min, adopting a 0.2 mm channel interval (Marzuki et al., 2010a) from 0.4 mm to 10.25 mm were constructed. The drops in excess of 10 mm

Table 1
Radar specifications.

Radar parameters	1.3-GHz BLR	EAR	MRR	X-band Radar
Radar system	Pulse	Pulse	FMCW	Pulse
Operating frequency	1.3 GHz	47.0 MHz	24 GHz	9.74 GHz
Transmit power	1.1 kW	100 kW	50 mW	40 kW
Antenna	5.9 m^2	110 m in diameter	60 cm in diameter	1.2 m in diameter
Beam width	4.1°	3.4°	2°	–
Range resolution	150 m	150 m	150 m	250 m
Observation period	2004–2009	2003–2010	2011–2012	2004–2010