Observational study on diurnal precipitation cycle over Indonesia using 1.3-GHz wind profiling radar network

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Variations in the diurnal precipitation cycle over equatorial Indonesia were investigated using 1.3-GHz wind profiling radars (WPRs) and rain gauges located at Pontianak (109.37E, 0.00S), Manado (124.92E, 1.55N), and Biak (136.10E, 1.18S). These WPRs were installed in the project of Hydrometeorological ARray for ISV-Monsoon AUtomonitoring (HARIMAU) on February 22, 2007, Setptember 18, 2009, and March 11, 2007, respectively.

WPR was originally designed to observe echoes from clear air turbulence. However, 1.3-GHz WPR is very sensitive to hydrometeor. Hence, in this study, the precipitation cloud type was classified from vertical profile of vertical beam Doppler velocity and spectral width observed by WPRs for each precipitation observed by rain gauges. At all three WPR sites, peak rain rate was detected during 1300-1500 LT by rain gauges. WPR observations showed that deep convective clouds were predominant during that period. At Biak, precipitation from midnight to morning was observed, whose dominant cloud types were both deep convective and stratiform. There was a clear difference in the afternoon-to-evening precipitation among the three WPR sites. Figure 1(a) shows the averaged diurnal rain rate for each cloud type at Pontianak. The peak rain rate was detected during 1400-1500 LT. During this period, the deep convective cloud type was predominant and accounted for more than 80% of the total rain rate. Figure 1(b) shows the frequency of precipitation for each cloud type. The frequency of deep convective type clouds increased from 1200 LT and reached a peak around 1500-1600 LT, which was similar to the result of the peak rain rate. There was a clear transition from the convective-type clouds to the stratiform-type clouds during 1500-2000 LT. The frequency of the stratiform-type clouds increased following the predominance of the deep convective type, and reached a peak during 1900-2000 LT. However, the stratiform rain rate was only about 0.2 mm/h. The afternoon-to-evening precipitation has the characteristics of a mesoscale convective system (MCS). Black

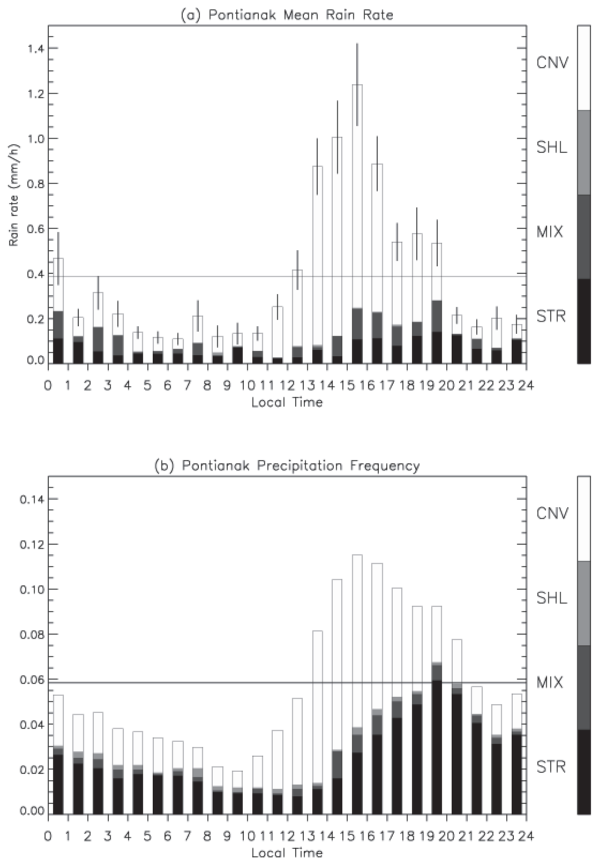

Figure 1. Diurnal cycle of (a) rain rate and (b) precipitation frequency at Pontianak as observed by WPR-gauge. For each precipitation event, the cloud type is classified as stratiform, mixed stratiform/convective, shallow convective, and deep convective types, which are indicated as STR, MIX, SHL, and CNV, respectively. Vertical lines indicate error bars of total rain rate defined by $\sigma/\sqrt{n}$. The horizontal lines in both panels indicate mean values.

body brightness temperature (Tbb) observed by MTSAT-1R satellite also indicated that the precipitation clouds had enough horizontal scale to be well organized as a MCS. At Manado and Biak, the peak rain rate in the early afternoon was characterized by a short period (within 3 h), and the precipitation after the convective precipitation was not clear.

Tbb data showed that the horizontal scale of cloud systems differs from Pontianak to Manado and Biak. The horizontal scale of the landmass around Pontianak is more than 100 km, while that of Manado and Biak is 10-100 km. The diurnal precipitation cycle was also investigated using 11 years of Tropical Rainfall Measuring Mission (TRMM) data. 3G68 grid data showed that the midnight to morning precipitation at Biak was caused by northward propagation of cloud system from northern coastal region of New Guinea Island. A 3G68 product with a horizontal resolution of 0.5 deg. could not resolve peak rain rate in the early afternoon at Manado and Biak, where convective clouds developed with the 10-100 km horizontal scale. Surface rain data with a horizontal resolution of 0.1 deg. were produced using the TRMM precipitation radar (PR) 2A25 product. This high-horizontal-resolution data set successfully detected the peak convective rain rate in the early afternoon at Manado and Biak. The rain rate peak was distributed in the land region of peninsula in Sulawesi Island, and the whole region in Biak Island.

The mechanism of diurnal precipitation cycle at Pontianak was further investigated. Around Pontianak, radiosonde and MTSAT-1R data showed that the zonal migration of each precipitation system was caused by zonal wind in the middle troposphere (in the altitude of 8-10 km). WPR echo intensity and spectral width clearly showed the development of the mixing layer in the daytime. Radiosonde observations at Pontianak revealed that water vapor showed a significant increase during 1000-1600 LT in the altitude of 1-4 km, and during 1300-1600 LT above 4 km. Minimum of water vapor around 1300 LT was observed below the altitude of 0.5 km. The upward atmospheric motion was frequently observed during 1000-1600 LT. The results showed that water vapor was transported upward by strong upward atmospheric motion in the daytime. The upward transport of water vapor is suggested to play an important role in the precipitation in the afternoon to evening at Pontianak.

At Pontianak, zonal wind variation was dominant below 1.5 km, which can be explained by sea-land breeze of Borneo (Kalimantan) Island. At Manado, zonal and meridional wind variation below 1 km can be explained by the sea-land breeze of Sulawesi Island, and the wind variation of meridional component in 1-3 km can be explained by return flow of sea-land breeze. At Biak, meridional wind variation below 2 km altitude was dominant, which can be explained by sea-land breeze of New Guinea (Papua) Island, not of Biak Island itself. At Biak, the diurnal variation of meridional wind was suggested to make a convergence in the lower troposphere, and acts an important role in northward propagation of precipitation system from northern coastal region of New Guinea Island. At all the three WPR sites, semidiurnal variation of zonal wind was observed in an altitude of 1-3 km, which is consistent with atmospheric tides. At Manado and Biak, upward atmospheric motion clearly increased in the daytime, which suggest that upward atmospheric motion plays an important role in the daytime precipitation.

The impact of intra-seasonal variation (ISV) to diurnal precipitation cycle was investigated. At all three WPR sites, peak rain rate and frequency in the afternoon were dominant in almost all MJO phases. The transition from convective clouds to stratiform clouds at Pontianak was clearly defined in almost all MJO phases. The precipitation from midnight to morning at Biak was dominant only in the active phase of MJO. The frequency of deep convective rain at three WPR sites did not show clear variation between active phase and inactive phase of MJO. On the other hand, the frequency of stratiform rain increased in the active phase of MJO.

The relationship between horizontal scale of landmass and precipitation feature from afternoon-to-evening was discussed based on this study and previous studies. In the case of landmass with a horizontal scale of less than 10 km, afternoon precipitation is not predominant. In the case of landmass with a horizontal scale of 10-100 km (like Manado and Biak), even though afternoon precipitation caused by localized convection occurs, cumulus convection is not well organized enough to produce a stratiform region after the peak of the deep convective rain rate. In the case of landmass with a horizontal scale of more than 100 km (like Pontianak), cumulus convection is well organized enough to produce a stratiform region of MCS in the afternoon to evening precipitation.