Interaction of MJO and diurnal cycle observed by radiosonde data during the first YMC campaign in Bengkulu (November 2017 - January 2018)

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Abstract. The interaction of MJO and diurnal cycle in the Maritime Continent has been identified from previous studies but more observations are needed to understand it clearly. The first campaign of Years of the Maritime Continent (YMC) was conducted in Bengkulu from 16 November 2017 to 15 January 2018. Among various kind of observations, the three-hourly radiosonde sounding was conducted in Bengkulu station during the campaign. This study analyses the radiosonde data to investigate the thermodynamic profile of the mean diurnal cycle (MDC) at different MJO phases. The MDC of potential temperature anomaly (PTA), relative humidity, winds, convective available potential energy (CAPE) and total precipitable water (TPW) in different MJO phases were compared to the MDC values during the campaign (average condition). The obtained MDC PTA has a similar pattern with the results from the Pre-YMC campaign (November - December 2015). During the active MJO phase (3-4), RH is much higher and the zonal westerly wind is up to 6 m/s faster than the average condition at most of the time and elevation below 15 km, and TPW is amplified about 1-4 mm. In contrast, the condition is reversed during inactive MJO phase (1-2). In addition, the CAPE peaks occurred at 06 - 09 UTC and followed by TPW peaks 6 hours later.

Keywords : MJO, YMC, radiosonde, CAPE

1. Introduction

The Maritime Continent (MC) is located within the Tropical Pacific Warm Pool and consists of many island and shallow oceans. The tropical MC has an important role in atmospheric circulation [1]. Due to the high sea surface temperature (SST) in the MC, there is a significant latent heat releases and accompanied by heavy precipitation over the MC. Because of releasing energy, the MC is known as an atmospheric 'boiler box' and one of the main drivers of the global atmospheric circulation [2, 3]. At intraseasonal timescale, the MC is influenced by the Madden Julian Oscillation (MJO) which is an atmosphere equatorial wave propagating from the Indian Ocean to the Pacific Ocean with a period of 30-90 days at speed of approximately 4-5 m/s [4, 5, 6]. MJO signals are observed to be strong in Austral summer (November – April) in the western Pacific [7] and systematically modulate the amplitude of the diurnal cycle of precipitation over the MC [8].

The diurnal cycle (DC) in the tropics is a principal mode of variability in the global climate system [9]. Activities of MJO have broad impacts on a wide range of global weather and climate phenomena,
which is related to rainfall variability [10]. Active (wet) phases of the MJO correspond to enhanced rainfall in the tropical Western Pacific, with typical rainfall anomalies between the wet and dry phases in the range of 2 – 6 mm/day [11]. Though the diurnal variations of tropical deep convection largely depend on the region, it is generally accepted that the convective or precipitation maximum occurs over the continents in the late afternoon or early evening and over the ocean in the early morning [12, 13, 14, 15, 16].

Many studies have suggested that the MJO interacts with DC. The suppressed MJO to be associated with small, short-lived cloud system which form and decay in the afternoon and the active MJO to be characterized by larger, longer-lived systems which form during the afternoon but not peak until the early hours of the following morning, before decaying [17]. The DC is enhanced during the suppressed phase and diminished during the active phase of the MJO [18], whilst diurnal cycles of atmospheric variations are more pronounced during the wet phase [19]. The diurnal cycle of deep convection over both land and ocean areas to be enhanced during the active MJO compared with the suppressed MJO, but the diurnal phase to be similar in both regimes [20, 21]. However, more observations and research are needed to understand more details.

![Figure 1](image.jpg)

**Figure 1.** The first YMC campaign in the west coast of Sumatera from 16 November 2017 – 15 January 2018. (Left panel) activities conducted during the campaign including atmosphere and ocean observations (source: [http://www.jamstec.go.jp/ymc/IOP_YMC-Sumatra_2017.html](http://www.jamstec.go.jp/ymc/IOP_YMC-Sumatra_2017.html)). (Right panel) Radiosonde launch in BMKG Fatmawati station with 3-hours intervals in a day (photos: BMKG).

Within the framework of “Years of the Maritime Continent” (YMC), a two-year (2017 – 2019) international project consisting of multiple intensive observation projects related to atmospheric and
oceanic research focusing on the MC (http://bmkg.go.id/ymc; http://www.jamstec.go.jp/ymc). In the MC, BMKG is the host country of the YMC. Its overarching goal is to expedite the progress of improving understanding and prediction of local multi-scale variability of the MC weather-climate system and its global impact through observations and modeling exercises.

The first campaign of YMC was conducted by collaboration of the Japan Agency for Marine–Earth Science and Technology (JAMSTEC), the Indonesian Agency for the Assessment and Application of Technology (BPPT), and the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) in the west coast of Sumatera from the mid-November 2017 to mid-January 2018 (Figure 1). Among various kind of observations, radiosonde observations were performed in Bengkulu station at 3-h intervals [01, 04, 07, 10, 13, 16, 19 and 22 local time (LT); LT = UTC + 7] with the use of Meisei-100 sensors manufactured by Meisei (Figure 1). Previously, the Pre-YMC intensive observation campaign was conducted in November-December 2015 by the same collaboration agencies at the same location for preliminary study [22].

This study investigates the atmospheric thermodynamic profile of the mean diurnal cycle (MDC) at different MJO phases using the radiosonde data collected from the first YMC campaign in Bengkulu station. The MDC of potential temperature anomaly, relative humidity, winds, freezing level height, convective available potential energy (CAPE), convective inhibition (CIN) and total precipitable water (TPW) at different MJO phases were compared to the MDC values during the whole campaign period to observe the interaction of MJO and MDC.

2. Data and Methods
In this study, we used radiosonde data collected at BMKG Fatmawati Station (102.337°E; 3.858°S) from 16 November 2017 to 15 January 2018. The recorded parameters consisted of pressure, temperature, relative humidity, wind speed, and wind direction in the vertical level. The highest recorded radiosonde height was 32430.9 meters (7.9 mb) on 5 January 2018 at 0600 UTC when the weather condition was clear. The lowest radiosonde height was recorded at 4587.5 meters (584.8 mb) on 22 December 2017 at 2100 UTC when the continuous rain was observed.

As the intensity of convective activity is influenced by the atmospheric thermodynamic profile before the convection begins, the potential temperature (\(\theta\)) was derived from radiosonde data. The potential temperature of an air parcel at pressure \(P\) is defined as the temperature that the parcel would attain if adiabatically brought to a standard reference pressure (usually 1000 mb). By a given air parcel with temperature \(T\) (°C) and pressure \(P\) (mb), the potential temperature (Kelvin) is calculated by the following formula:

\[
\theta = (T + 273.15) \times \left(\frac{1000}{P}\right)^{0.286}
\]

The vertical profiles of potential temperature anomaly (PTA), relative humidity (RH), zonal and meridional wind during the campaign at Bengkulu station are depicted in Figure 2 (Panel 1-4). The altitude is limited to 20.5 km (~ 20 mb) in this study. In order to obtain the MDC, the listed above parameters were averaged for eight particular times [00, 03, 06, 09, 12, 15, 18, and 21 UTC]. The MJO phase and intensity [23] during the campaign are shown in Figure 2 (Panel 5-6). In this study, the dates associated with strong MJO phases are defined as follows: phase 3-4 (23-30 November 2017), phase 5-6 (1-7 December 2017), phase 7-8 (8-26 December 2017), and phase 1-2 (27 December 2017-12 January 2018). The MDC at particular MJO phases were obtained by averaging the parameters in the associated dates. Furthermore, the CAPE, CIN and TPW for each radiosonde observation were calculated using SkewT library in Python language (https://pypi.org/project/SkewT). In addition, the changes of the freezing level height (FLH, the altitude at which the temperature is 0°C), CAPE, CIN and TPW were obtained at particular MJO phases.
Figure 2. Radiosonde (Meisei-100) data collected from 16 November 2017 to 15 January 2018. The vertical profiles of PTA, RH, zonal and meridional winds are shown in Panel 1-4. The MJO phase and intensity are given in panel 5-6. Colored boxes indicate the dates associated with the MJO phases used in this study (blue: phase 3-4, red: phase 5-6, green: phase 7-8, purple: phase 1-2).

3. Results and Discussions
The MDC of PTA, RH, zonal and meridional winds during the whole campaign period (defined as “average condition”) is shown in Figure 3. The obtained MDC of PTA has a similar pattern with the results from Pre-YMC campaign (November - December 2015) [23]. In the troposphere (< 10km), the
positive maxima PTA are observed at 06 UTC (13 LT) from the surface up to the altitude of 500 meters, whereas negative maxima are observed at 18, 21 and 00 UTC (01-07 LT) at the surface. In average, the positive PTA is observed at 03:00 UTC (13 LT) from 11 to 14 km, whereas the negative maxima were observed at 21 and 00 UTC (04-07 LT) from 11 to 13 km. Relative humidity is generally lower during 03-09 UTC (daytime) than during nighttime, which represents the typical weather in Bengkulu that usually have rainfall (high humidity) during nighttime. The highest relative humidity is observed at 18-21 UTC in altitude of ~5 km and at 00 UTC in altitude of ~2 km. During the campaign, the westerly wind (monsoon) is dominant from the surface up to 5 km with maxima occurs at the altitude of 2-3 km with the speed of 8-12 m/s. From 10 to 15 km, the tropical easterlies are dominant with a maximum speed of 24 m/s, whereas the winds are relatively calm all the time at 7 to 9 km (not shown) due to the meeting of monsoon westerlies and tropical easterlies. In the other hand, the northerly winds are strong below 2 km with a maximum speed of 5-6 m/s at 18, 21, and 00 UTC and a minimum speed of 1-2 m/s at 09 UTC below 500 meters.

![Figure 3. Mean diurnal cycle of potential temperature anomaly, relative humidity, zonal, and meridional winds at Bengkulu station.](image-url)
In order to observe the interaction between MJO and MDC, the differences between the MDC at particular MJO phases and the average condition are obtained for PTA and RH (Figure 4), and for zonal and meridional winds (Figure 5). The PTA differences are mostly positive from 2 to 14 km during MJO phase 3-4 (active) and 5-6, and mostly negative during MJO phases 1-2 (inactive) and 7-8. During active phases (3-4) of MJO over Sumatera, RH is much higher (5-15%), suggesting additional moisture in the atmosphere and the zonal westerly wind is up to 6 m/s faster than the average condition at most of the time and elevation below 15 km. In contrary, the condition is reversed during inactive MJO phase (1-2). In addition, the meridional northerly wind is faster during the active MJO phase (3-4) below 4 km. The higher wind speed observed during the MJO phase 3-4 from 23-30 November 2017 could also contribute to the formation of tropical cyclone Dahlia on 29 November 2017 in the southwest of Bengkulu.

**Figure 4.** Differences of the MDC at particular MJO phases and the average condition for PTA (left) and RH (right).

**Figure 5.** Differences between the MDC at particular MJO phases and the average condition for zonal (left) and meridional (right) winds.
Lastly, the MDC of FLH, CAPE, CIN and TPW at the average condition and at particular MJO phases in Bengkulu station are shown in Figure 6. The average FLH is about 4915 meters with maxima FLH of 4960 meters occurs at 09 UTC and minimum of 4840 meters at 00 UTC. During MJO phase 3-4 and 5-6, the FLH increased by 150 meters possibly due to rising warm air and strong convection, whereas during MJO phase 7-8 and 1-2, the FLH decreased by 30 meters. The CAPE peaks at 06 - 09 UTC (13-16 LT) with an energy of 3 KJ, describing strong convection during those times, while the CIN is near 0 KJ at most of the time. This condition suggests that precipitation would preferentially occur after 06-09 UTC, and it is shown by TPW peaks at 12-18 UTC (night-time rainfall). During MJO phase 3-4 and 5-6, the TPW is amplified by 1-4 mm, whereas during MJO phase 1-2, the TPW decreased by 2 mm.

Figure 6. Mean diurnal cycle of freezing level height (FLH), CAPE, CIN and TPW during the campaign period (at average condition) and at particular MJO phases in Bengkulu station.

4. Conclusions
The first campaign of YMC project was conducted in Bengkulu from 16 November 2017 to 15 January 2018. Among various kinds of observation, radiosonde observations were performed at 3-h intervals in Bengkulu station. The results show that the MDC PTA has a similar pattern with the results from the Pre-YMC campaign. During active phases (3-4) of MJO over Sumatera, RH is much higher (5-15%), suggesting additional moisture in the atmosphere and the zonal westerly wind is up to 6 m/s faster than the average condition at most of the time and elevation below 15 km. In contrary, the condition is reversed during inactive MJO phase (1-2). During active MJO phases over the MC, the FLH is increased which possibly due to rising warm air and strong convection. The CAPE peaks at 06 - 09 UTC with an energy of 3 KJ, describing strong convection during those times, while the CIN are near 0 KJ at most of the time. The TPW peaks at 12-18 UTC, 6 hours after the peaks of CAPE. The TPW is amplified by 1-4 mm during active MJO phases and decreased by 2 mm during inactive MJO phases over Sumatera.

Acknowledgments
Authors wishing to acknowledge assistance or encouragement from BMKG colleagues in Center for Research and Development, Fatmawati Meteorology Station, Bengkulu Climatology Station, Kepahiang Geophysics Station, Centre for Public Meteorology, Centre for Aviation Meteorology and Database Centre. Authors also want to acknowledge Bengkulu local government and Ristekdikti for given
permission for the research project. This research project is financially supported by the collaboration of JAMSTEC, BMKG and BPPT under the YMC framework.

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