Role of Maritime Continent Convection during the Preconditioning Stage of the Madden–Julian Oscillation Observed in CINDY2011/DYNAMO

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Abstract

We investigated the role of Sumatra Island convection over the maritime continent during the preconditioning stage of the Madden–Julian Oscillation (MJO) using intensive observations of CINDY2011/DYNAMO and HARIMAU2011. CINDY2011/DYNAMO and HARIMAU2011 were conducted over the Indian Ocean from October 2011 to January 2012 and Sumatra Island, Indonesia in December 2011. Both observation datasets covered the preconditioning stage of the MJO in December 2011. We found that convection was activated over the Sumatra Island with diurnal cycle associated with the moist air mass, which originated from a tropical depression generated in the South China Sea. Then, two-day period disturbances that propagated westward to the central Indian Ocean were coupled with the diurnal cycle of convection over the Sumatra Island. The structure of the two-day period disturbances was consistent with that of westward propagating inertia-gravity waves. When the westward propagating disturbances arrived over the central Indian Ocean, low-level moisture advection was excited. Moistening process was promoted in Gan Island over the central Indian Ocean, which had a two-day period. After the favorable condition of large-scale convection was established, the MJO was activated in the central Indian Ocean. The two-day period westward disturbances were organized when large-scale moisture convergence became positive in Sumatra Island and continued until a strong low-level westerly wind of the active phase of the MJO was formed.

Keywords Madden-Julian Oscillation; CINDY2011; maritime continent; preconditioning; two-day period
1. Introduction

One of the most prominent features in tropical convection is the intraseasonal oscillation, which has a time scale of 30–60 days and is often called the Madden–Julian Oscillation (MJO) (Madden and Julian 1971, 1972). The MJO is characterized by an organized convective cloud system propagating eastward from the equatorial Indian Ocean to the central Pacific Ocean associated with large-scale circulation. Its influences are widespread globally such as increasing tropical cyclone genesis (Hall et al. 2001), intensifying monsoon activity (Lau and Chan 1986a; Hendon and Liebmann 1990), triggering the El Niño-Southern Oscillation (ENSO) through westerly wind bursts (Lau and Chan 1986b; McPhaden 1999), and causing the westerly jet to meander over the midlatitude through teleconnection (Maeda 2007). In spite of its huge impacts on global weather systems, global circulation models still have difficulties in making MJO prediction (Hung et al. 2013). Once the MJO convection is organized, its propagation can be traced through its large-scale circulation structure (Wheeler and Hendon 2004).

The international field campaign of the Cooperative Indian Ocean experiment on intraseasonal variability in the year 2011 (CINDY2011) was conducted in cooperation with the Dynamics of the MJO (DYNAMO) in the central Indian Ocean from October 2011 to January 2012 (Yoneyama et al. 2013). The goals were to capture and understand the convective initiation process of the MJO. During the preconditioning stage of the MJO, shallow cumulus clouds are scattered and followed by congestus clouds (Johnson et al. 1999; Kemball-Cook and Weare 2001; Kikuchi and Takayabu 2004). Convective build-up is connected with the moistening process in the lower troposphere. Several theories have been proposed for the MJO moistening process, including frictional moisture convergence in the boundary layer (Wang 1988; Hendon and Salby 1994), and recharge process on the time-scale of the radiative–convective feedback (Bladé and Hartmann 1993; Hu and Randall 1994).

During CINDY2011/DYNAMO, moistening process and convective build-up were observed over the central Indian Ocean during the preconditioning stage of each MJO (Johnson and Ciesielski 2013; Yoneyama et al. 2013; Hagos et al. 2014; Sobel et al. 2014; de Szoeke et al. 2015; Nasuno et al. 2015). de Szoeke et al. (2015) suggested that the moistening process was not as simple as the recharge process. Nasuno et al. (2015) pointed out that the intraseasonal zonal and meridional moisture advections are important for local moistening. On the other hand, Kerns and Chen (2014) suggested that the off-equatorial intertropical convergence zone (ITCZ) convection first induced subsidence over the equator, and then the ITCZ convection was suppressed by dry-air intrusion that allowed moistening in the equator. It indicated that the off-equatorial convection acted as another key for the moistening process of the MJO. Figure 1 is a time-longitude diagram of infrared brightness temperature along the equator during CINDY2011/DYNAMO campaign from October to December 2011, showing three major MJOs being activated associated with large-scale convections over the equatorial Indian Ocean and propagated eastward to the Pacific Ocean. The convection originated over Sumatra Island in the maritime continent propagated westward, and some reached the central Indian Ocean before the first (Johnson and Ciesielski 2013) and third MJO events. Over Sumatra Island, diurnal cycle of the convection was dominant and nocturnal convection tended to propagate westward from Sumatra Island (Mori et al. 2004; Wu et al. 2008). Nocturnal westward propagating convection was activated when the active phase of the MJO was located in the Indian Ocean (Fujita et al. 2011; Kamimera et al. 2012). They considered the influence of the MJO on the convection in the maritime continent; however, they did not discuss the impact of maritime continent convection on the MJO. In contrast to previous studies of the moistening process at the preconditioning stage of the MJO, this study focuses on the role of maritime continent convection observed during CINDY 2011/DYNAMO, especially on the preconditioning stage of the third MJO (MJO3) when the joint intensive observation was conducted around Sumatra Island in December 2011 (Hydrometeorological Array for ISV-Monsoon AUtomon-itoring: HARIMAU2011) (Yamanaka et al. 2008). The data used in this study are described in Section 2. The preconditioning stage of the MJO observed during CINDY2011/DYNAMO is shown in Section 3, followed by discussion of the role of maritime continent convection through moistening process. Summary and discussion are provided in Section 4.

2. Data and methods

A sounding network of two quadrilateral arrays was set up over the central equatorial Indian Ocean during CINDY2011/DYNAMO (Yoneyama et al. 2013; Fig. 1b). However, during the target period of the preconditioning stage of MJO3 in December 2011,
the R/V Mirai in charge of the southeast edge of the array left the stationary observation site on December 1 and the R/V Roger Revelle at the east array in the equator left on December 11 to resupply and returned on December 19. Upper-air observation was also conducted while the R/V Roger Revelle was sailing over the Indian Ocean, which is used in this study. The R/V Baruna Jaya conducted 6-hourly upper-air observations at 7.0°S, 95.0°E during December 5–18. In this study, the 3-hourly sounding data in Gan Island (0.7°S, 73.2°E) at the west of the array in the equator are used (Fig. 1b). Therefore, both quadrilateral arrays do not have enough upper-air observations for in-situ budget analysis. Special observation HARIMAU2011 was conducted in West Sumatra, Indonesia in December 2011 under the collaboration among the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the Agency for the Assessment and Application of Technology (BPPT) of Indonesia, the Agency for Meteorology, Climatology and Geophysics (BMKG) of Indonesia, and the National Institute of Aeronautics and Space.
Global-merged, hourly 0.5° grid equivalent blackbody temperature data from the Climate Prediction Center of National Oceanic and Atmospheric Administration are used for detecting clouds. Japanese 55-year reanalysis dataset (JRA55) of 1.25° grid is used for three-dimensional structures of wind and moisture (Ebita et al. 2011). The best track data of the Joint Typhoon Warning Center are used for determining the location and intensity of tropical cyclone.

Wavelet analysis is performed on hourly equivalent blackbody temperature averaged over each 5° × 5° square using Morlet wavelet (Torrence and Compo 1998). The moisture tendency equation for moisture budget is

\[
\frac{\partial q}{\partial t} = -\nabla \cdot (\mathbf{V} q) - \omega \frac{\partial q}{\partial p} - \frac{Q_2}{L}
\]

where \( q \) is the specific humidity; \( \mathbf{V} \) and \( \omega \) are the horizontal and vertical velocities, respectively; \( t \) is time; \( \nabla \) is the horizontal gradient parameter; \( Q_2 \) is the apparent moisture sink; \( \gamma \) is the average of budget analysis domain (Yanai et al. 1973); and \( L \) is the latent heat of condensation. The tendency was estimated 6-hourly in each 5° × 5° square using JRA55.

3. Preconditioning stage of MJO3

3.1 Characteristics of moisture distribution in December 2011

On December 1, 2011, Second MJO (MJO2) reached Sumatra Island, which was activated over the Indian Ocean around November 23, 2011 and propagated eastward. Figure 2 shows the relative humidity and zonal wind observed by the upper-air sounding in Sipora Island off-coast of Sumatra Island. Convections associated with MJO2 were active in Sumatra Island area until December 4. After MJO2 moved eastward along the maritime continent, the circum-global structure of the MJO signal over the equator became weak in the real-time multivariate MJO index from December 11 (Wheeler and Hendon 2004; see Fig. 7 in Yoneyama et al. 2013). However, convections around Sumatra Island became active again from December 11 (Fig. 2a) and showed diurnal cycle from December 15 onward (Fig. 2b). On the contrary, a tropical depression was generated in the South China Sea on December 10. Figure 3 shows the moisture and horizontal wind at 850 hPa from December 10 to 14. The tropical depression was not yet developed into a tropical storm; however, it increased moisture in the Sumatra Island area on December 10 as it propagated southwestward (Fig. 3a). The tropical depression dissipated on December 14 when it approached the equator and increased moisture in Sumatra Island (Fig. 3e). Figure 4 shows horizontal and vertical moisture advection anomalies from December 2011 averaged in the Sumatra Island area. Horizontal moisture advection increased in the low-level troposphere over Sumatera Island on December 10 and continued until December 14 (Figs. 4a, c) before the diurnal cycle of convection started on December 15. Moisture was transported upward through convection mainly on December 11 and 14 (Figs. 2a, 4b, c). After MJO2 passed over the maritime continent, the tropical cyclone provided moisture to the Sumatra Island area, and contributed to activate the convection over this region from December 11 onward and to activate the dominant diurnal cycle from December 15 onward.

3.2 Two-day period westward propagating disturbances

Figure 5 shows the relative humidity and zonal wind profiles over Gan Island of the central Indian Ocean. After MJO2 passed by, the Gan Island convection was suppressed, and started again from December 8 and activated periodically from December 16. The atmosphere was gradually moistened upward associated with two-day period convections during December 16, 18, and 20 (Fig. 5b). Figure 6 shows a time-longitude diagram of infrared brightness temperature along the equator from December 13 to 22. Convection over Sumatra Island was activated by the diurnal cycle from December 15 onward; however, the westward propagating clouds started in Sumatra Island toward the Indian Ocean seemed to have a longer time scale than the diurnal cycle. The westward propagating clouds show the two-day period at a speed of 10°–13° day⁻¹ with a horizontal scale of about 25°. Figure 7 shows 12-hourly snapshot shots of clouds over the eastern Indian Ocean from 18Z December 14 to 18Z December 20. In fact, diurnal cycle of convection developed in Sumatra Island around 18Z every day from December 14 (Fig.2). However, westward propagating clouds originated from Sumatra Island were seen only every other day on December 15, 17 and 19. There was a selection of westward propagating clouds coupled with the diurnal cycle of convection. When the westward propagating clouds reached the Gan Island area, convec-
tion was observed in two-day period. The composite of two-day period observed in Gan Island is made by the center time in December 16 18Z, 19 00Z, and 20 18Z in Fig. 8. We removed the data after December 20 18Z for composite. Because MJO3 started in December 21, the vertical structure has been changed. Upward moistening appeared and relative humidity reached maximum around 4–6km height in 0 h (Fig. 8a). Upper-level zonal wind showed easterly wind anomaly from −12 h and changed to westerly wind anomaly at 0 h around 8–12 km (Fig. 8b). Maximum southerly wind anomaly appeared in 0 h at 10–12 km (Fig. 8c). 90° phase shift can be seen in the zonal and meridional wind anomalies. Upper-level and low-level wind clearly show opposite direction around 0 h in meridional wind in baroclinic structure. When Gan Island locates north of the center of the westward propagating disturbances, the composite of westward propagating disturbances is consistent with the theoretical n = 1 westward propagating inertia-gravity wave and the structure observed over the equatorial western Pacific (Takayabu et al. 1996).

Figure 9 shows the wavelet power spectrum of infrared brightness temperature from December 10 to 22 using Morlet wavelet analysis. Diurnal cycle was dominant around December 12–20 over Sumatra Island (Fig. 9a). On the other hand, two-day period clouds were seen in the west of Sumatra Island and central Indian Ocean starting from December 15 to 16 (Figs. 9b, c). This is corresponding to the westward propagating clouds that were active over the eastern Indian Ocean (Figs. 6, 7). Diurnal and two-day period clouds are consistent with the variation of moisture observed in Sipora and Gan Islands (Figs. 2b, 5b).

Figure 10 shows horizontal and vertical moisture advection anomalies from December 2011 averaged over the northern quadrilateral array centered at 2.5°N 77.5°E. Moisture budget analysis was performed using JRA55 instead of in-situ data (due to insufficient observations). Fortunately, the in-situ observations are reflected in the reanalysis data (Ciesielski et al. 2014). Horizontal moisture advection anomaly appeared up to 250 hPa until December 15. However, the two-day period disturbances did not reach the
central Indian Ocean yet on this time. Similar upper-level horizontal advection was observed in MJO1 and MJO2 over the central Indian Ocean in the intraseasonal time scale (Nasuno et al. 2015). On the other hand, the low-level horizontal moisture advection appeared in two-day period on December 16, 18–19,
and 21 were consistent with the two-day period disturbance arrival in this area (Figs. 7, 9c and 10a). Vertical advection became active in two-day period from December 16 onward (Fig. 10b). The time scales of horizontal and vertical advection are shorter than the intraseasonal time scale and around the two-day period. It is interesting that diurnal cycle of vertical advection was seen around December 13–15 (Fig. 10b). This feature also appeared in the wavelet analysis of clouds (Fig. 9c). However, we do not discuss this further in this study.

It is important to notice that horizontal and vertical advection started increasing about 18–24 h prior to the maximum of two-day period disturbances in the central Indian Ocean (refer to the composite time in Fig. 8). We speculate that this short time-scale advection was induced by westward propagating two-day period disturbances. The arrival of disturbances coupled with westward propagating inertio-gravity waves excited the horizontal moisture advection in this area. Therefore, the two-day period of upward moistening in Gan Island is linked to the westward propagating disturbances. After the moistening process was observed in the Gan Island area, MJO3 was activated in the central Indian Ocean on December 21 with strong westerly winds (Fig. 5c). We speculate that the arrival of westward propagating two-day period disturbances originated from Sumatra Island coupled with westward propagating inertio-gravity waves promoted low-level moisture advection in the central Indian Ocean in the two-day period, and contributed to favorable conditions for preconditioning an MJO. Once the large-scale convection and circulation of MJO3 developed, they propagated eastward and reached Sumatra Island on December 25 associated with strong westerly winds (Fig. 2c).

4. Summary and discussions

Intensive observations CINDY2011/DYNAMO and HARIMAU2011 were conducted over the Indian Ocean from October 2011 to January 2012 and in the Sumatra Island area, Indonesia in December 2011, respectively. The preconditioning stage of MJO3 was examined using both intensive observation data-
Fig. 5. Same as Fig. 2, except for Gan Island in the central Indian Ocean.

Fig. 6. Same as Fig. 1, except for infrared brightness temperature averaged over 5°S–5°N during December 13–21, 2011. Triangles are the longitude locations of Gan Island and Sipora. Dashed arrow traces the westward propagating convection.
sets. We proposed the contribution of Sumatra Island convection in the maritime continent during the preconditioning stage of the MJO based on the intensive observation datasets. After MJO2 passed over Sumatra Island area on December 5, convection was suppressed (Fig. 2a) and was activated over Sumatra Island area again in December 11 and showed diurnal cycle from December 15 onward (Fig. 2). Tropical depression was generated in the South China Sea in December 10 and horizontal moisture advection increased at Sumatra Island from December 10 and provided moisture upward through convection in December 11 and 14 (Figs. 3, 4). Moisture from the tropical cyclone may trigger the convection in the Sumatra Island area. Two-day period of westward propagating disturbances was coupled with diurnal cycle of convection over Sumatra Island and reached the central Indian Ocean during December 15–21 (Figs. 6, 7). Two-day period of convections were detected from wavelet analysis (Fig. 9). Horizontal scale, phase speed, and vertical structure of the wind are consistent with the westward propagating inertia-gravity wave (Figs. 6, 8). Two-day period of moistening was observed in Gan Island over the

Fig. 7. Twelve-hourly infrared blackbody temperature distributions from 18Z December 14 to 18Z December 20. Dashed arrow traces the westward propagating convection.
Low-level horizontal moisture advection appeared on December 16, 18–19, and 21 prior to the two-day period disturbance arrival in the central Indian Ocean (Fig. 10). The two-day period of upward moistening in Gan Island is linked to westward propagating disturbances. After the moistening process was observed in Gan Island area, MJO3 was activated in the central Indian Ocean in December 21 with strong westerly winds.

The combinations of diurnal cycle and two-day period westward propagating disturbances were discussed for the active phase of the MJO over the central Indian Ocean (Fig. 5).
equatorial western Pacific in the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) (Takayabu et al. 1996; Chen and Houze 1997). Diurnal cycle of convection is necessary over the open ocean due to the radiative cooling at night-time that promotes nocturnal convection; however, convection is suppressed during daytime due to the solar insolation that warms and stabilizes the atmosphere (Kubota et al. 2004). When the convection becomes large-scale, the recovery time of moisture to create favorable atmospheric condition for the next convection becomes longer to two-day period. The phase lock of inertia-gravity wave also affects the two-day periodicity. Therefore, the environment for large-scale convection selects the two-day periodicity. In the case of Sumatra Island of the maritime continent presented in this study, the diurnal cycle of convection was dominant. However, when large-scale moisture convergence became positive over the Sumatra Island area from December 16 onward (not shown) and large-scale convection developed, the combination of diurnal cycle and two-day period of convection was presumably promoted. Wavelet analysis supports the existence of two-day period of convection west of the Sumatra Island area.

During the active phase of the MJO in the TOGA-COARE, westward propagating inertia-gravity waves were observed (Takayabu et al. 1996). The environment was low-level westerly and high-level easterly in the troposphere (Lin and Johnson 1996). This sheared environment destabilized the west-
ward propagating waves (Han and Khouider 2010). On the other hand, the combination of diurnal cycle and two-day period of convection was seen in the Sumatra Island area during the preconditioning stage of MJO3. During the preconditioning stage of MJO1 in October 2011, the combination of diurnal cycle and two-day period of convection was also seen in the Sumatra Island area to central Indian Ocean (Johnson and Ciesielski 2013; Zuluaga and Houze 2013). The difference between MJO1 and MJO3 was that the two-day period westward propagating disturbances continued from the preconditioning stage to the active phase of the MJO1. Low-level zonal wind along the equator was weak during the second half of October of the preconditioning stage to the active phase of MJO1 (Fig. 10 of Sobel et al. 2014). Intraseasonal zonal moisture advection and moist static energy were accumulated during this period until the low-level wind changed to strong westerly (Nasuno et al. 2015; Sobel et al. 2014). On the other hand, when MJO3 was activated on December 21, low-level westerly wind became strong over the central Indian Ocean (Fig. 5c). The sheared environment did not restrict the westward propagating disturbances. However, when the strong low-level westerly wind exceeds $\sim 15$ m s$^{-1}$, westward propagating disturbances were suppressed during the active phase of MJO3 and the latter half of MJO1. Compared to MJO1 and MJO3 during the CINDY2011/DYNAMO intensive observation, the preconditioning stage of MJO2 has a longer interval of disturbances around 5–6 days over the central Indian Ocean (Johnson and Ciesielski 2013; Zuluaga and Houze 2013). Longer interval of disturbances was also observed in intensive observation over the central Indian Ocean in 2006 (Katsumata et al. 2009). Kikuchi and Wang (2010) showed westward propagating inertia-gravity waves being enhanced in advance of the MJO. It demonstrated the possibility of more frequent cases of the westward propagating disturbances during the preconditioning stage of the MJO.

While westward propagating disturbances traveled from the eastern to the central Indian Ocean, there was an opportunity to observe the vertical structure. Fortunately, the R/V Revelle was sailing over the central Indian Ocean on the way to the stationary

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**Fig. 12.** Same as Fig. 6, except from 00Z December 17 to 12Z December 18. Red triangle indicates the location of the R/V Revelle.
location (0.5°N, 80.5°E) during the westward propagating disturbances. Figure 11 shows the relative humidity and zonal wind collected by the R/V Revelle while it sailed westward along the Indian Ocean. The two-day period disturbances passed over the R/V Revelle at 12Z December 18 (Fig. 12). The thick layer of high relative humidity indicates that the convection came from the low-level troposphere. This suggests that the westward propagating disturbances not only consisted of upper troposphere anvil clouds but also active convection. The westward propagating disturbances activated convection while traveling to the central Indian Ocean. Shige and Satomura (2001) showed that new convection was generated westward under sheared environment of low-level westerly and high-level easterly. This indicates that westward propagating disturbances created a favorable condition for convection over the Indian Ocean for the preconditioning stage of the MJO. Remote convection over the Sumatra Island contributed to the moistening process over the Indian Ocean through westward propagating disturbances for the preconditioning stage of MJO3.

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References

Bladé, I., and D. L. Hartmann, 1993: Tropical intraseasonal oscillations in a simple nonlinear model. J. Atmos. Sci., 50, 2922–2939.

Chen, S. S., and R. A. Houze, Jr., 1997: Diurnal variation and life-cycle of deep convective systems over the tropical Pacific warm pool. Quart. J. Roy. Meteor. Soc., 123, 357–388.

Ciesielski, P. E., H. Yu, R. H. Johnson, K. Yoneyama, M. Katsumata, C. N. Long, J. Wang, S. M. Loehrer, K. Young, S. F. Williams, W. Brown, J. Braun, and T. Van Hove, 2014: Quality-controlled upper-air sounding dataset for DYNAMO/CINDY/AMIE: Development and corrections. J. Atmos. Oceanic Technol., 31, 741–764.

de Szoeke, S. P., J. B. Edison, J. R. Marion, C. W. Fairall, and L. Bariteau, 2015: The MJO and air-sea interaction in TOGA COARE and DYNAMO. J. Climate, 28, 597–622.

Ebita, A., S. Kobayashi, Y. Ota, M. Moriya, R. Kumabe, K. Onogi, Y. Harada, S. Yasui, K. Miyaoka, K. Takahashi, H. Kamahori, C. Kobayashi, H. Endo, M. Soma, Y. Oikawa, and T. Ishimizu, 2011: The Japanese 55-year reanalysis “JRA-55”: An interim report. SOLA, 7, 149–152.

Fujita, M., K. Yoneyama, S. Mori, T. Nasuno, and M. Satoh, 2011: Diurnal convection peaks over the Eastern Indian Ocean off Sumatra during different MJO phases. J. Meteor. Soc. Japan, 89A, 317–330.

Hagos, S., Z. Feng, C. D. Burleyson, K.-S. Sunny Lim, C. N. Long, D. Wu, and G. Thompson, 2014: Evaluation of convection-permitting model simulations of cloud populations associated with the Madden-Julian Oscillation using data collected during the AMIE/DYNAMO. J. Geophys. Res. Atmos., 119, 12052–12068.

Hall, J. D., A. J. Matthews, and D. J. Karoly, 2001: The modulation of tropical cyclone activity in the Australian region by the Madden–Julian oscillation. Mon. Wea. Rev., 129, 2970–2982.

Han, Y., and B. Khoudier, 2010: Convectively coupled waves in a sheared environment. J. Atmos. Sci., 67, 2913–2942.

Hendon, H. H., and B. Liebmann, 1990: The intraseasonal (30-50 day) oscillation of the Australian summer monsoon. J. Atmos. Sci., 47, 2909–2923

Hendon, H. H., and M. L. Salby, 1994: The life cycle of the Madden-Julian Oscillation. J. Atmos. Sci., 51, 2225–2237.

Hu, Q., and D. A. Randall, 1994: Low-frequency oscillations in radiative-convective systems. J. Atmos. Sci., 51, 1089–1099.

Hung, M.-P., J.-L. Lin, W. Wang, D. Kim, T. Shinoda, and S. J. Weaver, 2013: MJO and convectively coupled equatorial waves simulated by CMIP5 climate models. J. Climate, 26, 6185–6214.

Johnson, R. H., and P. E. Ciesielski, 2013: Structure and properties of Madden-Julian oscillation deduced from DYNAMO sounding arrays. J. Atmos. Sci., 70, 3157–3179.

Johnson, R. H., T. M. Rickenbach, S. A. Rutledge, P. E. Ciesielski, and W. H. Schubert, 1999: Trimodal characteristics of tropical convection. J. Climate, 12, 2397–2418.

Kamimera, H., S. Mori, M. D. Yamanaka, and F. Syamsudin, 2012: Modulation of diurnal rainfall cycle by the Madden-Julian oscillation based on one-year
continuous observation with a meteorological radar in west Sumatera. SOLA, 8, 111–114.

Katsumata, M., R. H. Johnson, and P. E. Ciesielski, 2009: Observed synoptic-scale variability during the developing phase of an ISO over the Indian Ocean during MISMO. J. Atmos. Sci., 66, 3434–3448.

Kemball-Cook, S., and B. C. Weare, 2001: The onset of convection in the Madden-Julian oscillation. J. Climate, 14, 780–793.

Kerns, B. W., and S. S. Chen, 2014: Equatorial dry air intrusion and related synoptic variability in MJO initiation during DYNAMO. Mon. Wea. Rev., 142, 1326–1343.

Kikuchi, K., and Y. N. Takayabu, 2004: Spatiotemporal wavelet transform and the multiscale behavior of the Madden-Julian Oscillation. J. Climate, 23, 3814–3834.

Kubota, H., A. Numaguti, and S. Emori, 2004: Numerical experiments examining the mechanism of diurnal variation of tropical convection. J. Meteor. Soc. Japan, 82, 1245–1260.

Lau, K.-M., and P. H. Chan, 1986a: Aspects of the 40-50 day oscillation during the northern summer as inferred from outgoing longwave radiation. Mon. Wea. Rev., 114, 1354–1367.

Lau, K.-M., and P. H. Chan, 1986b: The 40-50 day oscillation and the El Niño/Southern Oscillation: A new perspective. Bull. Amer. Meteor. Soc., 67, 533–534.

Lin, X., and R. H. Johnson, 1996: Heating, moistening, and rainfall over the western Pacific warm pool during TOGA-COARE. J. Atmos. Sci., 53, 3367–3383.

Madden, R. A., and P. R. Julian, 1971: Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific. J. Atmos. Sci., 28, 702–708.

Madden, R. A., and P. R. Julian, 1972: Description of global-scale circulation cells in the tropics with a 40–50 day period. J. Atmos. Sci., 29, 1109–1123.

Maeda, S., H. Sato, and M. Watanabe, 2007: Tropical convection and Japan abnormal cold winter in December 2005. Cold winter and heavy snow in Japan during 2005/2006 winter. Meteor. Res. Note, 216, 89–94 (in Japanese).

McPhaden, M. J., 1999: Genesis and evolution of the 1997–98 El Niño. Science, 283, 950–954.

Mori, S., J.-I. Hamada, Y. I. Tautihid, M. D. Yamanaka, N. Okamoto, F. Murata, N. Sakurai, H. Hashiguchi, and T. Sribimawati, 2004: Diurnal land-sea rainfall peak migration over Sumatran Island, Indonesian maritime continent, observed by TRMM satellite and intensive rawinsonde soundings. Mon. Wea. Rev., 132, 2021–2039.

Nasuno, T., T. Li, and K. Kikuchi, 2015: Moistening processes before the convective initiation of Madden-Julian oscillation events during the CINDY2011/DYNAMO period. Mon. Wea. Rev., 143, 622–643.

Shige, S., and T. Satomura, 2001: Westward generation of eastward moving tropical convective bands in TOGA COARE. J. Atmos. Sci., 58, 3724–3740.

Sobel, A., S. Wang, and D. Kim, 2014: Moist static energy budget of the MJO during DYNAMO. J. Atmos. Sci., 71, 4276–4291.

Takayabu, Y. N., K. M. Lau, and C. H. Sui, 1996: Observation of a quasi-2-day wave during TOGA COARE. Mon. Wea. Rev., 124, 1892–1913.

Torrence, C., and G. P. Compo, 1998: A practical guide to wavelet analysis. Bull. Amer. Meteor. Soc., 79, 61–78.

Wang, B., 1988: Dynamics of tropical low-frequency waves: an analysis of the moist Kelvin wave. J. Atmos. Sci., 45, 2051–2065.

Wheeler, M. C., and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. Mon. Wea. Rev., 132, 1917–1932.

Wu, P.-M., S. Mori, J.-I. Hamada, M. D. Yamanaka, J. Matsumoto, and F. Kimura, 2008: Diurnal variation of rainfall and precipitable water over Siburu Island off the western coast of Sumatera Island. SOLA, 4, 125–128.

Yamanaka, M. D., H. Hashiguchi, S. Mori, P.-M. Wu, F. Syamsudin, T. Manik, J.-I. Hamada, M. K. Yamamoto, M. Kawashima, Y. Fujiyoshi, N. Sakurai, M. Oh, R. Shirooka, M. Katsumata, Y. Shimbagaki, T. Shimomai, Erlansyah, W. Setiawan, B. Tejasukmana, Y. S. Djabajdharjda, and J. T. Anggadjiretda, 2008: HARIMAU radar-profiler network over Indonesian maritime continent: A GEOSS early achievement for hydrological cycle and disaster prevention. J. Disaster Res., 3, 78–88.

Yanai, M., S. Esbensen, and J.-H. Chu, 1973: Determination of bulk properties of tropical cloud clusters from large-scale heat and moisture budgets. J. Atmos. Sci., 30, 611–627.

Yoneyama, K., C. Zhang, and C. N. Long, 2013: Tracking pulses of the Madden-Julian oscillation. Bull. Amer. Meteor. Soc., 94, 1871–1891.

Zuluaga, M. D., and R. A. Houze, Jr., 2013: Evolution of the population of precipitating convective systems over the equatorial Indian Ocean in active phases of the Madden–Julian oscillation. J. Atmos. Sci., 70, 2713–2725.