MJO Initiation Processes over the Tropical Indian Ocean during DYNAMO/CINDY2011*

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ABSTRACT
A multinational joint field campaign called the Dynamics of MJO/Cooperative Indian Ocean Experiment on Intraseasonal Variability in Year 2011 (DYNAMO/CINDY2011) took place in the equatorial Indian Ocean (IO) in late 2011. During the campaign period, two strong MJO events occurred from the middle of October to the middle of December (referred to as MJO I and MJO II, respectively). Both the events were initiated over the western equatorial Indian Ocean (WIO) around 50°–60°E. Using multiple observational data products (ERA-Interim, the ECMWF final analysis, and NASA MERRA), the authors unveil specific processes that triggered the MJO convection in the WIO. It is found that, 10 days prior to MJO I initiation, a marked large-scale ascending motion anomaly appeared in the lower troposphere over the WIO. The cause of this intraseasonal vertical motion anomaly was attributed to anomalous warm advection by a cyclonic gyre anomaly over the northern IO. The MJO II initiation was preceded by a low-level specific humidity anomaly. This lower-tropospheric moistening was attributed to the advection of mean moisture by anomalous easterlies over the equatorial IO. The contrast of anomalous precursor winds at the equator (westerly versus easterly) implies different triggering mechanisms for the MJO I and II events. It was found that upper-tropospheric circumnavigating signals did not contribute the initiation of both the MJO events. The EOF-based real-time multivariate MJO (RMM) indices should not be used to determine MJO initiation time and location because they are primarily used to capture large zonal scale and eastward-propagating signals, not localized features.

1. Introduction
The Madden–Julian oscillation [MJO; i.e., the intraseasonal oscillation (ISO)] is the most prominent mode of intraseasonal variability in the tropics. First identified by Madden and Julian (1971) using single station data from Canton Island (2.5°S, 171.4°W), the MJO is characterized by a wavenumber one structure with a thermal direct vertical cell propagating eastward along the equator (Madden and Julian 1972). Later analysis of satellite
data, such as outgoing longwave radiation (OLR), confirmed the planetary scale of the MJO (Weickmann 1983; Murakami and Nakazawa 1985; Lau and Chan 1986; Li and Zhou 2009). Studies also show that the oscillation is more broadband than the original 40–50-day period identified by Madden and Julian (1971) and can span a range of 20–100 days (e.g., Krishnamurti and Subrahmanyan 1982; Annamalai and Slingo 2001; Lau and Waliser 2005; Zhang 2005; Li and Wang 2005, Waliser 2006). As the most significant variability between day-to-day weather and El Niño–Southern Oscillation, MJO is a major predictability source for extended-range (10–30 days) weather prediction.

The least understood aspect of MJO is its initiation process [see Li (2014) for a recent review on this topic]. A number of theories have been advanced in an attempt to understand the initiation mechanism. These theories can be classified according to a tropical or an extratropical origin. The tropical origin hypotheses include a forcing from upstream related to a preceding MJO event that circumnavigates around the global tropics (e.g., Lau and Peng 1987; Wang and Li 1994; Li and Wang 1994; Matthews 2000, 2008) and processes due to local changes of atmospheric planetary boundary layer (PBL) moisture, circulation and sea surface temperature (Kemball-Cook and Ware 2001; Jiang and Li 2005; Li et al. 2008; Ling et al. 2013; Sobel et al. 2014; Wang et al. 2015), or downward influence of midtropospheric potential vorticity (Seo and Song 2012). The promise behind the circumnavigation theory is that eastward-propagating MJO waves may trigger deep convection over the moist and warm Indian Ocean after passing the African continent, with a possible topographic lifting effect (Hsu and Lee 2005). Different from this upstream forcing scenario, Zhao et al. (2013) proposed a downstream forcing scenario in which a preceding suppressed-phase MJO over the eastern equatorial Indian Ocean (EIO) initiates new convection in the western equatorial Indian Ocean (WIO) through anomalous moisture advection. The extratropical origin hypotheses emphasize a forcing from midlatitudes including the Rossby wave energy dispersion and the momentum transport of midlatitude baroclinic eddies (e.g., Hsu et al. 1990; Matthews and Kiladis 1999; Pan and Li 2008; Ray et al. 2009; Zhao et al. 2013; Ray and Li 2013).

A multinational joint field campaign called the Dynamics of MJO/Cooperative Indian Ocean Experiment on Intraseasonal Variability in Year 2011 (DYNAMO/CINDY2011) took place in the equatorial Indian Ocean (IO) in late 2011 (Yoneyama et al. 2013). During the campaign period, two strong MJO events occurred from the middle of October to the middle of December (referred to as MJO I and MJO II, respectively). A number of site observational studies (e.g., Johnson and Ciesielski 2013; Gottschalck et al. 2013) have revealed the important role of low-level moisture and circulation in triggering MJO convection. However, as seen from the Hovmoller diagram of precipitation field along the equator, the MJO convection signals were already present before moving to the observational site. Therefore, the studies above, strictly speaking, are not aimed to the real MJO initiation issue but rather to the MJO propagation issue: namely, why new convection occurs to the east of existing MJO convection. The objective of the present study is to investigate real MJO initiation mechanisms in the WIO. We aim to reveal precursor signals and dynamic processes associated with the initiation of MJOs I and II in the WIO, based on multiple observational datasets. The remaining part of this paper is organized as follows: In section 2, data and analysis methods are introduced. The precursor signals and specific processes that trigger MJO convection during MJO I and II events are investigated in section 3. In section 4, we discuss the relationship between upper-tropospheric circumnavigating signals and convection initiation over the WIO and the possible role of high-frequency waves in MJO initiation. A summary is given in the last section.

2. Data and method

The primary datasets used for this analysis include 1) daily satellite-observed outgoing longwave radiation (OLR) from the National Oceanic and Atmospheric Administration (NOAA; Liebmann and Smith 1996), 2) the Interim European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-Interim; Dee et al. 2011), 3) the ECMWF final analysis (FNL), and 4) the NASA MERRA reanalysis (Rienecker et al. 2011). The horizontal resolution is 1.50 × 1.50° for ERA-Interim, 0.25° × 0.25° for ECMWF FNL, and 1.25° × 1.25° for MERRA. The observed OLR (2.50° resolution) is used as a proxy for deep convection. All analysis/reanalysis data have a 6-hourly interval, consisting of multiple vertical levels of horizontal velocity, vertical velocity, specific humidity, temperature, and geopotential height fields.

Daily OLR and atmospheric variables were first decomposed into a low-frequency background state (LFB; with a 100-day low-pass filter), an MJO component (with a 20–100-day bandpass filter), and a higher-frequency (HF; with a 20-day high-pass filter) component. Moisture and heat budgets were diagnosed to understand specific processes that give rise to moisture and temperature changes. According to Yanai et al. (1973), atmospheric temperature tendency at a constant pressure coordinate is determined by the sum of horizontal temperature advection, the adiabatic process associated with vertical motion, and the
atmospheric apparent heat source $Q_1$. The moisture tendency is determined by the sum of horizontal and vertical moisture advections and the atmospheric apparent moisture sink $Q_2$. The temperature and moisture tendency equations may be written as

$$\frac{\partial T}{\partial t} = -\mathbf{V} \cdot \nabla T + \frac{RT}{c_p} \frac{\partial T}{\partial p} + \frac{Q_1}{c_p}$$ and (1)

$$\frac{\partial q}{\partial t} = -\mathbf{V} \cdot \nabla q - \frac{Q_2}{L}$$

where $c_p$ denotes specific heat at constant pressure, $R$ is the gas constant, $\mathbf{V}$ is the horizontal gradient operator, $L$ is the latent heat of condensation, $t$ is time, $p$ is pressure, $T$ is temperature, $q$ is specific humidity, $\mathbf{V}$ is the horizontal velocity vector, and $\omega$ is vertical $p$-velocity. The expression $(RT/c_p) - (\partial T/\partial p)$ represents the atmospheric static stability. The term $Q_1$ represents total diabatic heating including radiation, latent heating, surface heat flux, and subgrid-scale processes, and $Q_2$ represents the latent heating due to condensational and evaporational processes and subgrid-scale moisture flux convergence (Yanai et al. 1973). For the detailed description of $Q_1$ and $Q_2$ calculation procedures, readers are referred to Hsu and Li (2011, 2012). Applying a 20–100-day bandpass filtering operator to each term at right and left sides of the equations above and integrating each term vertically from the surface (1000 hPa) to 700 hPa, one may derive the MJO-scale low-level moisture and heat budget equations, following Hsu and Li (2012).

3. Precursor signals associated with initiation of MJOs I and II

The MJO initiation region was determined based on the Hovmöller diagram of the observed intraseasonal OLR field (Fig. 1). Figure 1 shows that MJO convection was initiated in the WIO around 50°–60°E. To test the sensitivity of the budget result to the choice of initiation region, two initiation domains, (5°S–5°N, 50°–60°E) and (10°S–10°N, 45°–65°E), were used for the subsequent analysis.

To reveal precursor signals associated with the MJO convection initiation, we plotted the time evolution of the intraseasonal OLR, vertical motion, and specific humidity fields averaged over the initiation regions (Fig. 2). The OLR anomaly transitioned from a positive to a negative value on 14 October (Fig. 2a). Thus, this date is regarded as the initiation date for MJO I.

Precursor signals derived from the ensemble average of the ERA-Interim, ECMWF FNL, and MERRA datasets over the two initiation domains reveal that anomalous ascending motion appeared in the lower troposphere 10 days prior to the initiation date. Initially near the surface, the ascending motion anomaly gradually deepened into the upper troposphere. A positive specific humidity anomaly also appeared in the lower troposphere prior to the initiation date, but it lagged the anomalous ascending motion by 5 days (Fig. 2c). The precursor signals are consistent within the three datasets and the two initiation domains (figure not shown).

A low-level moisture budget diagnosis indicates that the moistening during 9–13 October was attributed to anomalous vertical advection (Fig. 3a). The result is robust among the three datasets and the two initiation domains. To examine specific vertical advection processes that contribute to the lower-tropospheric moistening, both the specific humidity and vertical velocity
are decomposed into three components: the LFBS, the intraseasonal (20–100 days) component, and the HF (with a period less than 20 days) component,

\[ q = \bar{q} + q' + q^*, \quad \omega = \bar{\omega} + \omega' + \omega^*, \quad (3) \]

where a bar, a prime, and a star denote the LFBS, MJO, and HF component, respectively.

The diagnosis result shows that the anomalous vertical advection is primarily attributed to advection of the mean moisture by anomalous ascending motion (Fig. 3b). As the mean moisture decays exponentially with height, the anomalous ascending motion advected high near-surface mean moisture upward. A key question is, what caused the anomalous ascending motion during the earlier initiation stage (5–8 October)?

The diagnosis of vertically integrated (1000–700 hPa) temperature budget reveals that the ascending motion is triggered by anomalous warm horizontal advection.
It is found that a warm advection anomaly appeared during the earlier initiation stage. The warm horizontal advection was balanced approximately by the adiabatic cooling term while local temperature tendency is relatively small (Fig. 4a). Again, this warm advection–adiabatic cooling feature is robust among the three datasets. This is physically reasonable because a warm advection promotes ascending motion so that adiabatic cooling associated with the ascending motion can offset the horizontal advection effect. This warm advective effect acts in a similar way as discussed in the traditional omega equation for a quasigeostrophic system (Holton 2004). The issue then becomes, what causes the anomalous warm advection?

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Similar to the above moisture diagnosis, temperature and horizontal wind fields can be decomposed into the LFBS, the intraseasonal, and the HF components: that is,

$$ T = T' + T^* + T^*, \quad u = \overline{u} + u' + u^*, \quad \text{and} \quad v = \overline{v} + v' + v^*, $$

Thus, the anomalous horizontal temperature advection may be decomposed into nine terms and the diagnosis result is shown in Fig. 4b. The most dominant term is
the advection of background mean temperature by the intraseasonal wind. (A further separation of zonal and meridional components showed that zonal advection dominates the horizontal advection term.) Figure 4 illustrates anomalous wind and mean temperature fields at 850 hPa during 5–8 October. A large-scale cyclonic gyre appeared in the northern IO. Associated with this cyclonic gyre were northeasterly anomalies that advected warmer mean temperature southwestward. There were pronounced westerly anomalies at most of the equatorial IO.

The large-scale cyclonic gyre in the northern IO was a Rossby wave response to positive heating anomalies off the equator over the western Pacific and South China Sea regions. It is noted that the anomalous cyclonic gyre and the western Pacific heating anomalies persisted from 1 to 8 October (Fig. 5). It is the anomalous low-level northeasterly associated with the gyre circulation that advected warm mean temperature southwestward, inducing the anomalous ascending motion. The ascending motion further moistened lower to middle troposphere through vertical advection. This built-up local moist static energy and set up a convectively unstable stratification. As a result, the ascending motion developed upward, triggering the MJO convection.

Different from MJO I, precursor signals associated with MJO II were characterized by the occurrence of both positive specific humidity and ascending motion anomalies almost the same time (Figs. 2e,f), 4 days prior to the initiation date (which was defined at 14 November according to the anomalous OLR evolution; Fig. 2d). To quantitatively examine the cause of low-level moistening, a vertically (1000–700 hPa) integrated moisture budget analysis was performed. Figure 6a shows the diagnosis result from this vertically integrated moisture budget analysis. It is clear that the moistening during the initiation period (10–13 November) is attributed to both the
horizontal and vertical advections. The apparent moisture source term \((-Q/L)\), on the other hand, plays a negative role. The result is robust among the three datasets.

Figure 6b shows the contributions from each of nine horizontal advection terms. The largest term is the advection of the mean moisture by the MJO flow \((-\nabla \cdot \mathbf{V} q)\). The horizontal patterns of the background specific humidity and the intraseasonal wind fields at 850 hPa averaged during 10–13 November were plotted in Fig. 6d. As maximum background specific humidity appears over the eastern IO/Maritime Continent region and decreases toward the west, anomalous low-level easterlies in the central equatorial IO advected the high background mean moisture westward and increased the lower-tropospheric moisture over the initiation region.

In addition to the horizontal advection, anomalous vertical advection also contributed to the moistening process. A diagnosis shows that the vertical advection was dominated by the advection of the background mean moisture by the intraseasonal wind (Fig. 6c). The in-phase growth of both the moisture and vertical motion fields suggests that there was a positive convection–circulation feedback during the period. On one hand, the low-level moistening triggered convective instability in lower troposphere and induced shallow convection. On the other hand, anomalous ascending motion associated with shallow convection deepened moist layer, promoting deeper convection. Through this interactive process, both the ascending motion and moisture anomalies developed upward.

An examination of the 1000–700-hPa integrated temperature budget shows that a warm advection anomaly appeared prior to the initiation of MJO II. This implies that both the convective instability and the warm horizontal temperature advection night play a role in triggering anomalous ascending motion during the initiation stage.

The result above suggests that the advection of the high mean moisture/temperature by low-level easterly anomalies holds a key for MJO II initiation. What caused the anomalous easterly prior to the initiation? Our analysis shows that the equatorial easterly anomaly was a result of Rossby wave response to a preceding suppressed-phase MJO that propagated eastward (Figs. 1, 7). This is consistent with the Rossby wave downstream forcing scenario previously identified by Zhao et al. (2013).

Thus, relevant processes for the initiation of MJO II may be summarized as follows: In response to a negative heating anomaly of the preceding suppressed phase MJO over EIO, equatorial easterly anomalies were set up. The easterlies advected the high mean moisture westward, leading to low-level moistening in the WIO.
The increase of the PBL moisture promoted a convectively unstable stratification, leading to the onset of shallow convection. The upward moisture transport associated with the anomalous ascending motion deepened the moist layer and favored deeper convection. An opposite precursor wind anomaly at the equatorial IO signified different initiation processes involved between MJO I and II events.

### 4. Discussion

#### a. Role of upper-tropospheric circumnavigating signals

An important issue related to MJO initiation is, what is the role of global circumnavigation of upper-tropospheric divergent signals associated with a preceding MJO? From the evolutions of the 20–100-day
filtered upper-tropospheric velocity potential field (Fig. 8), one can see that, on both of the initiation dates (14 October and 14 November), anomalous upper-tropospheric divergence centers appeared over the South America/Atlantic sector, far away from the WIO. The upper-tropospheric divergence centers arrived over the WIO around 23 October and 23 November, 9 days after the MJO initiation over the WIO. This implies that the upper-tropospheric forcing did not contribute to the occurrence of precursor low-level ascending motion and moisture signals over the WIO for both the events.
The upper-tropospheric divergence patterns shown in Fig. 8 are consistent with the evolution of vertical profiles of anomalous descending signals in the upper troposphere prior to and during the MJO initiation periods (Figs. 2b,e). Thus, Fig. 8 provides observational evidences that the upper-tropospheric forcing was not a cause of convection initiation for the MJO I and II events. The result is consistent with idealized ECHAM4 experiments conducted by Zhao et al. (2013) and Ray and Li (2013), who found that overall MJO variance does not change after the global circumnavigating mode is removed.

b. Detection of initiation time and location

One issue related to MJO initiation is how to determine the initiation time and location. The method used in Zhao et al. (2013) and the current study is based on the temporal and spatial evolution characteristics of the OLR anomaly field, by examining both the Hovmöller OLR or rainfall diagram averaged along the equator or time sequence maps of 2D anomalous OLR/rainfall patterns. Straub (2013), on the other hand, used the real-time multivariate MJO (RMM) index to identify the initiation location and time by examining where and when the RMM amplitude increases from a value below one to a value above one in the RMM diagram. As pointed out by Straub (2013), this method with use of the conventional RMM index cannot identify correct initiation time and location, because the index is heavily weighted by the circulation field, particularly the upper-tropospheric wind field. It was suggested that a simpler RMM index with the OLR only might be useful.

To examine this issue further, we plotted the RMM diagrams for both the conventional RMM index and the simplified one with the OLR only (see Fig. 9). As one can see, the conventional RMM index indicates the MJO activity center being in the Western Hemisphere on 14 October and 14 November, when significant dynamic and thermodynamic precursor signals have already been observed and the local OLR anomaly has already changed from a positive to a negative value. It is only until 20 October and 26 November that MJO activity signals appeared over the western IO. The cause of the mismatch is attributed to the fact that the RMM index is constructed based on two leading EOF modes, which are primarily used to capture large zonal scale and eastward-propagating signals. For initiation processes that happened in a narrow zonal scale, the method cannot capture the right signals.

The bottom panel of Fig. 9 shows the RMM diagram with the OLR field only. Does this simplified index perform better? The answer is no. A similar feature appeared. This is because the same EOF decomposition methodology was applied. Although the OLR anomaly is more localized compared to the upper-tropospheric wind, the calculation of two leading EOF modes of the OLR anomaly over the entire tropics domain can only capture large-scale eastward-propagating signals. Therefore, while the RMM index is an excellent diagnostic tool for detecting the MJO phase propagation, it is not proper to use this tool to detect the MJO initiation timing and location. This result is consistent with a recent study by Kiladis et al. (2014), who also examined the circulation and OLR-based indices. It is thus recommended that the best way to detect the MJO initiation timing and location is to examine both the time–longitude cross section and 2D evolution patterns of the anomalous OLR/precipitation field.

c. Higher-frequency wave effect

The heat budget analysis in Fig. 4b shows that HF eddy heat transport also contributed to the anomalous warm temperature advection during the earlier initiation stage of MJO I. A further diagnosis indicates that zonal advection dominates (Fig. 10). Separating the HF component into convectively coupled Kelvin waves (CCKW), mixed Rossby–gravity waves (MRG), eastward inertial–gravity waves (EIG), and westward inertial–gravity waves (WIG) based on the Wheeler–Kiladis spectral filtering method (Wheeler and Kiladis 1999; calculation package obtained from the NCL website: https://www.ncl.ucar.edu/Applications/space_time.shtml), one may calculate their relative importance.

Our calculation shows that CCKW contribution is largest among these wave components (Fig. 10d). To illustrate how CCKW contributed to the anomalous warm advection, we plotted the horizontal structure of the CCKW (Fig. 11). It illustrates the phase relationship between the eddy zonal wind and temperature fields. As CCKW moved eastward, the nonlinear temperature advection always contributed positively to the intra-seasonal temperature tendency over the initiation region. The CCKW vertical structure illustrates that the eddy zonal wind is indeed in phase with the eddy geopotential height field (figure not shown), being consistent with the Matsuno (1966) theoretical solution.

5. Summary

The precursor signals of convection initiation associated with MJOs I and II during the DYNAMO/CINDY2011 field campaign period were investigated through the diagnosis of the multiple datasets (ERA-Interim, ECMWF FNL, and MERRA reanalysis). The western equatorial Indian Ocean (around 50°–60°E) is a key initiation region for both MJO events.
For MJO I, a marked ascending motion anomaly appeared in the lower troposphere 10 days prior to the convection initiation. A warm temperature advection anomaly was responsible for triggering of the upward motion during the earlier initiation stage. The ascending motion moistened the air column and induced a convectively unstable stratification. The upward development of large-scale ascending motion anomalies eventually led to onset of MJO convection. The anomalous warm advection was primarily attributed to the advection of the background mean temperature by anomalous northeasterly, which was a part of large-scale cyclonic gyre in response to preceding intraseasonal heating anomalies over the western Pacific–South China Sea region. HF waves contributed, to a certain extent, to the anomalous warm advection and thus the MJO initiation.

Different from MJO I, the initiation of MJO II was primarily caused by a moistening in the lower troposphere induced by advection of the background mean specific humidity by anomalous easterlies arising from the Rossby wave response to a preceding suppressed-phase MJO over the EIO. The initiation process of MJO II resembles well that described in Zhao et al. (2013) based on a 20-yr composite analysis.

It is worth mentioning that the initiation processes described here differ from those focused on the observational campaign sites. In the latter case, initiation of convection is primarily caused by existing MJO convection to its west,
Fig. 10. 1000–700-hPa integrated (a) anomalous horizontal temperature advection, (b) zonal advection, and (c) meridional advection (unit: K day$^{-1}$) at different vertical levels during 5–8 Oct 2011. The result is based on the ensemble average of ERA-Interim, ECMWF FNL, and MERRA with two initiation domains: (5°S–5°N, 50°–60°E) and (10°S–10°N, 45°–65°E). Bars with whiskers indicate a standard deviation of six ensemble members. (d) Same as (a) but for the 850-hPa zonal temperature advection anomalies contributed by HF waves (from left to right: CCKW, MRG, EIG, and WIG). The vertical axis scale in (d) is 10 times smaller than that in (a)–(c).
which essentially is a propagation problem. As demonstrated by Hsu and Li (2012), the PBL moistening associated with the eastward propagation is primarily attributed to anomalous vertical advection, which differs from dominant anomalous horizontal advection in the “pure” WIO initiation scenario (Zhao et al. 2013).

An interesting issue related to MJO initiation is, what is the relative role of tropical forcing versus midlatitude forcing? It is likely that the former is mostly responsible for successive MJO events, while the latter may be responsible for primary MJO events. From dynamics point of view, the two processes differ markedly. The former

![Fig. 11. Evolutions of 850-hPa temperature (shading; unit: K) and wind perturbation field (vector; unit: m s^{-1}) associated with CCKW from 5 to 7 Oct 2011.](image)
emphasizes low-level moistening in situ, and the latter emphasizes extratropical upper-tropospheric wave energy dispersion and accumulation. In a future study, we will examine individual MJO events in the past 20 yr to reveal the relative roles of the local and remote processes in triggering MJOs.

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References


Wang, S., A. Sobel, F. Zhang, Y. Sun, Y. Yue, and L. Zhou, 2015: Regional simulation of the October and November MJO events observed during CINDY/DYNAMO field campaign at gray zone resolution. J. Climate, doi:10.1175/JCLI-D-14-00294.1, in press.