Eastward propagating ~2- to 15-day equatorial convection and its relation to the tropical intraseasonal oscillation

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Abstract. Anomalies of outgoing longwave radiation (OLR) in 1980–1989 were examined in a narrow latitude band about the equator to elucidate the propagation and interaction of tropical intraseasonal oscillations (TIOs) and synoptic-scale convective activity. Hovmöller diagrams of OLR data reconstructed from two frequency bands (corresponding to periods of ~30–60 days and ~2–15 days, respectively) revealed a clear distinction between the phase speed of eastward moving TIOs (3–7 m s⁻¹) and that of eastward synoptic-scale convection (10–13 m s⁻¹). Coherent propagation of TIOs from the Indian to the western Pacific Oceans was often observed with temporary diminution of amplitude over the maritime continent. Propagation of high-frequency anomalies was generally confined to an individual basin. Dominance of eastward propagating synoptic-scale convection in the equatorial zone contrasts sharply with the westward propagation of off-equatorial convergence zones. Interaction between the TIO and high-frequency activity resolved by daily OLR was visible as a modest enhancement of eastward synoptic-scale events (and of high-frequency activity in general) during the convectively active phase of the TIO.

1. Introduction

The tropical intraseasonal oscillation (TIO) is an important source of variability in the Earth’s atmosphere. Since its discovery by Madden and Julian [1971, 1972] and a related observation of slow Kelvin waves at 100 mbar by Parker [1973], this phenomenon has received considerable attention. Intraseasonal (~30- to 60-day) oscillations were found in various data sets, including rawinsonde zonal wind, outgoing longwave radiation (OLR), analyzed velocity potential, and stream function (e.g., Madden and Julian, 1971; Weickmann, 1983; Lau and Chan, 1985; Knutson and Weickmann, 1987). Eastward propagating circulation anomalies are apparently coupled to regions of eastward propagating equatorial convection [Rui and Wong, 1990]. Convection anomalies attain largest amplitude over the Indian and western Pacific Oceans. Circulation anomalies extend further east, possibly all around the equator [Knutson and Weickmann, 1987; Hendon and Salby, 1994]. There are demonstrated or postulated relationships between the TIO and monsoons [Hendon and Liebmann, 1990], tropical cyclones [Liebmann et al., 1994], El Niño/Southern Oscillation (ENSO) [Lau and Lim, 1986], and extratropical latitudes [Liebmann and Hartmann, 1984; Lau and Phillips, 1986]. Observational aspects of the TIO were recently reviewed by Madden and Julian [1994].

All of this literature may lead us to suppose that the TIO is a prominent feature in observations of tropical convection in the eastern hemisphere. In fact, the TIO is not obvious without temporal filtering of the data. Its discovery, after all, is relatively recent in the history of tropical meteorology. In unfiltered data the TIO is obscured by convection on shorter spatial and temporal scales. Figure 1 displays a 10-year record of near-equatorial daily OLR for 1980–1989 (low OLR only), on which our remaining discussion is based. Considerable evidence of eastward propagating convection is seen at all longitudes, but this activity occurs on timescales much shorter than intraseasonal. As will be shown later, the phase speed of high-frequency activity is distinct from that of the TIO. That zonal propagation of convection resolved by daily OLR is mainly eastward near the equator contrasts sharply with off-equatorial convergence zones, where propagation of synoptic-scale convection is westward owing to tropical depression disturbances and Rossby-gravity waves [Lau and Lau, 1990, 1992; Hendon and Liebmann, 1991; Takayabu and Nitta, 1993; Dunkerton and Baldwin, 1994].

Upon closer examination, broad clumps of enhanced convection appear in Figure 1, such as around April 1980, April 1982, and January 1988, also propagating eastward but at a slower rate than the high-frequency activity. With appropriate time filtering, these events prove to be quite common but are somewhat variable from year to year. They correspond to the convectively active phase of the TIO.

The TIO’s convection does not consist of a single huge cloud cluster. Instead, several smaller clusters are embedded within the convectively active phase of the TIO [Nakazawa, 1988]. On the synoptic scale, many of these equatorial clusters propagate eastward at a rate similar to that of propagating clusters during the inactive phase of TIO. The term “supercluster” (or supercloud cluster) has been applied to clusters having horizontal scales of 2000–4000 km and timescales, broadly speaking, of the order of ~2–15 days [Hayashi and Sumi, 1986; Nakazawa, 1988; Lau et al., 1991; Sui and Lau, 1992]. Superclusters are thought to be networks of mesoscale convective complexes that are so gregarious as to become spatially and temporally interconnected [Mayes and Huse, 1993]. They are one of perhaps several forms of synoptic-scale cloud organization in the tropics. Analogous to the TIO, synoptic-scale activity forms a spatial-temporal envelope for rapidly evolving mesoscale cloud clusters, many of which propagate westward [Nakazawa, 1988;]
Figure 1. Near-equatorial outgoing longwave radiation (OLR) (2.5°S–2.5°N) for 1980–1989, showing low OLR only. Contours are 120, 160, and 200 W m⁻².

Lau et al., 1991; Hendon and Liebmann, 1994]. The daily OLR obtained from polar orbiting satellites cannot resolve the inner scale of synoptic activity, as the cloud imagery can, but is apparently adequate for the envelope of mesoscale convection. According to Figure 1, the synoptic-scale organization of equatorial convection is at least as important as that of the TIO.

In this paper we examine further the morphology of castward propagating synoptic-scale convection near the equator and its relation to the TIO, extending the earlier discussions by Nakazawa [1986a, b]. In the first paper, Nakazawa examined OLR in the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE) year (1979), investigating the role of short-period fluctuations within intraseasonal oscillations. In the second paper he used eight years of OLR
data (1975–1983 excluding 1978), documenting the behavior of low- and high-frequency convection without discussing in detail the morphology of these disturbances and their relationship. Our analysis extends these studies using 10 years of OLR data beginning in 1980. We show Hovmöller diagrams of OLR data reconstructed from the respective frequency bands (corresponding to periods of \( \approx 30-60 \) and \( \approx 2-15 \) days) to elucidate their episodic behavior and relationship in physical space. By examining eastward and westward propagating components of daily OLR separately, a spectrum of phase speeds is obtained for synoptic-scale convection events during this time period. For eastward propagating disturbances, the spectrum is sharply peaked at 10–15 m s\(^{-1}\).

2. Data Analysis

We used daily OLR data for 1980–1989 on a 2.5° × 2.5° latitude-longitude grid. To focus clearly on the latitudes of eastward propagating convection and to avoid regions of westward propagating activity in off-equatorial convergence zones, OLR data were averaged from 2.5°S to 2.5°N. Discussion is therefore limited to the zonal component of propagation along the equator, although it is recognized from Madden and Julian [1994] that a meridional component of propagation is sometimes observed. For OLR spectra (but not Hovmöller diagrams), the annual cycle was removed by calculating the mean and first three harmonics of the 10-year average annual cycle and subtracting them from the total field. Statistical significance of peaks was assessed by computing red noise spectra from the data following Gilman et al. [1963] and considering the signal-to-noise background power ratio as a chi-square random variable with 2M degrees of freedom, where M is the number of points in the periodogram smoother. Two temporal filters were designed to separate low- and high-frequency variability associated with TIO and synoptic scales, respectively.

On the high-frequency end, spectra of daily OLR are limited to periods greater than 2 days. There is no meteorologically significant reason to exclude the shorter periods characteristic of mesoscale convection, but only the envelope of mesoscale activity is described by daily OLR. For our purpose, high-frequency OLR” here refers to disturbances in daily OLR obtained from polar-orbiting satellites, with a minimum resolvable period of 2 days.

3. Results

3.1. OLR Spectra

Average spectra of near-equatorial OLR in longitude sectors representing the Indian and western Pacific Oceans are shown in Figures 2a and 2b, respectively. The combined spectrum of both regions, including the maritime continent lying in between, is shown in Figure 2c. The OLR spectra are generally featureless except for a TIO peak near 40 days, a dip in the spectrum near 15 days, and broad power extending down to at least 3 days. The TIO is relatively more important over the Indian Ocean. This region has a shallow minimum near 15 days and broad ledge of power from 3 to 15 days. Over the western Pacific the TIO peak is again evident but weaker. A minimum near 15 days is not seen except with respect to the red noise curves. It is unclear where to divide the western Pacific spectrum, but this is not crucial to our analysis. Several sharp peaks emerge at 5–10 days. Spectra at individual longitudes have peaks like these extending above the red noise curves, similar over a narrow band of longitudes (≈15°). Some of these peaks may represent important phenomena at particular longitudes, but this is unclear. Rather than trying to explain individual peaks below 15 days, we incorporate them simultaneously into a broad high-frequency band.

On the basis of average spectra shown in Figure 2, temporal filters were used to separate intraseasonal variability from convective activity on ~2- to 15-day timescales. A band-pass filter was designed to capture intraseasonal variance with half-power points at 30 and 60 days. High-frequency variations were obtained from a high-pass filter with half-power point at 15 days. There was essentially no overlap in the response of the two filters.

3.2. Filtered Data

Figure 3 shows a Hovmöller diagram of ~30- to 60-day band-passed anomalies. Eastward propagating anomalies are now obvious (unlike in Figure 1), mainly over the Indian and western Pacific Oceans, with phase speeds of 3–7 m s\(^{-1}\). A typical plume speed is 360° per 90 days (≈5 m s\(^{-1}\)), which would correspond to a wavenumber 2 disturbance if the con-
Figure 3. Near-equatorial anomalously low OLR in the tropical intraseasonal oscillation (TIO) frequency band (~30–60 days). Contour interval is 10 W m$^{-2}$, beginning at 10 W m$^{-2}$.

Convection anomaly were to propagate all the way around the equator. The zonal width of coherent negative anomalies, indicative of the convectively active regions, is typically 40°–50°. Zonal extent of the active phase is smaller than what one might infer from a space-time spectrum of OLR, which is dominated by planetary wavenumbers. The distance traversed by the active region in a lifecycle is larger, typically 60°–150°. Amplitudes weaken over the maritime continent, but stronger TIOs seem coherent between the two ocean basins. Such events reappear in the western Pacific soon after their apparent termination in the eastern Indian Ocean.

TIO events are more prominent over the Indian Ocean, as suggested by the spectra. Their eastward propagation is apparent within this region, more so than in the western Pacific.
Events in the western Pacific sometimes propagate eastward with equal clarity but often appear as a “blob” following an event in the Indian Ocean (e.g., the sequence in 1989). On a few occasions, westward propagation is observed. The timing of events in the western Pacific Ocean opposes the idea of a seesaw of convection between the Indian and western Pacific Oceans, because events in the western Pacific occur prior to the minimum of activity in the Indian Ocean. Intrasessional variability of OLR is best interpreted in terms of coherent propagation from one ocean basin to the other, with amplitude temporarily diminished over the maritime continent.

There is large annual and interannual variation of the TIO. Anomalies are often strongest and most coherently propagating during the northern winter and spring, but weaker and/or less coherently propagating in the summer and fall. This is not true in every year; the annual variability is complex, as described by Madden [1986]. Results of Hondon and Liebmann [1994] suggest opposite seasonal variations of the TIO in convergence zones north and south of the equator [see Madden and Julian, 1994, and references therein]. Effects of the 1982–1993 and 1986–1987 ENSO events are apparent as an eastward shift of TIO convection closer to, but not east of, the dateline. As discussed in section 3.4, TIO events east of the dateline in early 1983 may be defined in terms of the ~30- to 60-day amplitude envelope of high-frequency convection, rather than of the ~30- to 60-day convection itself.

High frequency (~2 to 15 day) anomalies are shown in Figure 4. Eastward propagating features over the Indian and western Pacific Oceans are obvious throughout the record, along with less frequent episodes of westward propagation (e.g., mid-1983). Eastward phase speeds are ~10–13 m s⁻¹, faster than those of the TIO. Because of their faster propagation, only a few high-frequency events extend through an entire life cycle of the TIO. More commonly, an event in one phase of the TIO over the Indian Ocean terminates and is replaced by a new event in the western Pacific when the TIO arrives there. The zonal width of coherent negative anomalies is 15°–40°, considerably less than the distance traversed in a typical sequence of events (40°–150°). A similar amplitude gap is apparent over the maritime continent with coherent propagation on either side. Eastward propagating synoptic-scale clusters are occasionally seen over the equatorial Atlantic Ocean and Africa, where the convective TIO is relatively weak or absent.

As in the TIO band, annual variability of high-frequency convection is complex. More coherent behavior is suggested in the first half of the calendar year (March–July, in most of the years), but exceptions are found (as in October 1987). Interannual variability is strongly influenced by the two FNSO events during which anomalies have significant amplitude and coherent propagation east of the dateline.

By “coherent propagation” of high-frequency activity we are referring to the tendency eastward propagating negative OLR anomalies to occur in close alignment along a line x = const, where the phase speed c at the equator has a positive bias for synoptic-scale convection. These events are seldom defined by a single continuous cluster, since on closer inspection, propagating clusters are usually broken into segments along such a line. The daily OLR data, in any case, do not resolve fine structure such as mesoscale convective complexes and individual clouds. A simple mathematical transform introduced in the next subsection easily identifies coherently propagating groups of synoptic-scale cloud clusters.

The predominance of eastward over westward convection was clearly seen in the space-time spectrum of near-equatorial OLR (not shown). Activity in the TIO frequency band comprises mainly low zonal wavenumbers 1–6, while the high-frequency band contains significant power at wavenumbers 2–10, centered in a range of phase speeds 10–22 m s⁻¹. It is important to note that for near-equatorial OLR, eastward propagating activity is much larger than westward propagating activity, not only in the TIO band but at higher frequencies as well, consistent with the fine structure displayed in Figures 1 and 4. This statement does not apply to mesoscale convection unresolved by daily OLR, for which westward propagation is considerably more important.

3.3. Equatorial Convection Events

To investigate the episodic nature of high-frequency convection events, a simple transform was applied to the ~2- to 15 day near equatorial OLR:

\[ F(x, t, c) = \int_{t-\Delta t}^{t+\Delta t} f(x - ct', t') dt' \]

where \( \Delta t = \Delta x/c \) and \( \Delta x \) is the half width of a longitude sector. For the two ocean basins of interest, we set \( x = 90^\circ \text{E} \) or \( 150^\circ \text{E} \), and \( \Delta x = 30^\circ \). This transform was actually applied to a subset of OLR data reconstructed from the eastward (or westward) propagating components of the space-time spectrum with periods below 15 days. Isolation of the eastward component is justifiable because of its dominance over the westward component and from our observation (based on the space-time spectrum) that the standing component of near-equatorial OLR is small. Over the oceans the eastward and westward components of OLR correspond mainly to propagating events, rather than standing oscillations of convection. This is not to deny the existence of standing oscillations over land or local flare-ups of convection that inevitably occur at various times and places. Westward events can be found in Figure 1 but are relatively small, and large events are rare.

Figures 5a, 5b, and 5c show the raw OLR data (low OLR only), ~2- to 15 day filtered data, and eastward ~2- to 15 day data, respectively, for a 90-day segment early in the record. Westward ~2- to 15 day data for the same time period are shown in Figure 5d. Superimposed are the active phases of ~30- to 60-day TIO signal (shading) and dominant phase speeds for individual high-frequency events (thick sloping lines). These events were defined in the convectively active period by searching for periods of large negative OLR anomaly along a line \( x - ct = \text{const} \); a dominant phase speed \( c \) was then selected from within the range \( \pm 1-50 \text{ m s}^{-1} \). There were a few cases where multiple phase speeds occurred simultaneously; for simplicity, only one value of \( c \) from each 3 day interval was retained in the analysis. After exploring various thresholds, a minimum value of 300 W m⁻² was selected for the integrated amplitude of each event, corresponding to an average grid point OLR anomaly of ~12 W m⁻². This threshold captured most of the propagating events visible in the data but was large enough to avoid random alignments of insignificant clusters.

The phase speed transform provides a useful phenomenological description of the propagation of high-frequency clusters, including events lying off center to one side or the other of 90°E or 150°E. As seen in Figure 5b, there is considerable variation of OLR along the cluster track, much of which is
Figure 4. As in Figure 3, but for ~2 to 15 day negative anomalies with TIO events of Figure 3 superimposed (shaded regions). Contour interval is as in Figure 3.

eliminated when plotting eastward data (Figure 5c). Propagating clusters are usually large enough to be visible in the raw data (Figure 5a) but are obscured by TIO events and climatological convection.

The time period chosen for display in Figure 5 contains an interesting variety of behavior, including a well-defined TIO event with weak high-frequency events (first half) and a weak TIO with strong and unusually coherent eastward high-frequency events (second half). Many events satisfied our minimum amplitude criterion: Altogether, the 10-year OLR record gave 324 eastward events in the Indian Ocean and 312 eastward events in the western Pacific Ocean, of which only about 49 could be described as reasonably coherent between the two oceans. Thus the majority of high-frequency events did
not span an entire region, nor did they cross the maritime 
continent. Westward events were slightly less numerous and 
generally much smaller.

The cumulative amplitude of OLR events as a function of 
phase speed is shown in Figures 6a and 6b for the Indian and 
western Pacific Oceans, respectively. Strictly speaking, this is a 
spectrum of finite amplitude events (with unique phase speed 
assigned to each event), not a spectrum of phase speeds ob-
tained from the continuous space-time spectrum, although the 
two would agree qualitatively since most of the high-frequency 
OLR power lay in the range 10–22 m s\(^{-1}\) as noted earlier. The 
eastward component in Figure 6 has a much larger amplitude, 
particularly over the Indian Ocean, with most events in the 
range 5–20 m s\(^{-1}\) and a sharp peak at 10–13 m s\(^{-1}\). Evidently, 
the phase speed transform is biased toward the low end of 
dominant phase speeds suggested by the space-time spectrum. 
The westward component maximizes at a smaller absolute 
speed of about \(\sim 8\) m s\(^{-1}\). The shaded area of the histogram 
refers to the active phase of the TIO, as discussed in the next 
subsection. The minimum phase speed resolved by high-
frequency OLR is that corresponding to a wavelength of $5^\circ$–$30^\circ$ and a period of 15 days, or 0.4–2.4 m s$^{-1}$, well below the observed falloff of amplitude in Figure 6.

The seasonal variation in each basin is shown in Figure 7 for eastward and westward events; the dominance of eastward over westward propagation is again seen. High-frequency activity is largest in northern spring-summer, with a hint of semi-annual variation (from western Pacific). Interestingly, this season contains the majority of easterly and westerly quasi-biennial oscillation (QBO) phase onsets in the equatorial lower stratosphere [Dunkerton, 1990]. Also, Maruyama [1991] found enhanced 70-ubau Kelvin-wave activity in northern hemisphere spring. Kelvin waves in the lower stratosphere are responsible, in part, for the westerly acceleration phase of the QBO. These waves are thought to have planetary scales and phase speeds of 20–30 m s$^{-1}$ [Wallace and Kousky, 1968], longer and faster than the synoptic-scale convective activity described here. Whether stratospheric Kelvin waves originate in these eastward propagating equatorial convection events is unclear. The two could not remain in phase for very long because of the mismatch in propagation speed. Nonnegligible power exists in equatorial OLR, however, at wavenumbers and frequencies characteristic of Kelvin waves in the stratosphere.

Gravity waves excited within the envelope of convective activity may also transmit the seasonal variation of equatorial convection to the stratospheric QBO. Although such waves would have a wide range of positive and negative phase speeds, selective filtering in descending QBO shear zones would produce a net body force and help account for the required QBO acceleration [Pfister et al., 1993]. The level of gravity-wave activity relevant to the QBO would of course be determined by convection at all longitudes, in addition to events comprising Figure 7. We observe from Figure 1 that equatorial convection in the western hemisphere also maximizes around northern spring equinox [Mitchell and Wallace, 1992].

3.4. Relation to the TIO

The relation between high-frequency (~2- to 15-day) anomalies and (~30- to 60-day) TIOs is now examined to determine if strong high-frequency events cluster during periods of strong low-frequency activity. There is no mathematical reason why this need be so. If different parts of the frequency spectrum are noninteracting, episodes of high- and low-frequency convection would be uncorrelated. To address this question, two methods were employed.

First, each high-frequency event defined in the preceding subsection was split into active and inactive TIO categories by summing amplitudes in the two phases of TIO separately. This was done by integrating along the line of dominant phase speed in each high-frequency event. Such a line would generally intersect regions of positive and negative TIO anomaly. The assignment of negative and positive ~30- to 60-day OLR anomalies to the active and inactive phases, respectively, of TIO is arbitrary, but each has a roughly equal probability of occurrence in the time series at any grid point. From Figure 4 it seems that no obvious relation exists between the high-frequency events and TIO anomalies, and Figure 5 provides a good example of noninteraction. However, a hint of scale interaction is evident when the entire data are examined. The shaded region of Figure 6 corresponds to the convectively active phase of the TIO, which explains ~60% of the eastward event amplitudes. This would imply enhancement of eastward

![Figure 6](image-url)  
**Figure 6.** Histogram of event amplitudes (integrated over longitude, in units of watts per square meter; see text for explanation) as a function of dominant phase speed $c$ (in meters per second) for (a) Indian Ocean and (b) western Pacific Ocean. Shading refers to active phase of the TIO.

![Figure 7](image-url)  
**Figure 7.** Histogram of event amplitudes as a function of month for eastward (solid) and westward (dashed) events.
high-frequency events by no more than 50% in the active phase of TIO, a result comparable to that inferred by Hendon and Liebmann [1994] for synoptic-scale convection during “windowed” time series corresponding to the most significant episodes of the TIO. Some of our best events fall outside the active phase of the ~30- to 60-day TIO, so this result is not surprising.

Second, the ~30- to 60-day envelope of ~2- to 15-day OLR variance was calculated by applying the TIO band-pass filter to the absolute value of high-frequency activity. Results of this calculation were quite noisy, but demonstrated on many occasions a good correspondence between the envelope of high-frequency and band-passed TIO. A nonzero correlation must exist, if for no other reason than that inactive periods of TIO are sometimes devoid of convection, so that high- and low-frequency activity are both suppressed. However, we also observe a slight enhancement of high-frequency activity during the active phase of TIO.

An intriguing observation is that the ~30- to 60-day envelope of high-frequency activity sometimes suggests eastward group propagation at a speed equal to that of the TIO itself, even though the “linear TIO” (defined by the ~30- to 60-day component of convection) is entirely absent, as in the eastern Pacific during early 1983. There is evidently some process that causes eastward group propagation of high-frequency activity that does not require a ~30- to 60-day OLR signal to exist.

On the other hand, the ~30- to 60-day OLR signal does not require high-frequency activity on synoptic scales as resolved by daily OLR (Figure 4). It is therefore unnecessary to suppose that synoptic-scale activity or superclusters are essential to the TIO. The role of superclusters in the cloud hierarchy suggested by Nakazawa [1988], while relevant in some TIO events, is not relevant to all, nor is the eastward propagation of synoptic-scale activity confined to the active phase of the TIO.

4. Conclusions

Anomalies of outgoing longwave radiation (OLR) in 1980–1989 were examined in a narrow latitude band about the equator to elucidate the propagation and interaction of tropical intraseasonal oscillations (TIOs) and synoptic-scale convective activity. The latter includes superclusters, which were previously thought to play an important role in the TIO.

Hovmöller diagrams of OLR data reconstructed from two frequency bands (corresponding to periods of ~30–60 and ~2–15 days, respectively) revealed a clear distinction between the phase speed of eastward moving TIOs (3.7 m s\(^{-1}\)) and that of eastward synoptic-scale convection (10–13 m s\(^{-1}\)). Coherent propagation of TIOs from the Indian to the western Pacific Oceans was often observed with diminution of amplitude over the maritime continent, presumably owing to the strong diurnal cycle there [Hendon and Woodberry, 1993]. Propagation of high-frequency anomalies was generally confined to an individual basin, although coherent anomalies were sometimes found to propagate through both regions. Dominance of eastward propagating synoptic-scale convection in the equatorial zone contrasts sharply with the westward propagation of synoptic-scale convection in off-equatorial convergence zones.

Interaction between the TIO and high-frequency activity resolved by daily OLR was visible as a modest enhancement of eastward synoptic-scale events (and of high-frequency activity in general) during the convectively active phase of the TIO. This effect did not occur in every TIO event, and many eastward propagating synoptic-scale events were seen during the inactive phase of the TIO. It is therefore unnecessary to regard the synoptic activity or superclusters as essential to, or uniquely associated with, the convectively active phase of the TIO. Nevertheless, modulation of convection on shorter spatial and temporal scales is an important and perhaps essential feature of the tropical intraseasonal oscillation. Cloud imagery shows that mesoscale activity is strongly enhanced in the active phase of the TIO [Hendon and Liebmann, 1994]. The mechanism is unknown but presumably involves the large-scale circulation associated with the TIO.

Given the prominence of synoptic-scale and mesoscale activity in equatorial convection, what is important to the TIO’s large-scale circulation is not the enhancement of a large contiguous region of convection in the active phase, but the ~30- to 60-day enhancement of high-frequency convective activity on shorter spatial and temporal scales. Either scenario leads to enhanced precipitation and latent heat release when averaged over the active phase of the TIO, because there are no “negative clouds.” Although clear-sky conditions exist here and there within the envelope of convection, the net heating remains when averaged over the active phase of a TIO event. Detailed observations of convection highlight the importance of the second mechanism. A potential feedback therefore exists between the large-scale circulation induced by the envelope of synoptic-scale and mesoscale convection, and the effect of this circulation on the development of convective elements making up the envelope.

This survey of equatorial OLR invites further study using cloud imagery in order to elucidate the propagation and interaction of equatorial convection at various spatial and temporal scales. An example described by Hendon and Liebmann [1994, Figure 9] provides a striking illustration of scale interaction involving the TIO and mesoscale convection. It would be interesting to explore these interactions with a longer record and also to consider in more detail the role of synoptic-scale cloud organization, particularly during times of strong, coherent eastward propagation. Further examination of these events in conjunction with circulation data may shed light on the mechanisms of Kelvin wave excitation in the troposphere, the seasonal variation of these waves, and the effects on the stratospheric QBO.
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