NOTE AND CORRESPONDENCE

An Attempt at Obtaining the Local Structure of the
Tropical Intraseasonal Oscillation

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The tropical intraseasonal oscillation was found by Madden and Julian (1971) by analyzing observed data. Their interpretation was that the oscillation consisted of a pair of convection cells having a planetary scale in the zonal direction (a planetary-scale Walker cell) that propagates eastward over the Indian Ocean through the central Pacific Ocean (Madden and Julian, 1972). The existence of eastward-moving convective disturbances over this area was confirmed by making use of outgoing longwave radiation (OLR) data (e.g., see Lau and Chan, 1985; Murakami *et al.*, 1986; Nakazawa, 1986). The eastward-moving speed of the convective disturbances associated with the intraseasonal oscillations is about $4\sim 6\text{ms}^{-1}$ (Murakami *et al.*, 1984; Lau and Chan, 1985; Knutson *et al.*, 1986). After moving east of the dateline, the convective disturbance begins to decay rapidly, and another eastward-moving convective disturbance can be observed in the Indian Ocean. These phenomena of eastward-moving convective disturbances do not appear as oscillatory motions, but each phenomenon seems independent of the other, as like a pulsation with a repeating period of about 40 days.

In order to study the intraseasonal oscillation, band-pass time filters have been conventionally used, and the global distributions and the phase propagations of the oscillation have been revealed (e.g., Krishnamurti *et al.*, 1985; Hayashi and Golder, 1986). However, it is not appro-

priate to analyze the time evolution of such filtered data in order to study the local structure of the oscillation. Consider, for example, the extreme case in which a localized convective heating having a δ -function form in the zonal direction, propagates zonally around the earth with a 40 day period, keeping its magnitude constant. In this case, the heating consists of all zonal wavenumber components with each component having an equal magnitude. The atmospheric response to this localized moving heat source may also consist of many wavenumbers. Needless to say, the lower wavenumber response may be greater than that of the higher one, due to a selective response of the atmosphere. However, the higher wavenumber response is indispensable for forming the entire response to the heating. If this response is subjected to a 20-60 day band-pass time filter, only the zonal wavenumber 1 and 2 components will be retained. All other wavenumber components are filtered out since, in this case, the higher wavenumber components have periods shorter than 20 days.

This extreme example shows that the band-pass filtered data contain only the global response of the atmosphere to a localized moving heat source, and they lose the higher wavenumber part of the response that moves with the heating. Although these higher wavenumber components have periods shorter than 40 days, they are relevant to the local structure of the disturbance with an intraseasonal time scale. Recently, Yamagata and Hayashi (1984) and Hayashi and

Miyahara (1987) showed that the localized heating which includes the higher wavenumber components is important to simulate the intraseasonal oscillation, as well as the globally traveling lower wavenumber components.

This suggests that it is appropriate to analyze the time evolution of the local structure of the intraseasonal oscillation moving with the convective disturbance by using a filter that is locked to the moving speed of the phenomena rather than using a filter locked to its frequency. This kind of filter has been used by Hayashi and Sumi (1986) to analyze the structure of the 30-40 day oscillation simulated by a general circulation model.

In the real atmosphere, no uniform eastward-moving global disturbance is observed. However, there is a considerable regular eastward propagation of the OLR pattern over the Indian Ocean through the central Pacific Ocean (e.g., see Lau and Chan, 1985). On the basis of the above mentioned idea, the present note will try to obtain the local structure of eastward-moving disturbances with speeds of about 5ms^{-1} that are relevant to intraseasonal oscillations over the Indian Ocean through the central Pacific Ocean, using the FGGEIIIb analysis processed at the GFDL.

It has been shown by Krishnamurti *et al.* (1985) that the oscillation was relatively active during the period from April 1979 through August 1979 of the FGGE year (Fig. 4). Therefore, the data from 1 April through 4 July 1979 were used for the present analysis*.

The method used in the present analysis to obtain the structure of the eastward-moving disturbance can be described as follows. The FGGEIIIb data set has twice-daily data (00Z and 12Z) at every 1.875° longitudinal and latitudinal grid point at each pressure level. Data along a latitude circle around the equator at a pressure level is denoted by

$$a(\lambda, t) = a(m\Delta\lambda, t_k + n\Delta t), \quad (1)$$

$$m=0, 1, 2, 3, \dots, 191$$

$$n=0, 1, 2, 3, \dots$$

where $\Delta\lambda$ and Δt denote the longitudinal grid size and the time interval of the data, respectively. The time t_k denotes 00Z of a selected or "key" day of the analysis. Taking a time mean defined by

$$\begin{aligned} \bar{a}(m\Delta\lambda, t_k) \\ = 1/2N \sum_{n=0}^{2N-1} a((m+n)\Delta\lambda, t_k + n\Delta t), \end{aligned} \quad (2)$$

will result in a selectively obtained N -day mean structure of eastward-moving disturbances whose speeds are mainly distributed around a prescribed mean according to the given $\Delta\lambda$ and Δt . In other words, $\bar{a}$ is an N -day mean projection of the moving disturbance over the longitudes of $m\Delta\lambda$ at the key day t_k . The $\Delta\lambda$ and Δt are chosen as 1.875° and 12hrs, respectively. This results in a central phase speed for the filter of about 5ms^{-1} *. In this study the key days are chosen every 10th day ($N=10$) or every 5th day ($N=5$) as the case may be, so that a 10-day or 5-day mean structure of the eastward-moving disturbance can be obtained for every key day. From the obtained time series of the 10-day or 5-day mean structure, a time evolution of the structure of eastward-moving disturbances ($\approx 5\text{ms}^{-1}$) relevant to the intraseasonal oscillation over the Indian Ocean through the central Pacific Ocean, can be traced.

First, the time mean behavior of the zonal wind over the equatorial region is investigated. The longitude-height distribution of the zonal wind (averaged over 10°N - 10°S , with the zonal mean removed) averaged over the period from 1 April through 28 June 1979 is shown in Fig. 1. The existence of the Pacific Walker circulation is

*The data during the period from 6 May through 9 May are defective in the FGGEIIIb data set used in this study, therefore the data for this period was not used.

*As pointed out by Murakami *et al.* (1986), the intraseasonal oscillation has a wide range of propagation speed even over the Indian Ocean through the central Pacific Ocean. In the present study, the analysis is applied for the period when the eastward propagation with a phase speed of about 5ms^{-1} is clearly seen.

Fig. 1. Longitude-height distribution of the zonal wind (averaged over 10°N - 10°S , with the zonal mean removed) averaged over the period from 1 April through 28 June 1979. Intervals are 4ms^{-1} and shaded areas show negative values (easterly). The longitudes are labeled as 0° through 360° .

clearly seen, over the west Pacific Ocean with a secondary circulation centered near the South American Continent. These distributions are very close to the results of other analyses (e.g., see Newell *et al.*, 1974).

Fig. 2 shows the longitude-time diagram of the 5-day running mean zonal wind at the 250mb level (averaged over 10°N - 10°S , with the zonal

mean removed). The existence of the eastward-moving ($\approx 5\text{ms}^{-1}$) pair of easterly and westerly winds confined over the Indian Ocean through the Pacific Ocean can be clearly seen in this period, as well as weaker and faster-moving components along with westward-moving components.

Next, the time evolution of the eastward-

Fig. 2. Longitude-time diagram of the 5-day running mean zonal wind at the 250mb level (averaged over 10°N - 10°S , with the zonal mean removed) during the period from 3 April through 2 July. Dark shaded areas show westerlies greater than 5ms^{-1} , and light shaded areas show easterlies greater than -5ms^{-1} .

moving disturbances over the Indian Ocean through the Pacific Ocean, seen in Fig. 2, is studied, using the filter that is locked to an eastward speed of about 5ms^{-1} defined by Eq. 2. Figures 3a-i show the 10-day mean longitude-height distributions of the zonal wind (averaged over 10°N - 10°S , with the zonal mean removed) projected over the longitudes of $m\Delta\lambda$ at each key day (every 10th day). The data in Fig. 3 are labeled with the key (1 Apr., 11 Apr., etc.) but actually represent an average for the period (1 Apr. – 10 Apr., 11 Apr. – 20 Apr., etc.).

In Fig. 3, for 1 April, a very prominent Pacific Walker cell centered around 160° is seen. On 11 April (Fig. 3b) the Walker cell is still clearly seen, however the location of the cell has moved eastward. The eastward-moving speed, estimated from the position of the center of the eastern cell is about 7ms^{-1} . The movement of the western cell is not as clear, but in the lower stratosphere some eastward movement can be detected. During this period, another Walker cell centered over the South American Continent also becomes prominent. On 21 April (Fig. 3c), the Pacific and South American Walker cells are not as strong as in the previous period. The position of the Pacific Walker cell shifted to that of 1 April.

In the period from 1 May through 10 May (Figs. 3d and 3e), the location of the Pacific Walker cell is almost fixed (slight eastward movement), but its magnitude has become stronger. On 10 May, although the magnitude is somewhat stronger, the pattern of the cell is similar to that of 1 April.

In the next period (from 20 May through 9 June), similar distributions to those of April appear. On 19 June, a very similar distribution to that of 1 April and 10 May appears. As shown by Fig. 3, the time evolution of the Walker cell moves eastward with a period of about 40 days. However, its movement is almost completely confined to the Indian Ocean through the Pacific Ocean.

In order to see the time evolution of the disturbance more precisely, composite distributions of the zonal wind averaged over 5 days (key days are chosen every 5th day) and averaged over two periods which have a similar distribution, such as (1 April + 10 May)/2, (6 April + 15

May)/2 etc. are shown in Figs. 4a-h. In these figures, the above-mentioned time evolution of the Walker cell can be seen clearly; the eastward-moving phase (Figs. 4a-4c), the decaying phase (Figs. 4d-4e) and the reconstruction phase (Figs. 4f-4h), all having the intraseasonal time scale.

This time evolution of the eastward-moving Walker cell is consistent with the behavior of the OLR with the intraseasonal time scale mentioned earlier. It is also consistent with the interpretation of the intraseasonal oscillation by Madden and Julian (1972). The spatial structure of the cell is similar to that obtained by numerical studies of the intraseasonal oscillation (Hayashi and Sumi, 1986; Lau and Peng, 1987; Miyahara, 1987). However, the westward tilt of the zero wind line with altitude in the lower troposphere, which is commonly seen in numerical results, is not very clear in the present study. It should be noted that in the stratosphere (above the 100mb level) another Walker cell that flows inversely to that of the lower cell is seen. This structure is also found in Hayashi and Sumi's result (Fig. 6), although their simulation shows two cells between the 100mb and 10mb levels.

It should be also noted that the Walker cell structure obtained in the present analysis is confined within the longitudinally smaller region than that obtained by applying a 40-50 day time filter to the same FGGE data (Hayashi and Golder, personal communication). According to their analysis, the zonal wind oscillation at 200 mb has its maxima at about 120°W and 75°E . The similar broadening due to the time filtering is also seen in a numerical result by Miyahara (1987, see Fig. 3 and Fig. 5).

In the present note, attention was focused on the time evolution of the local structure of the eastward-moving disturbance with an intraseasonal time scale in the Indian Ocean through the Pacific Ocean. Thus, the eastward-moving speed of the disturbance was assumed to be constant, and the center of the response of the filter was chosen as 5ms^{-1} . However, it is known that the propagation in regions other than this is faster (e.g., Knutson *et al.*, 1986, also, see Fig. 2). Moreover, a north/south propagating disturbance with an intraseasonal time scale has been reported (e.g., Yasunari, 1981; Krishnamurti *et*

Fig. 3. As in Fig. 1, except for the 10-day mean defined by Eq. 2 for every 10th key day. Fig. 3d shows the 5-day mean over 1 May through 5 May due to the lack of data from 6 May through 9 May.

Fig. 4. As in Fig. 1, except for the 5-day mean and the composite of distributions for two different key days whose interval is about 40 days. Fig. 4h shows the distribution only for the key day 14 June due to the lack of the data from 6 May through 9 May.

al., 1985).

These facts make it necessary to use both kinds of filters (a filter with a fixed propagation speed and a frequency locked filter) to analyze the local behavior of the intraseasonal oscillation. It depends on the property of the disturbance to be analyzed and/or the objective of the analysis

as to which kind of filter is suitable for use. However, if the objective is to obtain the local structure of the eastward-moving intraseasonal oscillation, as in the present case, a filter with a fixed propagation speed should be used instead of the conventionally used frequency locked filter. Otherwise, higher zonal wavenumber

components will be lost when analyzing the data.

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季節内振動の局所的構造を求める試み

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