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Coupling of Bay of Bengal Tropical Cyclones with the Myanmar Monsoon Onset

Boniface Opoku Fosu, and Shih-Yu Wang

Department of Plants, Soils, and Climate, Utah State University, Logan, UT

1. Introduction

The Madden-Julian Oscillation (MJO) greatly modulates the onset and intensity of the South Asian summer monsoon (*e.g.* Wu and Schubert 1999). The MJO also modifies the large-scale environment that leads to tropical cyclone (TC) development, such as those in the Bay of Bengal (BoB); (Kikuchi and Wang 2010). However, the extent to which the MJO affects monsoon onset and TC activity collectively and/or concurrently has not been analyzed. This study shows the extent to which certain MJO events provide favorable conditions for springtime (pre-monsoon) TCs in the BoB to occur concurrently with the monsoon onset in Myanmar.

Having only recently opened to the western world after years of civil unrest and political instability, Myanmar employs 65 percent of its active labor force in agriculture, an industry that is heavily reliant on monsoon rainfall. This country is also very vulnerable to TCs, such as Cyclone Nargis in May 2008 that killed about 126,000 people. The purpose of this study was to provide insight into predicting the Myanmar monsoon onset and to aid in disaster planning.

2. Data and methodology

The identification of yearly monsoon onset dates over Myanmar was focused on western and central Myanmar (16-23°N and 92-97°E). The APHRODITE gridded daily precipitation dataset (Yatagai *et al.* 2012) available on a 0.5° resolution was used from 1979-2010. In order to deal with the strong seasonal variability associated with the monsoon, we used the 5-days running mean of rainfall to define onset. The procedure is as follows: beginning April 1, the onset selection criterion was met on a day from which the accumulated rainfall of the preceding 14 days was less than the accumulated rainfall of the following 14 days. To ensure the difference between the two totals was substantial, as is expected for monsoon onsets, it had to be greater than a third of the total May precipitation (Fig 1). Using the selected onset dates, a composite rainfall evolution was constructed based on the relative day of onset in each year. The evolution starts with composites of rainfall sixty days prior to each onset, up until 40 days afterwards resulting in a 101-days composite of monsoon evolution. Day 0 is the composite onset, or May 20 on average.

Next, the European Centre for Medium Range Forecasts reanalysis dataset available on a 1.5° by 1.5° latitude and longitude grid (Dee *et al.* 2011), was used to derive 850-hPa streamfunction (ψ and velocity potential (χ).

Based on the 101-days evolution, two ψ fields were composited and averaged over longitude 80 -100°E: 1) total (shaded) and 2) 30-60 day band passed (contours, to depict the MJO signal). Furthermore, we made composites of χ using 30-60 days band passed fields. But unlike ψ, these composites were based on springtime cyclogenesis dates (*e.g.* Ventrice *et al.* 2011).

Lastly, empirical orthogonal functions (EOFs) of daily band passed VP fields were constructed from May 1 to June 30. The corresponding principal components (PCs) of the first two modes were used to construct phase-space diagrams. The PCs were normalized with their variances as a way to gauge the strength of the MJO at any time.

The tropical cyclone data was obtained from UNISYS (http://weather.unisys.com/hurricane/n_indian/index.php). Genesis day was defined when a disturbance was

Correspondence to: S.-Y. Simon Wang, Department of Plants, Soils, and Climate, Utah State University, Logan, Utah; E-mail: simon.wang@usu.edu.

first classified as a tropical depression in the North Indian Ocean (NIO). The tropical cyclogenesis days are plotted relative to the composite onset in Fig. 2, at the same latitude they occurred.

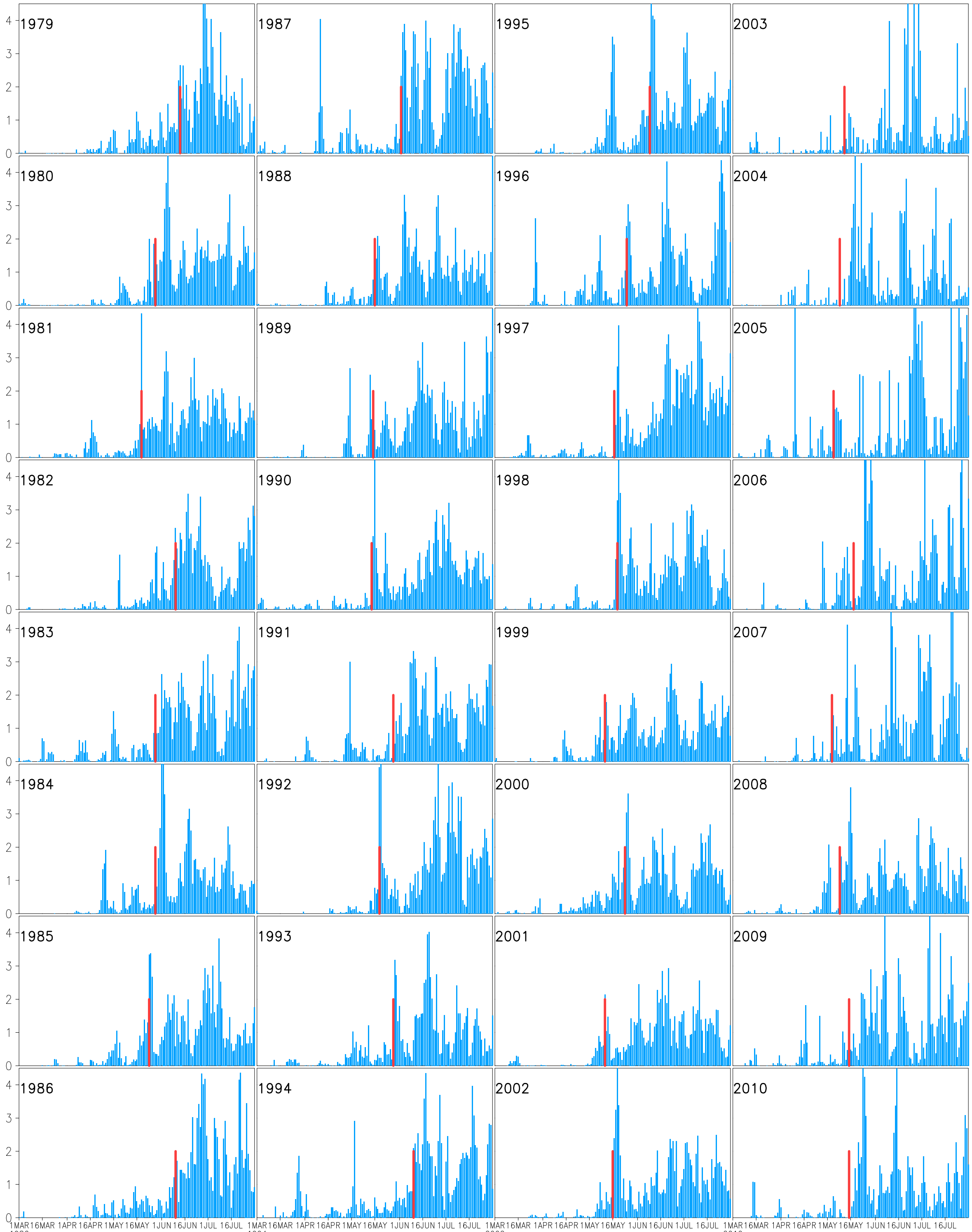

Fig. 1 Histograms of the mean daily 5-days running mean precipitation from March-July averaged over 16-23°N and 92-97°E (1979 to 2010). Each year is normalized with its corresponding mean May precipitation. The red lines show the onset dates.

3. Results and discussion

Fig. 2 shows the composite onset lies within the positive MJO phase. In the analysis, 26 out of the 32 onsets occurred during the positive phase of the MJO (not shown). This phase of the MJO enhances rising motion and acts to induce lower tropospheric convergence that leads to the intensification of the monsoon trough, as opposed to the dry phase, which suppresses rising motion. The monsoon is not a constant deluge of rainfall but it is characterized by regular breaks that have been associated with the negative phase of the MJO, otherwise known as monsoon breaks. Fig. 2 also shows the monsoon break occurs within the negative phase of the MJO. In addition, 11 of the 27 cyclogenesis cases are clustered around the composite onset, coinciding with the positive phase of the MJO. The large-scale positive circulation patterns of the MJO provide favorable conditions for tropical cyclogenesis, and also modulate the onset and breaks of the monsoon. It is now apparent that monsoon precipitation of western and central Myanmar is very sensitive to the phasing of the MJO with respect to the seasonal cycle. In general, the onsets (breaks) are associated with an increase (decrease) in cyclonic vorticity and a decrease (increase) in surface pressure over the central monsoon trough region, and a subsequent deepening (weakening) of the low level trough caused by the enhanced (suppressed) convection tendencies of the MJO positive (negative) phase.

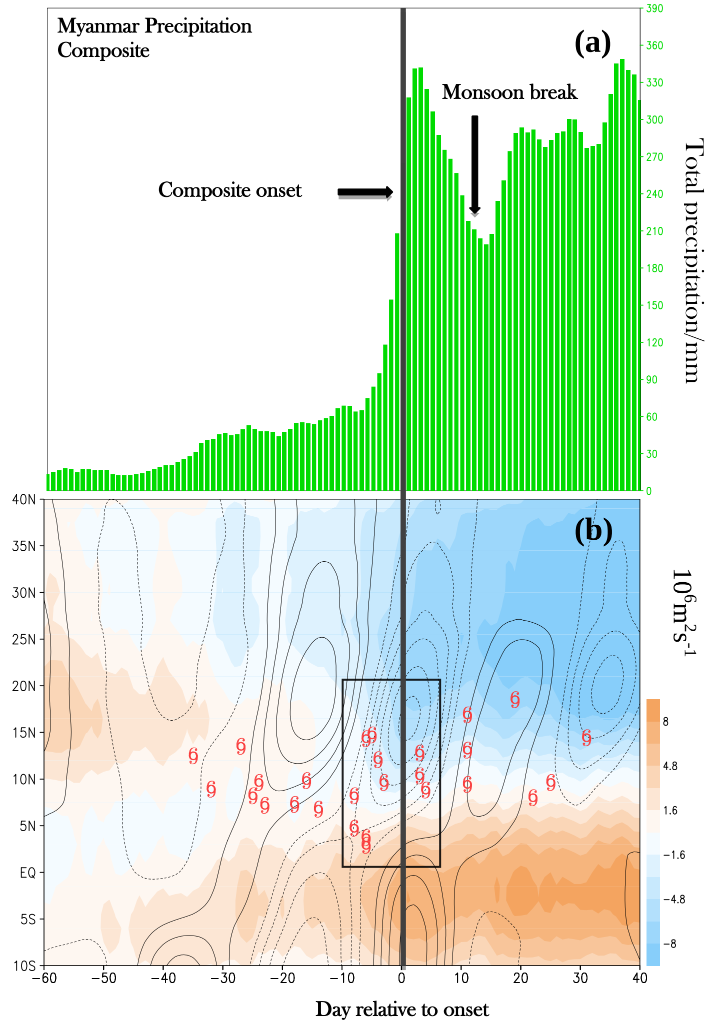

Fig. 2 (a) Evolution composite of rainfall accumulated averaged over western/central Myanmar (16-23°N and 92-97°E; 1979-2010. The composite onset day is May 20 (day 0, black line). (b) Evolution composite of 850-hPa total SF fields (raw data, shaded); superimposed with 30-60 days band passed streamfunction (SF, contours), averaged over longitude 80-100°E; and the locations of tropical cyclogenesis (red marks) relative to the onset from 1979-2010. The black box shows coupled onset-cyclogenesis events.

It is possible to see the relationship between TCs and the MJO in Fig. 2; however, the interpretation is different since those composites were made relative to the evolution composite of rainfall. By treating the TC genesis itself as part of a stochastic process that is driven by large-scale intraseasonal variability, and employing a composite χ method that averages all 27 TCs together as shown in Fig. 3, we are able to depict the synoptic convective and divergent variations associated with the eastward propagating MJO and bring out the large-scale environmental features favorable for TC formation in five-day increments.

The results so far illustrate how the MJO modulates the Myanmar monsoon onset and the majority of TC geneses in the BoB. But why did some TCs occur with the onset whiles others did not? In an attempt to explain this relationship, we analyze two groups of the EOF phase space diagrams and spatial plots: the coupled group comprises years where with TC and the Myanmar monsoon onset are coupled within 10 days of occurrence of one from the other. The other, which we will call the “decoupled group”, was the years having no observed coupling (Fig 4). Comparisons of the two groups reveal that the coupled group has well defined tracks of sequential days, which signifies a strong and systematic eastward propagation of the MJO. The second group shows the opposite for most years. We see weak MJO activity as rather random motions near the origin in most of those years. As we have already mentioned, since 1979, 11 out of the 27 monsoon onsets were coupled with TC genesis in the BoB within 10 days of formation, with at least 8 of them occurring earlier than the onset (Fig. 2b).

It appears when the tropical storm is formed (especially the stronger ones), the associated latent heating contributes to the intensification of the lower tropospheric westerlies. Together with the warm ocean waters in the NIO at this time, a low-level cyclonic circulation and an upper level anticyclone are formed, enhancing local cyclonic vorticity. As the positive phase of the MJO coincides with the emerging westerlies, the disturbances act to enhance local convection, westerly surface winds and low level cyclonic rotation that initiates the Myanmar monsoon onset. Thus the MJO helps the TC to form with the tendency of tracking eastwards toward Myanmar (Wang *et al.* 2013). The storm then releases substantial latent heating that concurrently, together with the MJO acts to intensify local convection and the emerging westerlies leading to the beginning of the onset over western and central Myanmar.

4. Concluding remarks

The work presented here suggests strong MJO events favor the coupling of spring TCs in the BoB with the Myanmar monsoon onset. It does so by modifying large-scale environmental features that favor TC geneses that subsequently initiate or intensify the monsoon onset over western and central Myanmar.

We have also showed that the large-scale circulation patterns of the MJO provide favorable conditions for tropical cyclogenesis, and in the meantime also modulate the onset of the Myanmar monsoon.

These results may provide guidance for seasonal and/or short-term prediction during the spring and early summer season in the BoB.

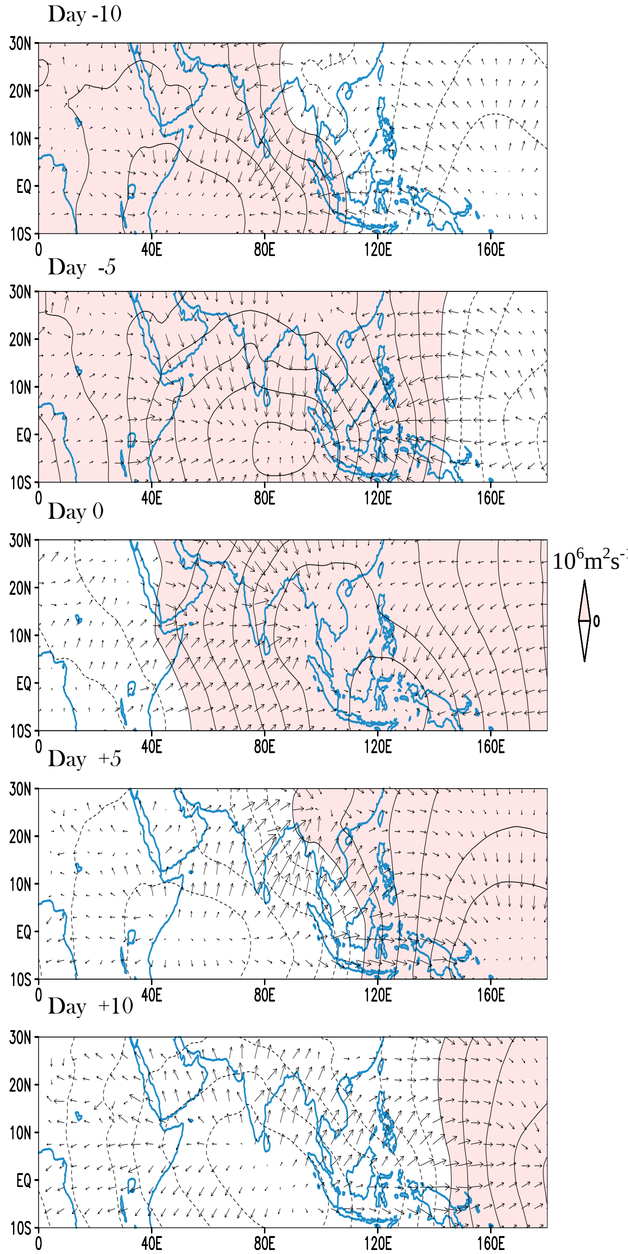

Fig. 3 Composite mean of bandpassed χ at 850-hPa based on 27 spring tropical cyclogenesis (1979-2010).Vectors represent divergent winds. Positive anomalies are shown with contours in shade. The data has been band passed within a frequency of 30-60 days to isolate the MJO signal associated with TC development.

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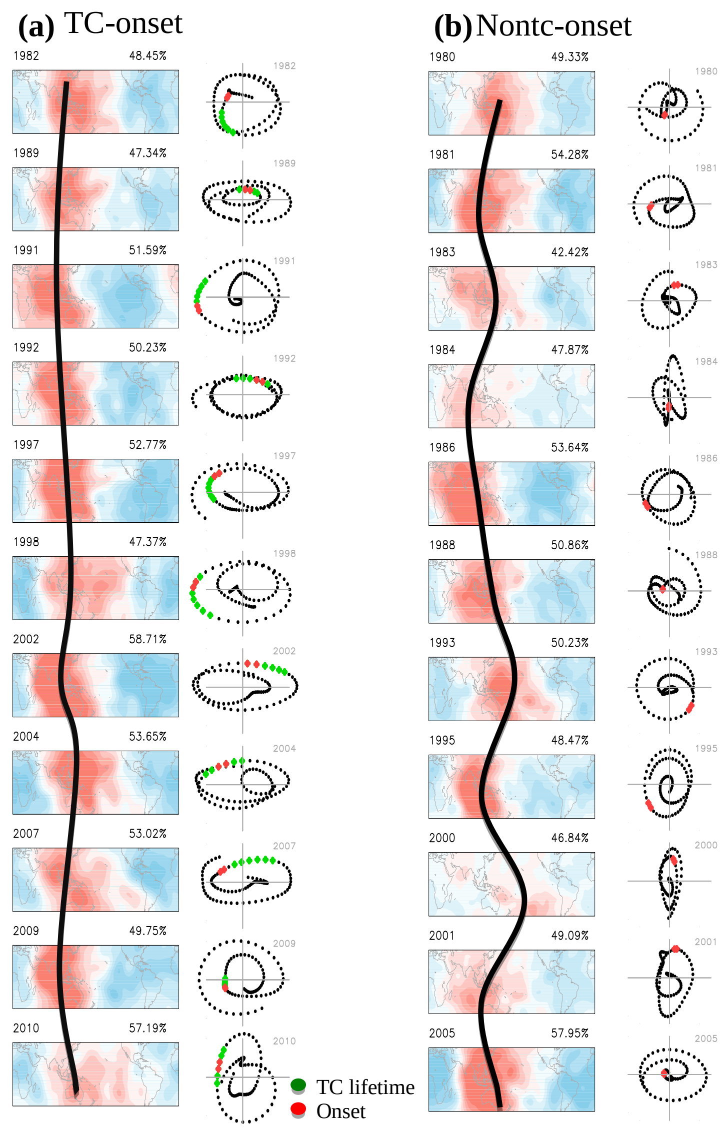

Fig. 4 EOF one loading patterns of bandpassed χ at 850-hPa for (a) coupled onset-cyclogenesis events and (b) uncoupled onset-cyclogenesis periods, along with yearly phase space points for all available days in May and June, using PC1 and PC2. The black lines join centers of enhanced convergence. Each field is normalized by its explained variance (shown above on right). The red dots show monsoon onset whiles the green dots show the spring tropical cyclone lifetime.