The Birth and Death of the MJO: An Observational Study

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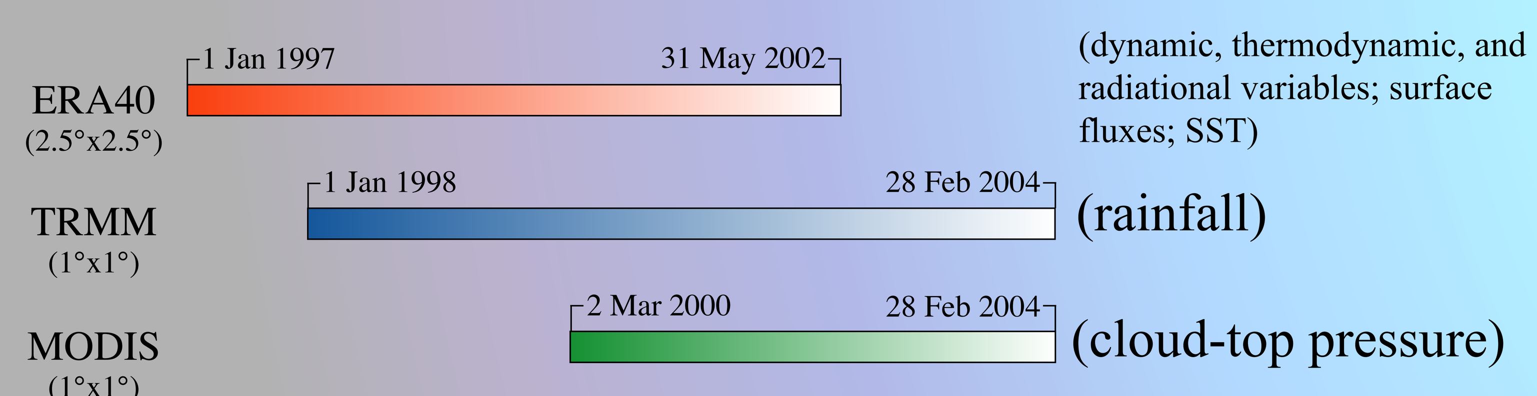
Motivation

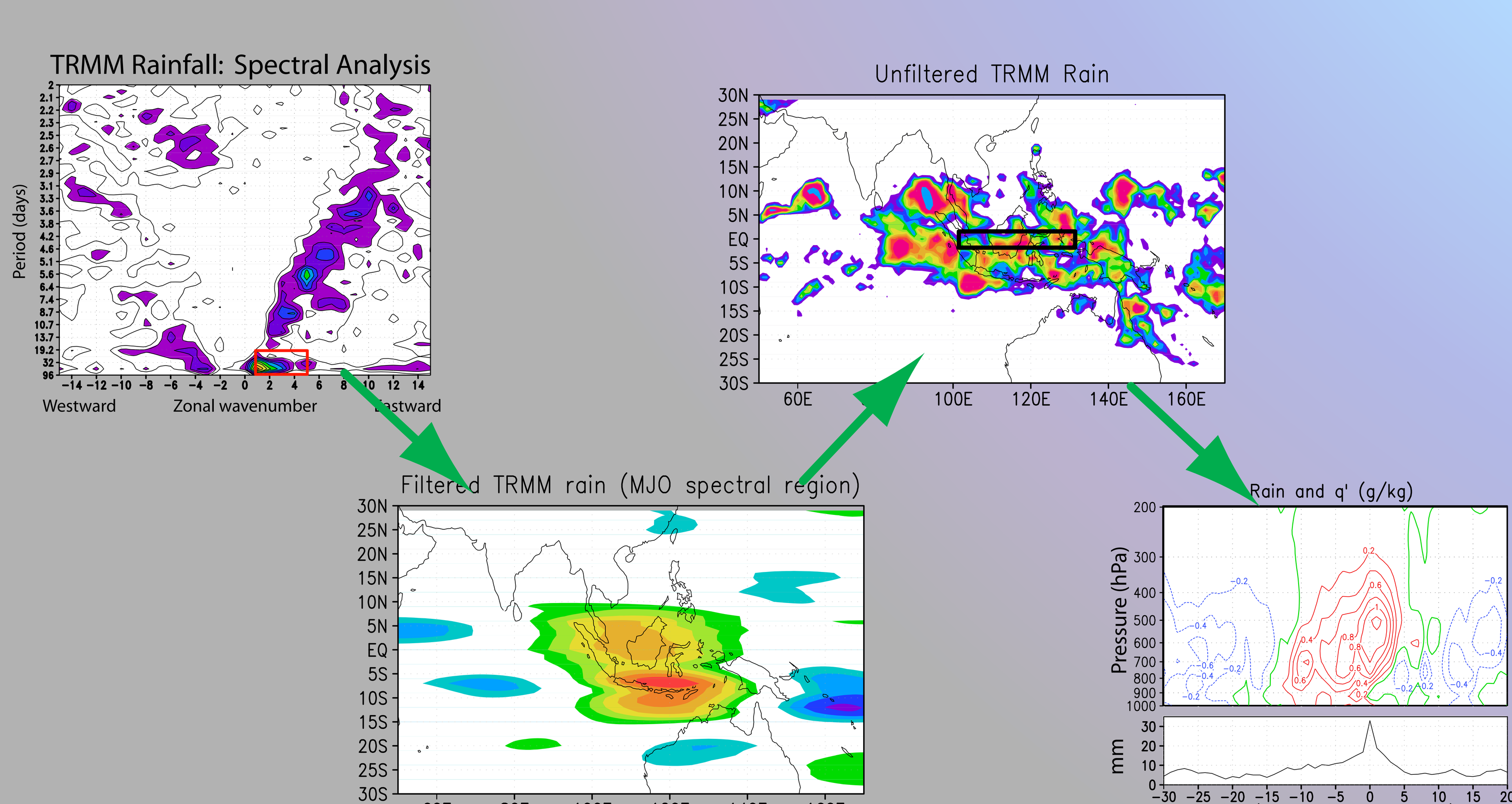
The Madden-Julian Oscillation (MJO), an equatorial wave first noted in the early 1970s (see Madden and Julian 1994), involves multiscale cloud and precipitation processes and is manifested in numerous atmospheric variables. Despite decades of research, the combination of a poor representation of this tropical wave in most current GCMs and a lack of comprehensive understanding of several of its mechanisms highlights the need for continued exploration of the MJO. This report focuses on the "birth" (approaching wet phase) and "death" (departing wet phase) of the MJO and their related precipitation, convective, and advective processes using a host of observational datasets.

The purpose of this study is to explore certain features of the MJO through analyses of both single events and event composites based on TRMM rainfall data. We focus on the cloud and advective processes, as gathered from reanalysis datasets, that are associated with an evolving MJO event. We also compare our composite results with proposed wave instability theories. Novel aspects of this study are that (a) it bases MJO events on TRMM daily rainfall and (b) it deals with both the immediate and delayed drying responses following MJO wet phase departure. This facet of the wave has not been analyzed explicitly in previous observational studies; rather, most studies (e.g., Maloney and Hartmann 1998) have implemented smoothed or filtered data fields to highlight the drying associated with Rossby wave circulations.

Data & Methodology



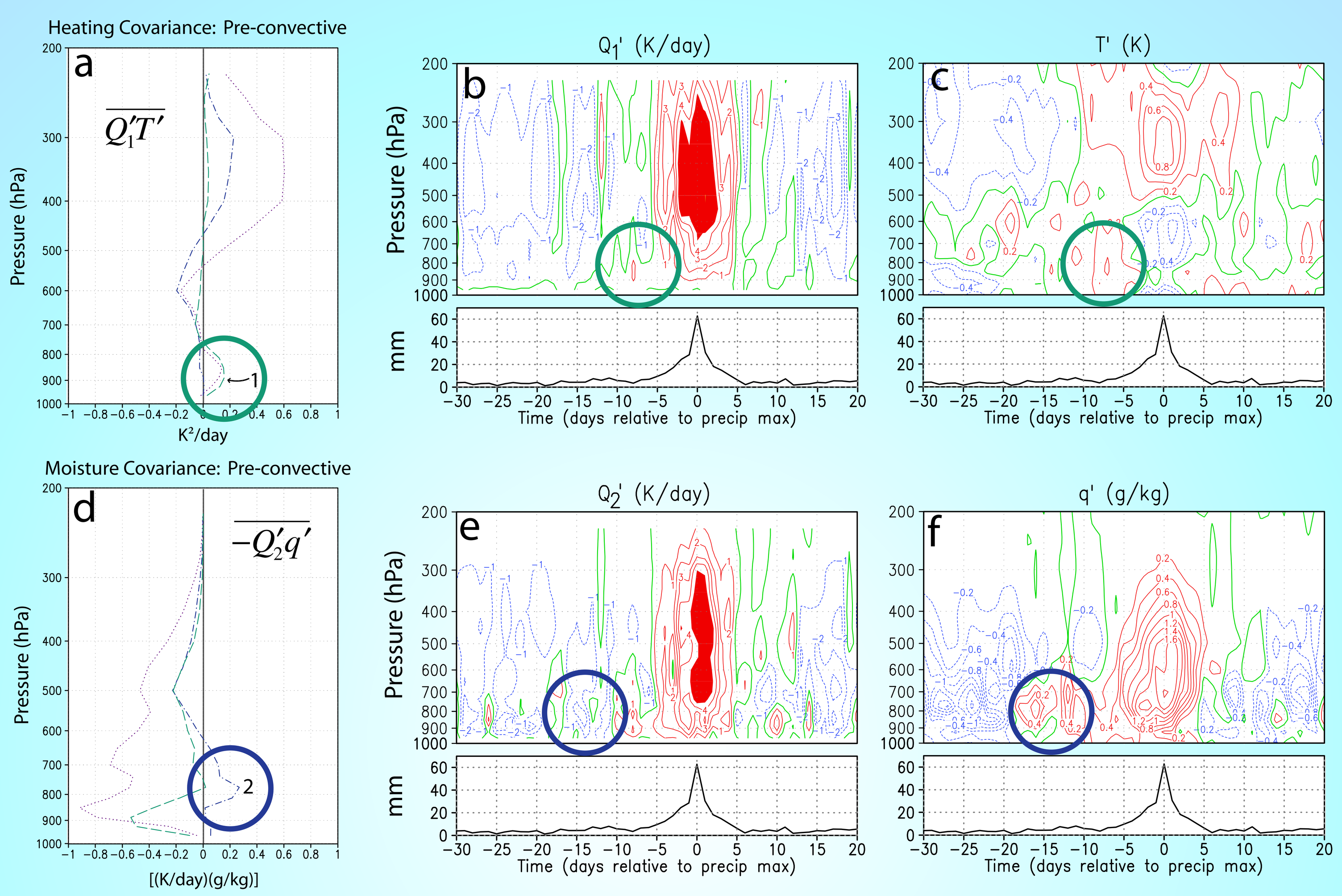
Convective envelopes assessed from filtered TRMM rain [only signals from MJO spectral region (wavenumbers 1-5, periods 20-100 days) are retained] pinpoint MJO events. This envelope and small search area are used to locate rain maxima in the corresponding *unfiltered* rainfall data. Event timeseries of non-precipitation variables are centered on the day and geographic location of rain max, and composites are made. Lag day 0 corresponds to maximum rain.



Selected Results

A. *Convective mechanisms*

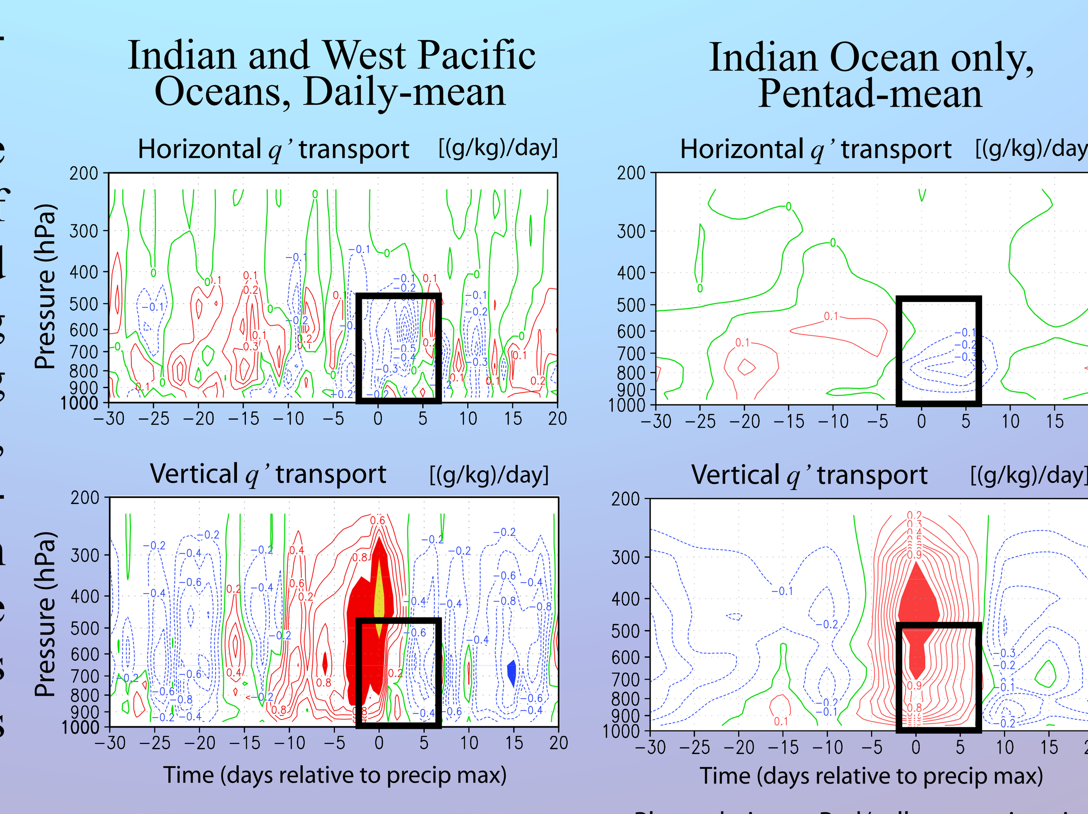
Prior to maximum rainfall associated with an MJO event (lag days -10 to -5), positive covariances (below, a) between the apparent convective heat source Q_1 and temperature T suggest the generation of eddy available potential energy, a fuel source of tropical waves (see "1" and aqua circles below). Similarly, subgrid-scale convective processes also work to increase specific humidity q variance during lag days -15 to -10 (see "2" and dark blue circles below).



Shallow convective clouds—the signature of which can be seen in both T and q cross-sections above as well as in a host of other composite atmospheric profiles obtained (not shown)—play a critical role during MJO onset (lag days -15 to -5). The profiles above indicate that shallow cumuli are involved in a warming and moistening of the lower troposphere during the MJO "birth" stage. This, combined with the overlying dry and radiatively-cooled mid- and upper-troposphere (see panels b and f above 650 hPa during days -15 to -5), results in destabilization and preconditioning for deeper convection.

B. *Advective mechanisms*

While convective processes are linked to the birth of the MJO, advective features are most important during the drying stage, or "death" of the wave. The horizontal and vertical moisture transport components (below, black boxes) indicate distinct differences in post-convective drying. The *horizontal* transport of dry air occurs at and immediately following peak rainfall. Drying due to *vertical* motions, although larger in magnitude and greater in vertical extent than the horizontal transport, is delayed until 4-5 days after the peak rainfall.

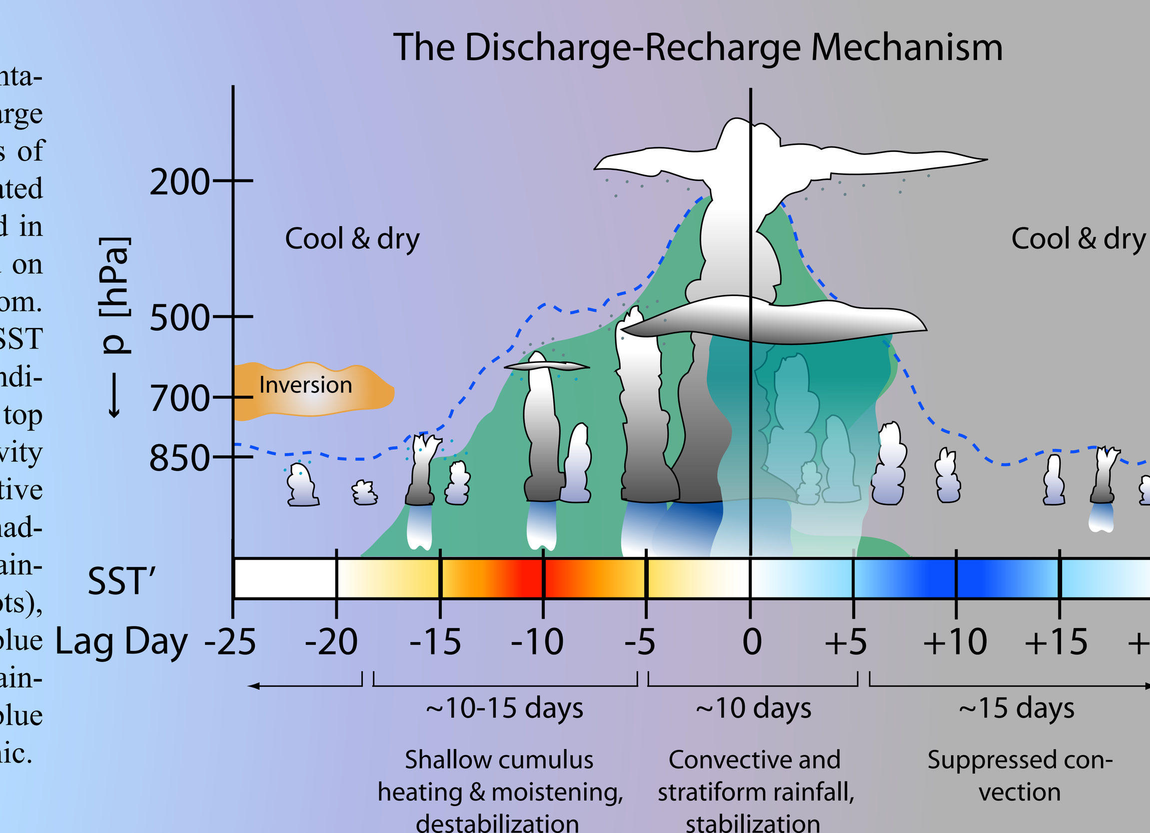


Selected Results (cont.)

C. *Wave instability theories and the composite MJO*

Four proposed wave instability theories are examined in the context of our composite MJO results. Although shallow cumuli preceding deep convection may partake in a CISK-like process in which shallow heating generates weak low-level moisture convergence, a pure application of **wave-CISK** does not match observations. Weak surface evaporative fluxes prior to intense rain suggest that the **WISHE** mechanism is not critical to the events making up our composite MJO. Although several key features of **stratiform instability** theory are not seen in our results, it is possible that this mechanism prolongs convection and possibly the MJO wet phase itself by reducing CIN and regenerating or maintaining residual convection.

(Right): Schematic representation of discharge-recharge mechanism. General stages of convective activity associated with the MJO (as evidenced in our composite results based on reanalysis) appear at bottom. Lag days and qualitative SST anomalies (shading) are indicated. The approximate top level of convective activity (dashed blue line), positive moisture anomaly (green shading), moistening via detrainment (light blue/gray dots), convective rainfall (dark blue rain shafts), and stratiform rainfall (slightly transparent blue shading) appear in the graphic.



Our results strongly suggest that the theory of localized destabilization and **discharge-recharge** mechanisms—a local, gradual buildup of instability through low-level warming and moistening—is highly appropriate in explaining most observed MJO features (see graphic above). Whether triggering of deep convection is due to local stochastic instability or extratropical forcing remains a topic of current research.

Summary

1. The birth of the MJO involves low-level heating and moistening by shallow cumuli, increased instability, and an erosion of the mid-tropospheric dry layer.
2. There is a transition from convective to stratiform rain during the MJO wet phase.
3. The death of the MJO is first associated with horizontal advective drying followed by delayed but stronger subsidence drying.
4. Our observations lend support to the discharge-recharge theory of wave instability.

List of Acronyms

- TRMM: Tropical Rainfall Measuring Mission
- ERA40: European Centre for Medium-range Weather Forecasts 40-yr Reanalysis Dataset
- MODIS: Moderate Resolution Imaging Spectroradiometer
- wave-CISK: Conditional Instability of the Second Kind (associated with tropical waves)
- WISHE: Wind Induced Surface Heat Exchange
- CIN: Convective Inhibition