

# Clouds Associated with the MJO: A New Perspective from CloudSat

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## 1. Introduction

The Madden Julian Oscillation (MJO) is the dominant mode of intraseasonal variability of convection and circulation in the tropics. Past studies have characterized the thermodynamics, dynamics, and precipitation characteristics of the MJO (e.g. Lin and Johnson 1996, Kiladis et al. 2005, Benedict and Randall 2007, Morita et al. 2006). Schematics from the above studies generally show a progression of cloud types from shallow, to middle-topped, to deep clouds, followed by high-topped somewhat thick clouds, with an eventual return to shallow clouds.

In this study we use direct observations from two years (June 2006 - June 2008) of CloudSat data to characterize clouds associated with various phases of the MJO.

## 2. Data and Methods

- Use version 5 of 2B-GEOPROF CloudSat product
- Echo Object (EO) – contiguous region of radar dBZ
- Seven EO types are defined by top and base height (Fig. 1).

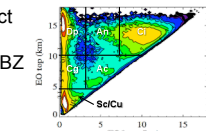


Figure 1 – 2D histogram of EO top and base height in the tropics. (from Riley and Mapes 2009)

Two methods are used to define MJO phases:

### (1) Pinwheel Phases:

- MJO filtered OLR ( $k=[0-9] \& 30-96d$ ) avg  $+15^\circ$
- Standardize filtered OLR and its local d/dt
- Define 8 phases in scatter plot (Fig. 2a)

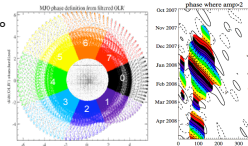


Figure 2 – (a) Standardized OLR vs. local time derivative of standardized OLR pinwheel phase space. (b) Pinwheel phases in time-longitude space. Each color corresponds to the same color phase in panel (a).

- Phase 0 = suppressed; Phase 4 = active
- Use EOs where amplitude  $> 2$

### (2) Wheeler & Hendon (2004) RMM Phases:

- Phase is only a function of time
- Each diamond is a day in CloudSat data era
- Colored diamonds have  $(RMM1^2 + RMM2^2) > 1$

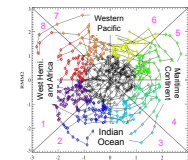


Figure 3 - RMM1, RMM2 phase space. Diamonds are CloudSat days in our data set. Colored diamonds indicate strong MJO events.

## 3. Results: Pinwheel Phases

### Actual and normalized area by phase:

- Red = narrow Dp  $< 200$  km, Orange = wide Dp  $> 200$  km
- Twice as much cover in active vs. suppressed
- Narrow (wide) Dp greatest in suppressed (active) phases
- An greatest after active phases
- Sc and Cu greatest during suppressed phases

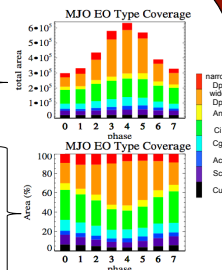


Figure 4 – (a) actual (b) normalized percent contribution of EO type per pinwheel phase

### Mosaic of actual clouds across the MJO:

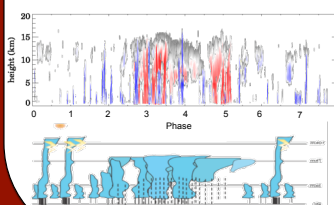


Figure 5 – Pictorial realization of clouds across the MJO. Wide Dp = red, all other types = grey-to-blue. Colored shading starts at dBZ  $> 0$ .

- Random samples of EOs
- Wide Dp only appear in active phases
- Narrow Dp appear in all phases
- Anvil lags deep convection
- Cf. Morita et al. (2006)

## 4. Results: WH04 RMM Phases

### Anomalous echo cover by type :

- Anomalies relative to all phase mean
- Magenta line = approx. slope of wide Dp propagating anomalies
- Wide Dp, An, and Ac have two bands of eastward propagating positive anomalies (Fig. 6a, c, f)
- Narrow Dp and Cu have zonal anomaly oscillations (Fig. 6b, h)
- Ci has 1 eastward propagating band of positive anomalies (Fig. 6d)
- Cg leads and An lags wide Dp signal (Fig. 6e, 6c)

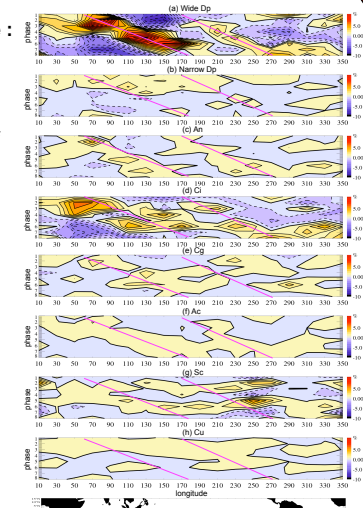


Figure 6 – Anomalous cloud cover each EO type (labeled a – h). Contour levels are 1% with positive (negative) anomalies in solid (dashed) lines. Thick solid line is the zero difference contour. In panels (a-h) the longitude values represent the middle value of the 20° bins.

### Mosaic of actual clouds across the MJO:

- Random selection: Where anomaly,  $A(lon, phase, type) > 0$ , grab random samples proportional to A from set of EOs(lon, phase, type)

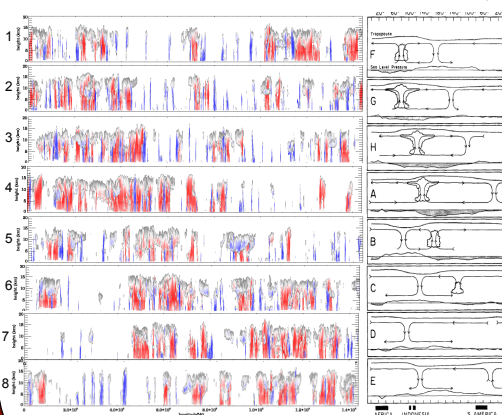


Figure 7 – (a) One example of a pictorial realization of EOs across the tropics during each WH04 RMM phase. Phases run downwards from 1 to 8. Each stamp is plotted centered over its true mean longitude. The longitude scale (x-axis) has been multiplied by 40 to maximize viewing clarity. A map of the tropics from  $15^\circ S - 15^\circ N$  is provided in the bottom panel as a reference. (b) Figure 16 of Madden and Julian (1972).

- Mainly see propagation of wide Dp, narrow Dp, and An types
- Two envelopes of convection
- Strong Western Hemi. signal
- Cf. Madden & Julian (1972)

## 5. Summary

**Pinwheel Phases:** A doubling of echo cover occurs from suppressed to active phases. The normalized bar graphs suggest that suppressed MJO phases favor shallow clouds and narrow deep convection, while active phases favor wide deep convection. Additionally, anvil is more common after active phases.

**WH04 RMM Phases:** The wide Dp, An, and Ac EO types have two bands of eastward propagating anomalies, while Ci has only one, and narrow Dp, and Cu have a zonal anomaly structure.

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