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The Precipitating Cloud Population of the MJO and its Relation to Large-Scale Atmospheric Conditions

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Introduction

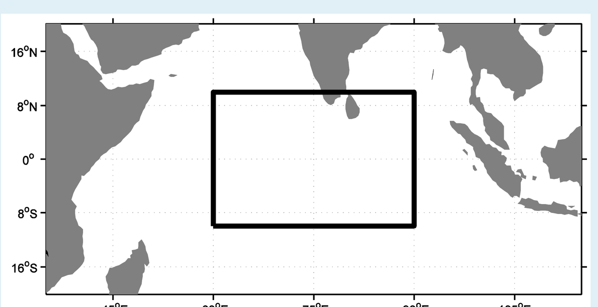
The cloud population and synoptic environment coherently varies as the MJO initiates in the central Indian Ocean and propagates through the western Pacific Ocean. The MJO predominately modulates the areal coverage of mesoscale convective systems (MCSs), which are large precipitating regions comprised of convective cells embedded within a relatively large stratiform region (Houze, 2004). However, the MJO is also theorized to be sensitive to shallow convective cells, especially during its initiation (e.g. Bladé and Hartmann, 1993; Haertel et al., 2008). While the suppressed stage of the MJO is characterized by easterly winds at the surface and a dry mid-upper troposphere, the active stage has westerly winds at the surface and a moist mid-upper troposphere. Additionally, shortly after the active stage a westerly wind burst occurs at the surface and vertical wind shear maximizes (e.g. Chen et al., 1996; Lin and Johnson 1996). Despite these observations, the coupling between the precipitating cloud population and large-scale synoptic environment is poorly understood and numerical models struggle to accurately model the MJO (Zhang, 2005; Kim et al., 2009). Observations of the precipitating cloud population and its relationship with large-scale atmospheric conditions provide the first step in improving numerical simulations of the MJO.

Objectives

- Document variability in precipitating cloud population using TRMM Precipitation Radar (TRMM PR).
- Relate changes to large-scale relative humidity, wind, and vertical wind shear fields from ERA-Interim.

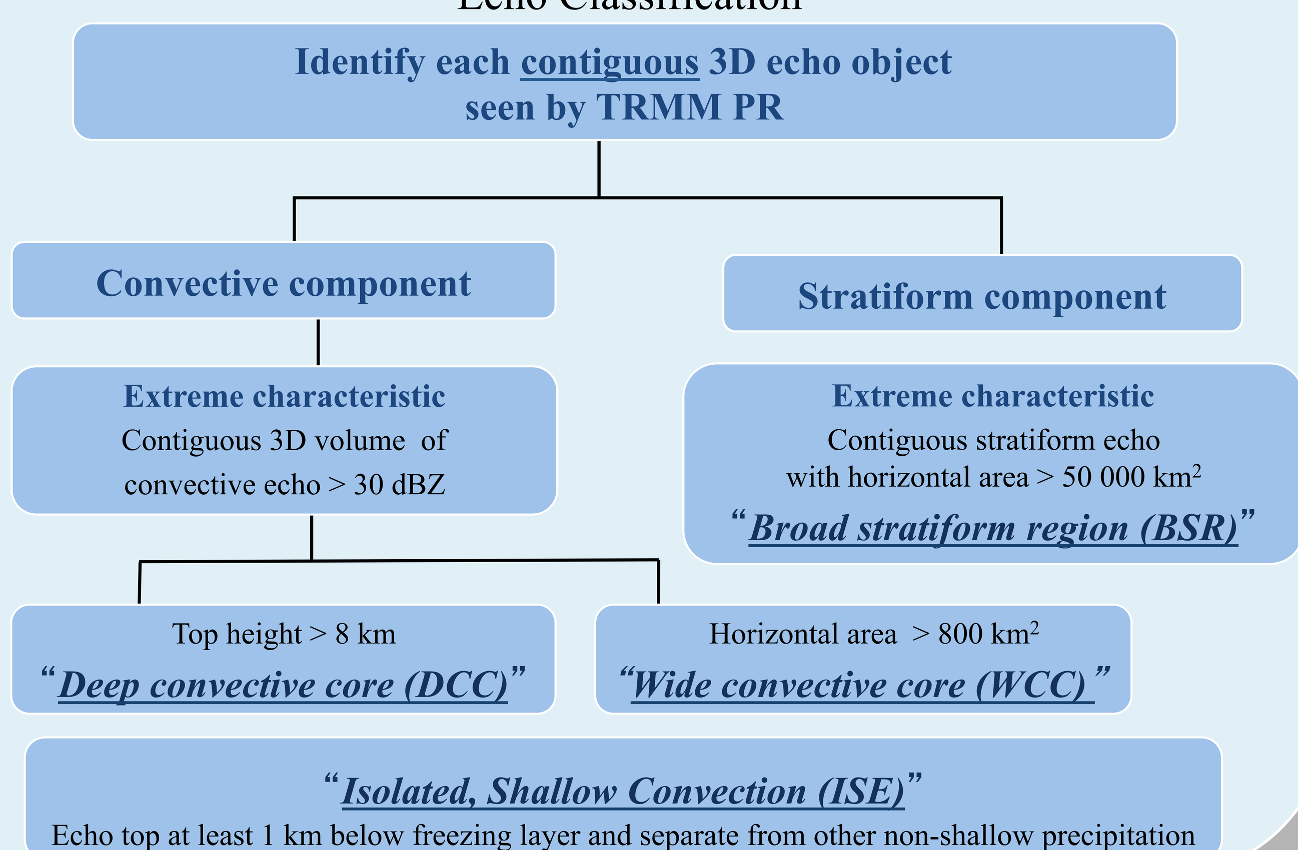
Data and Methodology

- TRMM Precipitation Radar (TRMM PR) and ERA-Interim Reanalysis
- 14 years of data during October – February from 1999-2011 when the Real-Time Multivariate Index amplitude > 1 (Wheeler and Hendon, 2004)
- Create composites of the precipitating cloud population and large-scale atmospheric conditions using the 8 phases of the Real-Time Multivariate Index
- Statistical significance of the variability of the precipitating cloud population assessed using a Monte Carlo method to create 20 samples of 100 randomly selected days during each phase.

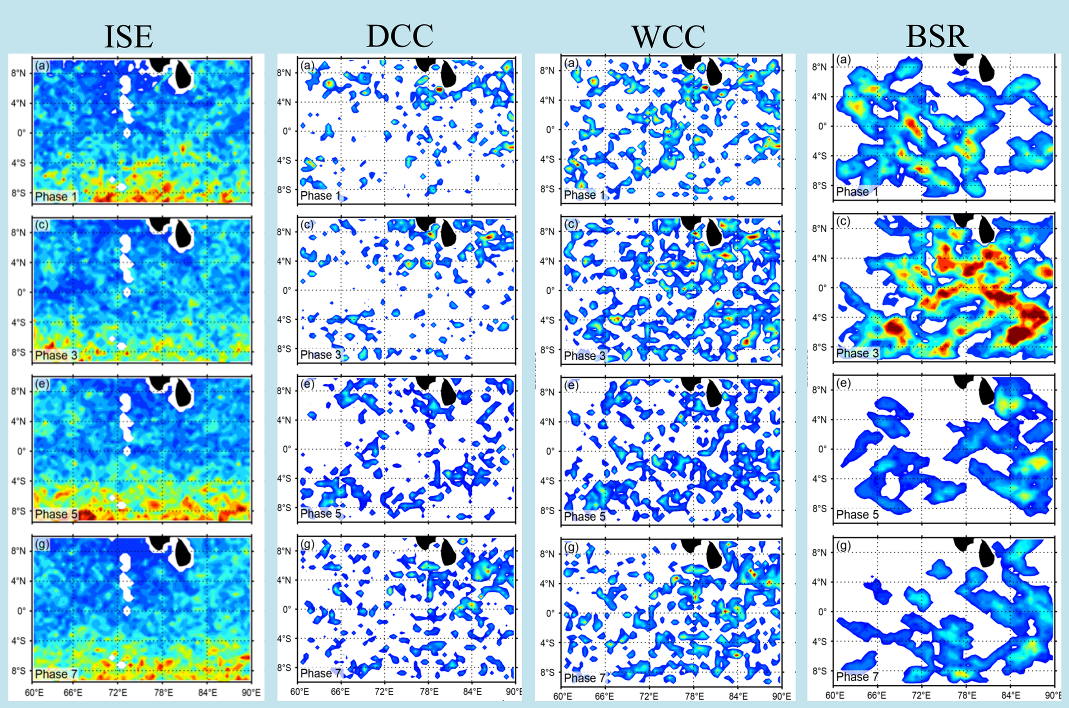


Physical map of geographic region of study outlined in black. This region is located in the central Indian Ocean and extends from 60° - 90°E and 10°S - 10°N.

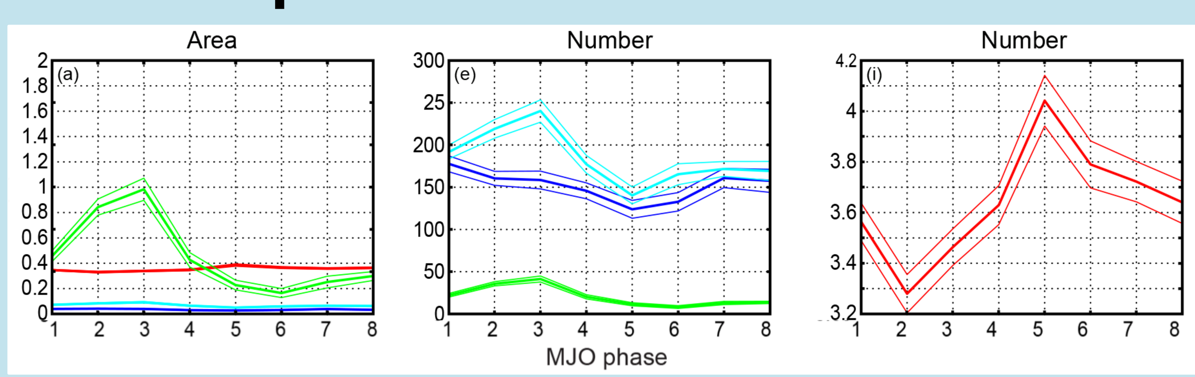
Echo Classification



Precipitating Cloud Population



Geographic distribution of the average ISE, DCC, WCC, and BSR frequency in phases 1, 3, 5, and 7. The frequency is defined as the number of times the TRMM PR detects a given echo type normalized by the total number of TRMM PR detects a pixel regardless if it is echo-covered or echo-free. Thus, the frequency provides a measure of the areal coverage of each echo type.



(a) Average total frequency and 99% confidence interval of ISE (red), DCC (blue), WCC, (cyan), and BSR (green).
(e) Average number and 99% confidence interval of DCC (blue), WCC (cyan), and BSR (green).
(i) Average number (x10⁴) and 99% confidence interval of ISE.

- The areal coverage and number of ISE, DCC, WCC, and BSR echoes significantly vary with phase of the MJO.
- In terms of areal coverage, BSRs dominate the variability.
- In terms of number, ISEs are the most common and variable.
- The maximum areal coverage of BSR echoes defines the active stage of the MJO (phase 3).
- DCC, WCC, and BSR echoes maximize during the active stage (phase 3).
- ISEs maximize during suppressed stage (phase 5).

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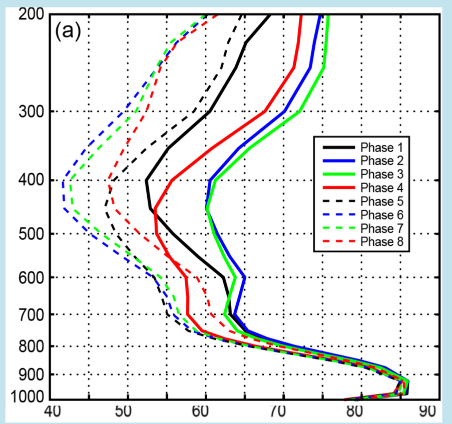
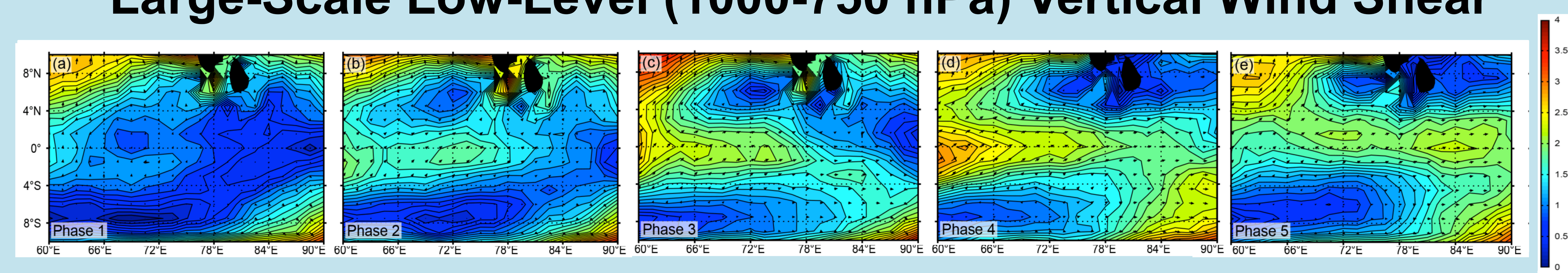
Large-Scale Relative Humidity



- Lower tropospheric relative humidity is uniformly moist below 800 hPa.
- Mid-upper tropospheric relative humidity rapidly rise from phase 1 to 2, which is one phase prior to the DCC, WCC, and BSR maximum.
- Mid-upper tropospheric moisture maximizes during the active stage (phases 2-3).
- Mid-tropospheric relative humidity rapidly declines from phase 3 to 4, which is one phase after DCC, WCC, and BSR maximize.

The average relative humidity profile during each phase. Dashed lines represent phases in the suppressed stage. Solid lines represent phases in the active stage with the solid green line representing the active stage (phase 3).

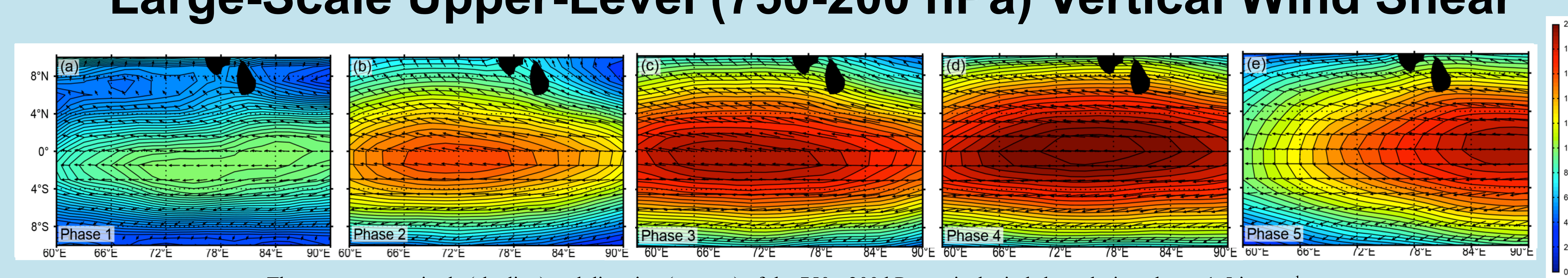
Large-Scale Low-Level (1000-750 hPa) Vertical Wind Shear



The average magnitude (shading) and direction (vectors) of the 1000-750 hPa vertical wind shear during phases 1-5 in m s⁻¹.

- As DCC, WCC, and BSR echo coverage increases during phases 1-3 low-level westerly shear also increases. The simultaneous rise in mesoscale activity and low-level shear may be expected since MSC downdrafts transport mid-level winds downward, which helps create surface convergence and convective initiation.
- Low-level westerly shear maximizes in phase 4, but DCC, WCC, and BSR significantly decline. This reduction in mesoscale activity is attributed to the rapid decrease in mid-level relative humidity from phase 3 to 4 (see above).
- Low-level westerly shear is moderately strong in phase 5 when ISEs maximize

Large-Scale Upper-Level (750-200 hPa) Vertical Wind Shear



The average magnitude (shading) and direction (vectors) of the 750 - 200 hPa vertical wind shear during phases 1-5 in m s⁻¹.

- A large increase in easterly upper-level shear occurs during phases 1-3 as DCC, WCC, and BSR echo coverage significantly increase. The increase in the magnitude of the upper-level shear is four times greater than the increase in magnitude of the low-level shear.
- Easterly upper-level shear maximizes during phase 4 as DCC, WCC, and BSR echoes significantly decline.
- Stratiform regions of MCSs are partially sustained by the advection of moisture from the convection regions of the storm. While moderate upper-level shear aids in the mesoscale organization of the storm, excessively strong upper-level shear may sever the stratiform region from its convective moisture source. This may account for the reduction of BSR echoes in phase 4.

Conclusions

	Transition to Active Stage (Phase 1-2)	Active Stage (Phase 3)	Transition to Suppressed Stage (Phase 4-5)
Areal Coverage (Number) of ISE	Decrease (Decrease)	Slight Increase (Increase)	Increase and Peak (Increase and Peak)
Areal Coverage (Number) of DCC	Peak (Peak and Decrease)	No Change (No Change)	Decrease (Decrease)
Areal Coverage (Number) of WCC	Increase (Large Increase)	Peak (Peak)	Decrease (Large Decrease)
Areal Coverage (Number) of BSR	Large Increase (Increase)	Peak (Peak)	Large Decrease (Decrease)
Low-Level Relative Humidity	←	Moist	→
Mid/Upper-Level Relative Humidity	Moisten	Peak	Dry
Low-Level (1000-750 hPa) Shear	Moderate Increase Westerly	Increase Westerly	Peak and Slight Decrease Westerly
Upper-Level (750-200 hPa) Shear	Large Increase Easterly	Increase Easterly	Peak and Moderate Decrease Easterly

- While broad stratiform regions dominate the variability in the areal coverage of the precipitating cloud population, isolated shallow echoes are the most common and variable element of the population in terms of number.
- These relationships also apply to the active stage of the MJO in the West Pacific Ocean.

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