Latent Heating Associated with the MJO in the Central Indian and West Pacific Oceans

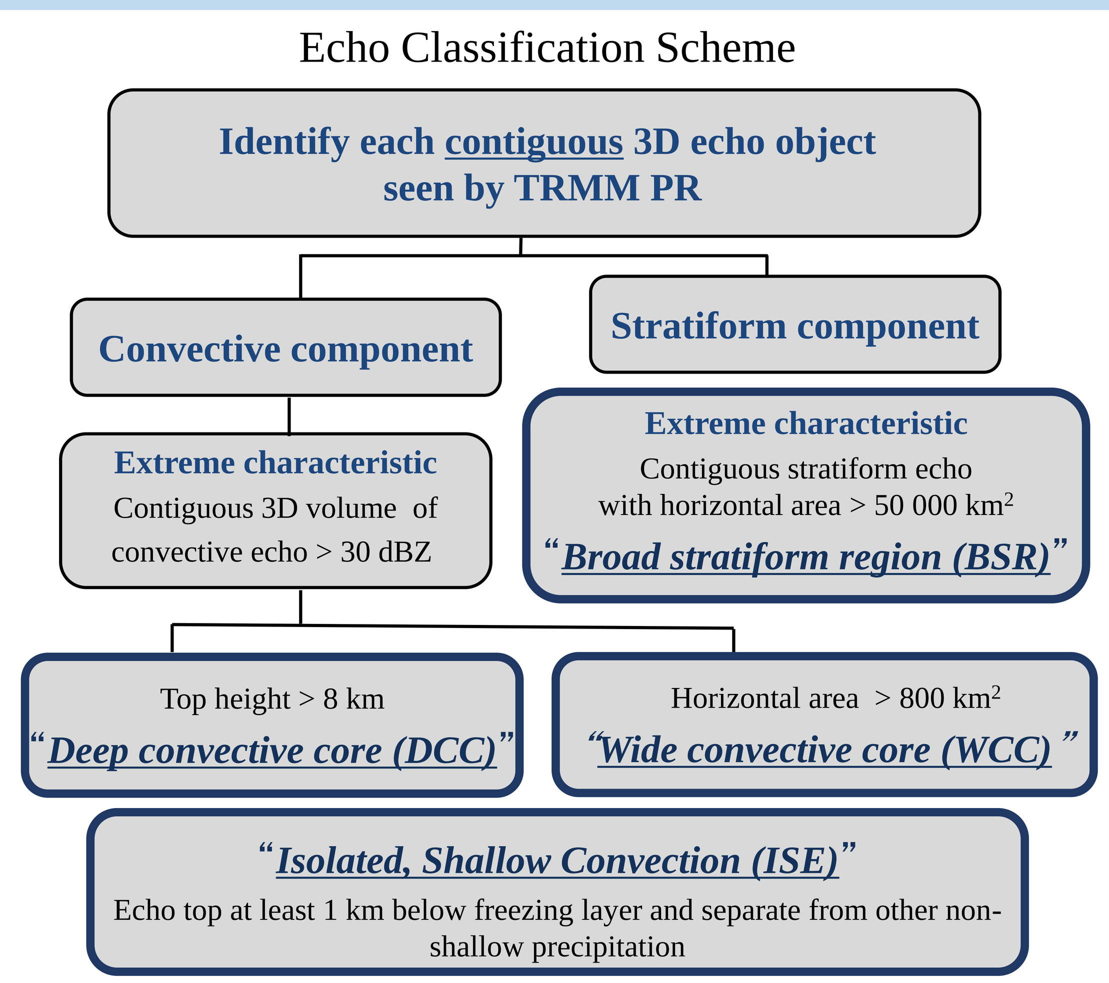
Hannah C. Barnes, R. A. Houze Jr., and M. D. Zuluaga
University of Washington

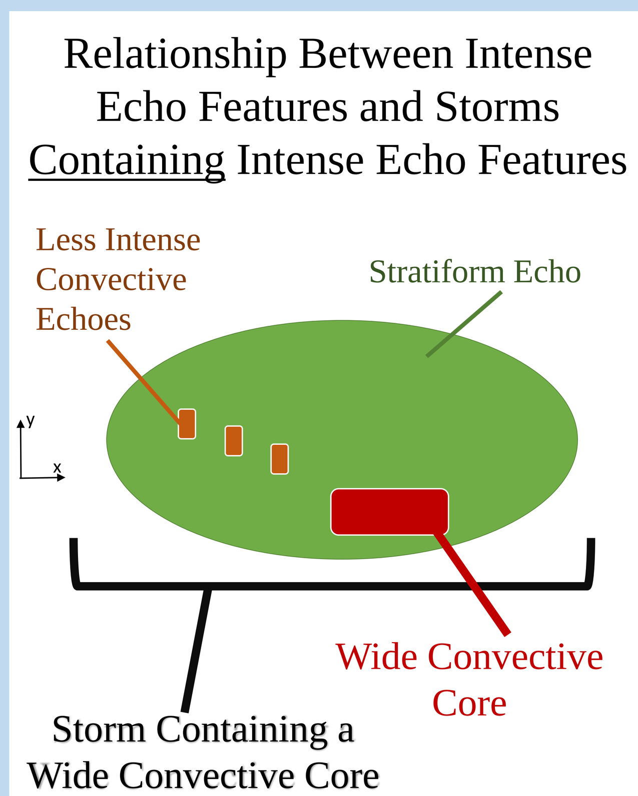
Introduction

Barnes and Houze (2013) investigated how the precipitating cloud population associated with the Madden-Julian Oscillation (MJO) varies in the central Indian and west Pacific Oceans using the TRMM Precipitation Radar (TRMM PR) and suggested how that cloud population is associated with the large-scale circulation using ERA-interim reanalysis. The cloud population analyzed included isolated, shallow echoes (Shallow) and extreme echo features called deep convective cores (Deep), wide convective cores (Wide), and broad stratiform regions (Broad), which represent the deepest and widest components of the convective and stratiform portions of the precipitating cloud population. In the central Indian and west Pacific Oceans, broad stratiform regions experience the greatest variability during the MJO and strongly peak during the active stage. The deep and wide convective cores experience less variability and the timing of their maximum differs in the central Indian and west Pacific Ocean, which was related to differences in the variability of mid-level relative humidity and vertical wind shear between the geographic regions.

Houze (1982) demonstrated that the latent heating profile in convective regions is characterized by heating at all levels which maximizes in the low-mid troposphere. The latent heating profile in stratiform regions are characterized by heating at upper-levels and cooling at low-levels. Additionally, *Houze* (1982, 1989) showed that the overall vertical structure of heating is related to the proportion of convective and stratiform precipitation. The classification technique employed by *Barnes and Houze* (2013) and the spectral latent heating (SLH) algorithm for the TRMM PR enables the authors to investigate how changes in the precipitating cloud population are related to variability in the latent heating profile during the MJO in the central Indian and west Pacific Ocean.

Storm Classification





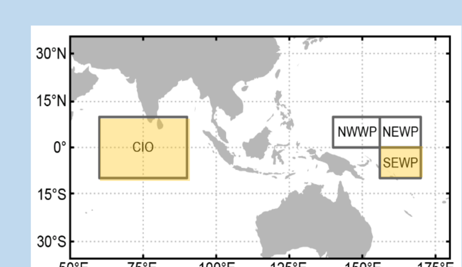
Latent Heating Methodology

- Latent heating from the spectral latent heating (SLH) algorithm using TRMM PR (*Shige et al*., 2004, 2007, 2009).
  - Convective, stratiform, and anvil look-up tables based on precipitation-top height and precipitation rate at surface and melting level. Developed from numerical simulations of convection during TOGA COARE.
- Composite each phase of the Real-Time Multivariate (RMM) Index (*Wheeler and Hendon*, 2004) when amplitude > 1 from October – February from 1999-2012.

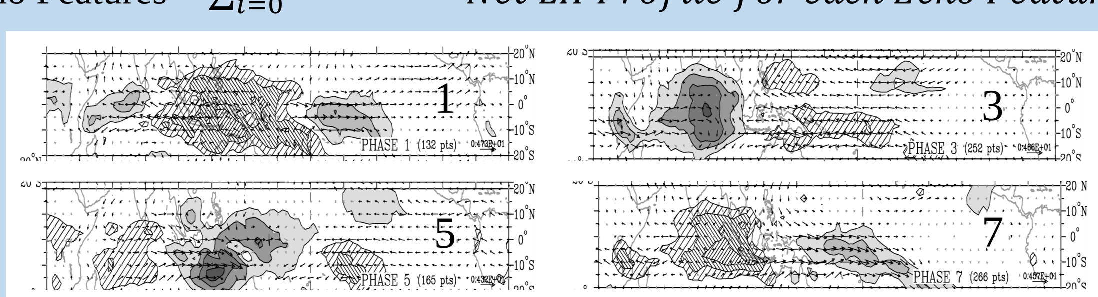
Net Heating by Intense Echo Features =

$$\left[\sum_{i=0}^{\#\,Echo\ Features} Average\ LH\ Profile\ for\ each\ Echo\ Feature\right]\left[\overbrace{\frac{\#\,Echo\ Feature\ Pixels\ during\ MJO\ phase}{\#\,Pixels\ Sampled\ by\ TRMM\ PR\ during\ MJO\ phase\ (echo\ or\ no\ echo)}}^{Area\ Scaling\ Factor}\right]$$

Net Heating by Storms Containing Intense Echo Features = $\sum_{i=0}^{\#\,Echo\ Features} Net\ LH\ Profile\ for\ each\ Echo\ Feature$



Physical map of geographic regions of study outlined in black.



DJF composite of OLR and 850 hPa wind anomalies during phase 1, 3, 5, and 7. Negative (positive) OLR shaded (hashed). (*Wheeler and Hendon*, 2004)

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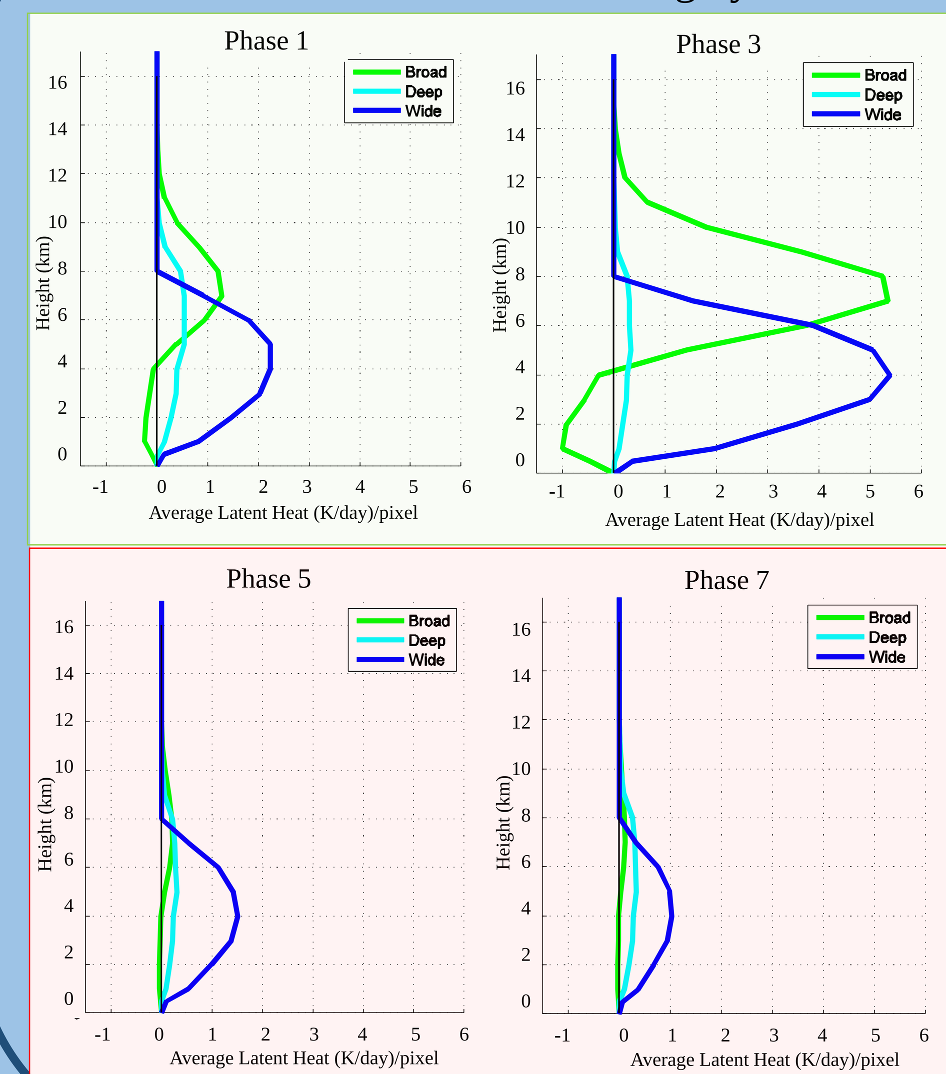
Contact: hannah@atmos.washington.edu

Comparing Central Indian and Southeast West Pacific Oceans

Central Indian Ocean (CIO)

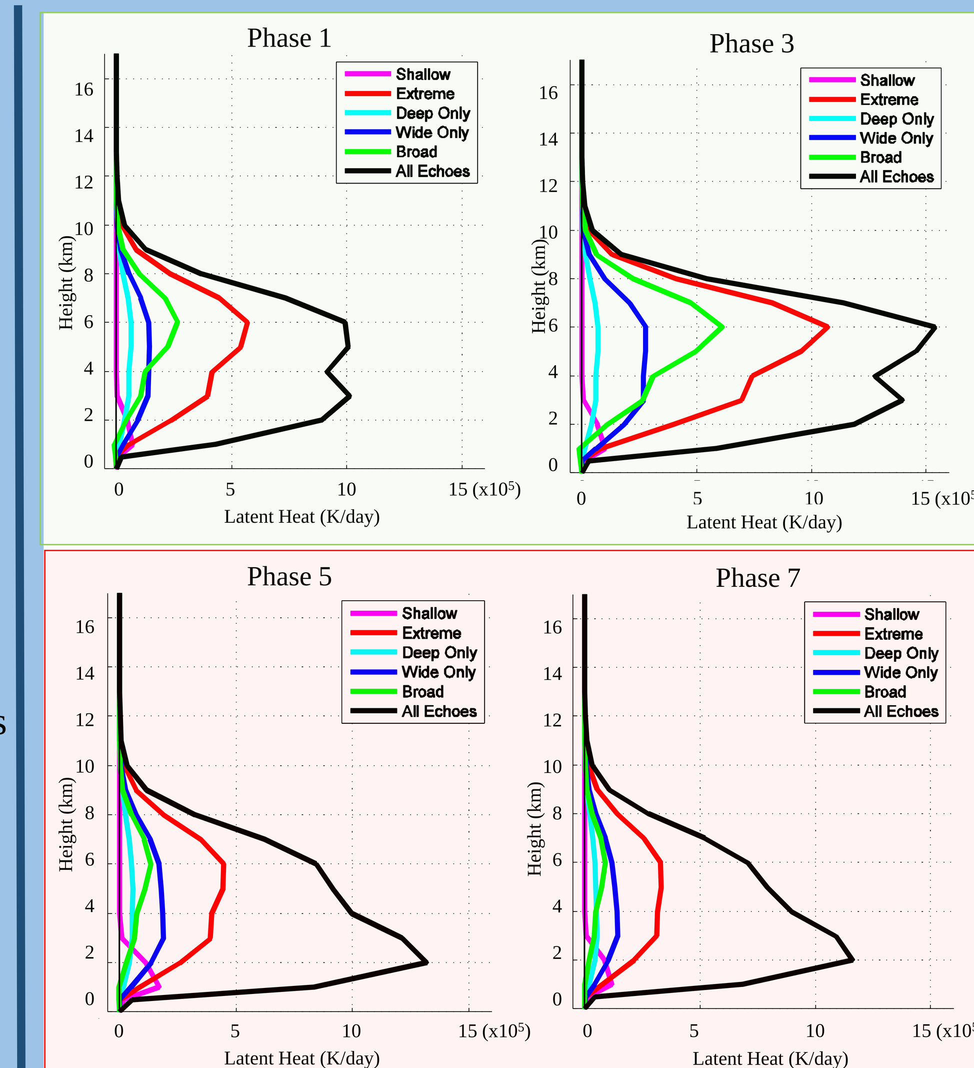
Net Heating by Intense Echo Features



Vertical profile of net latent heating by intense echo features during phase 1, 3, 5, and 7.

- Profile shape similar, only magnitude changes
  - Magnitude related to areal coverage
- Broad stratiform regions
  - Exhibits greatest variability
  - Peak in active phases
  - Maximum heating at high levels
- Wide Convective Cores
  - Dominate Deep Convective Cores
  - Magnitude similar to Broad Stratiform Regions in active phases
- Deep Convective Cores
  - Contributes the least net heating

Net Heating by Storms Containing Intense Echo Features

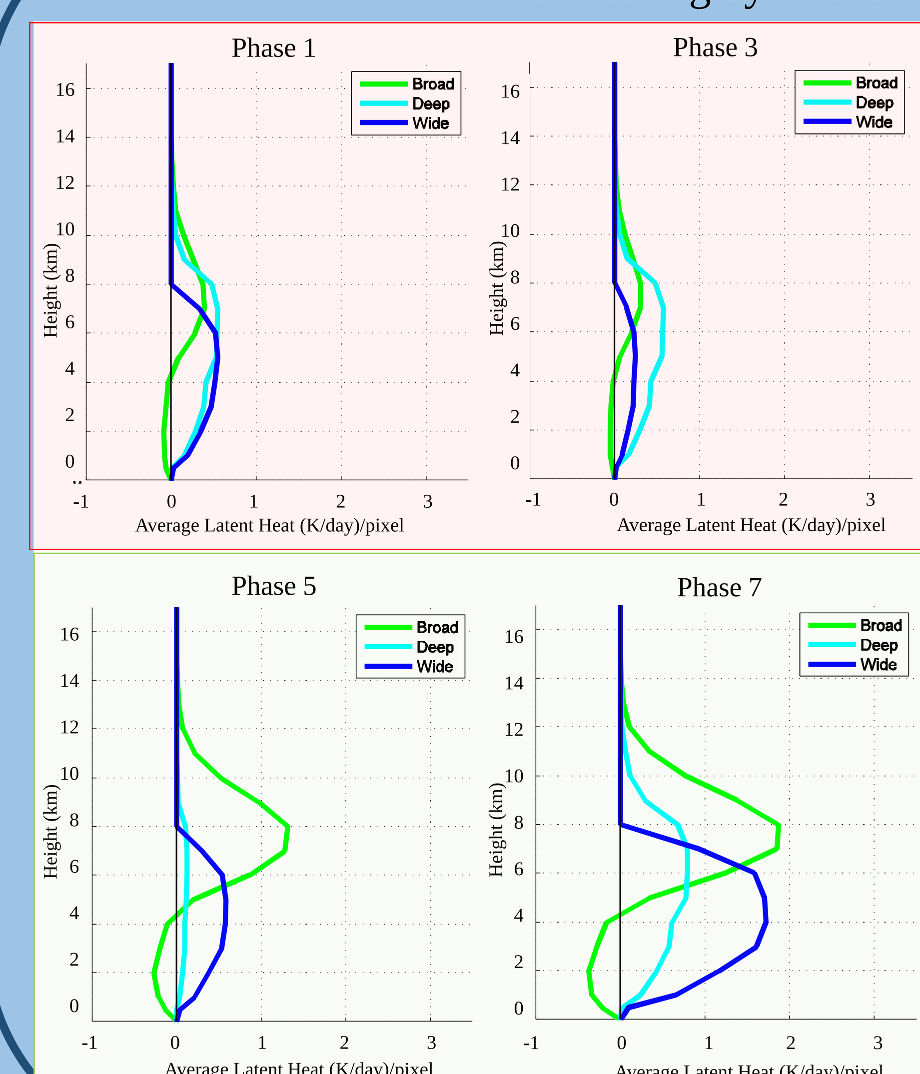


Vertical profile of net latent heat from all TRMM echoes and storms containing intense echo features during phase 1, 3, 5, and 7.

- All Echoes (Net TRMM Obs. Heating)
  - Active stage top heavy
  - Suppressed stage bottom heavy
- All Storms containing Intense Echo Features
  - Large portion of net obs. heating
  - Contributes more during active stage
- Storms containing Broad Stratiform Regions
  - Largest contribution during active stage
- Storms containing Wide Convective Cores
  - Always greater than storms containing Deep Convective Cores
- Shallow, Isolated Convection
  - Contributes little to net obs. heating
  - Non-classified, medium intensity convection contributes significantly to bottom heavy heating

Southeast West Pacific Ocean (SEWP)

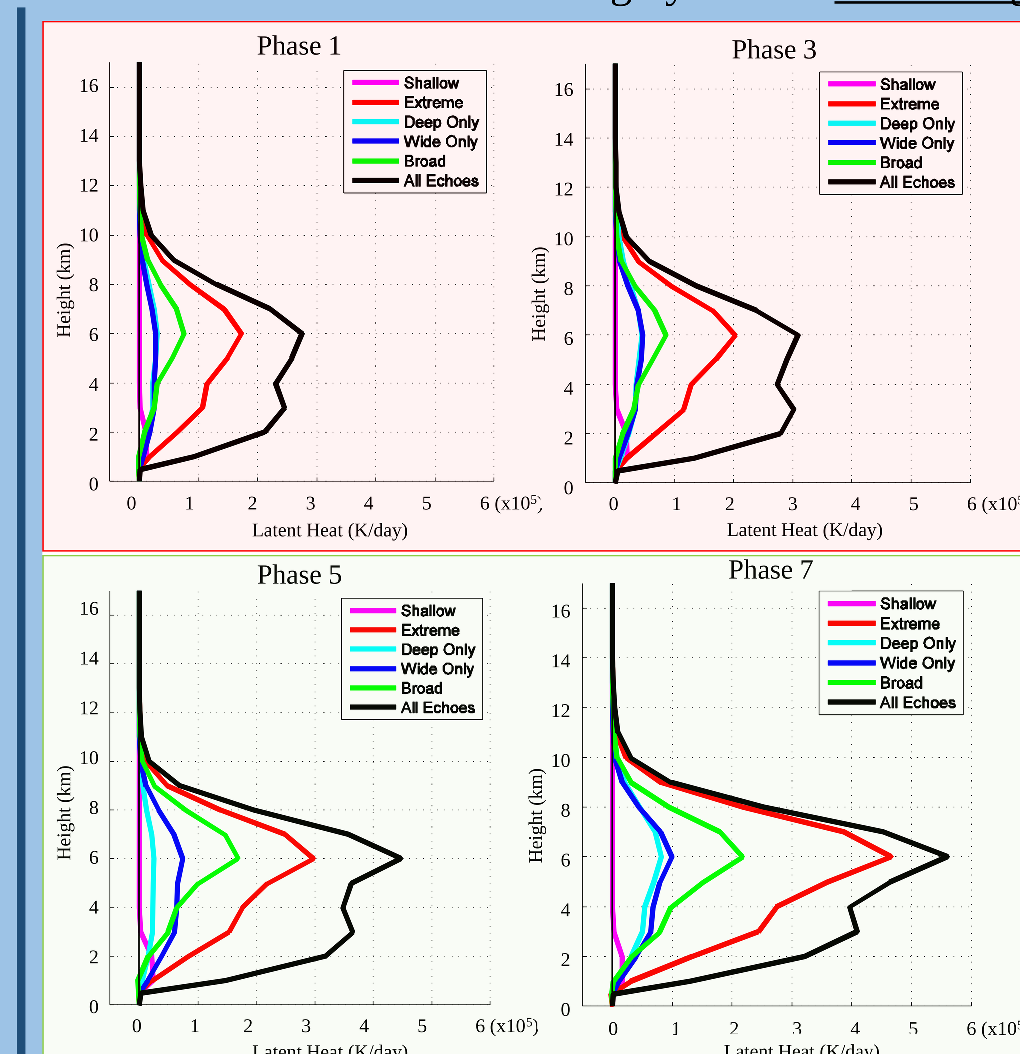
Net Heating by Intense Echo Features



Vertical profile of net latent heat by intense echo features during phase 1, 3, 5, and 7.

- Profile shape similar, only magnitude changes
  - Magnitude related to areal coverage
- Broad stratiform regions
  - Exhibits greatest variability
  - Peak in active phases
  - Maximum heating at high levels
- Wide Convective Cores
  - Dominate Deep Convective Cores only in active phases
  - Magnitude less than Broad Stratiform Regions in active stage
- Deep Convective Cores
  - Contributes the most heating in suppressed stage

Net Heating by Storms Containing Intense Echo Features



Vertical profile of net latent heat from all TRMM echoes and storms containing intense echo features during phase 1, 3, 5, and 7.

- All Echoes (Net TRMM Obs. Heating)
  - Active stage top heavy
  - Suppressed stage middle heavy
- All Storms containing Intense Echo Features
  - Large portion of net obs. heating
  - Contributes more during active stage
- Storms containing Broad Stratiform Regions
  - Contributes more in active stage
- Storms containing Wide Convective Cores
  - Magnitude similar to storms containing Deep Convective Cores
- Shallow, Isolated Convection
  - Contribute little to net obs. heating
  - Non-classified, medium intensity convection contributes significantly to bottom heavy heating

Conclusions

- Latent heating associated with the precipitating cloud population in the central Indian and west Pacific Oceans varies during the MJO.
  - Storms containing intense echo features account for a substantial amount of the net TRMM observed heating, especially during the active stage.
    - Heating associated with broad stratiform regions systematically maximizes in active stage, minimizes in suppressed stage, and increases the depth of the heating profile.
    - Heating associated with deep and wide convective cores differ between regions in terms of their relative magnitude and variability.
      - Central Indian Ocean: wide convective echoes always dominate deep convective echoes
      - West Pacific: wide convective echoes dominate during active stage, deep convective echoes dominate during suppressed stage
  - Isolated, shallow convection accounts for little of the net TRMM observed heating. Non-classified, medium intensity convection important to low-level heating.
- Latent heating in central Indian and west Pacific Ocean differs the most in terms of the magnitude, nature, and pattern of variability associated with convective heating.