CERES Observations of Cloud Regimes within a Composite Madden-Julian Oscillation

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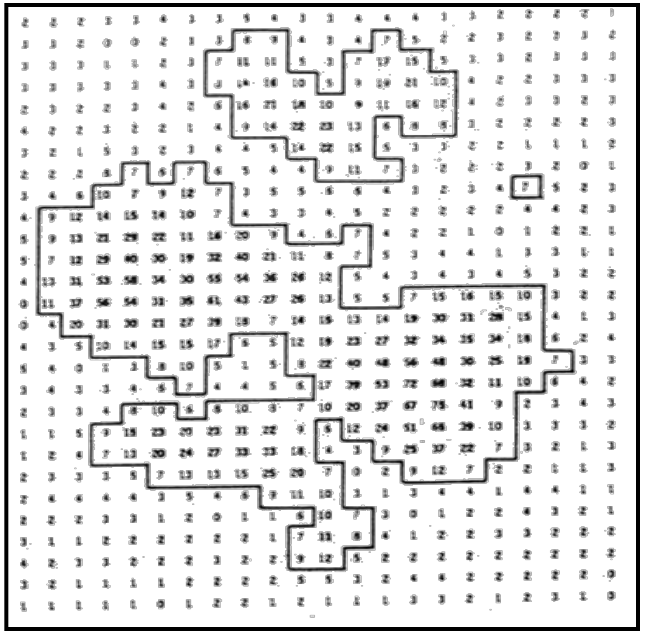
Motivation

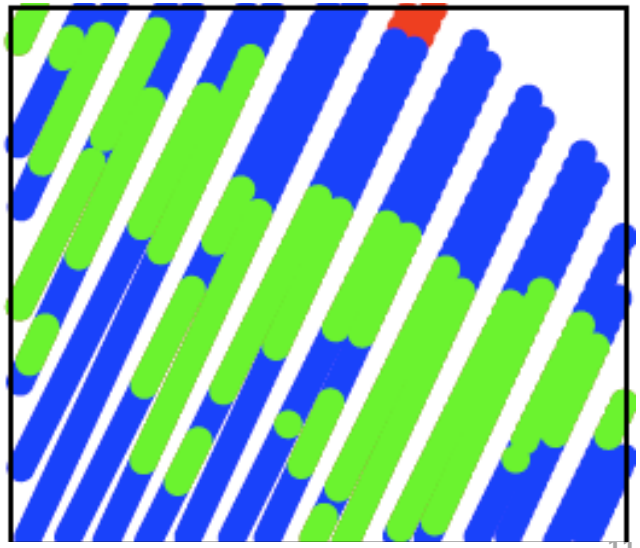
- Web of Science search results:
  - Madden-Julian Oscillation: ~1400
  - CERES: ~600
  - MJO + CERES: 1 (Loeb et al. 2012)
- Loeb et al. (2012): "***Regional*** cloud-radiation variations among several Terra and A-Train instruments show consistent patterns and exhibit marked fluctuations ***at monthly timescales*** in response to tropical atmosphere-ocean dynamical processes associated with ENSO and ***Madden-Julian Oscillation***."
- Cloud structure changes are direct reflection of changes in large-scale dynamics in the tropics from one phase of Madden-Julian Oscillation (40-45 day period) to another. It is important to isolate the changes associated with different cloud types (cumulus, stratocumulus, stratus and deep convection) within MJO phases.
- How much changes in these properties are due to changes in the proportion of cloud types and how much due to changes in the properties within each cloud type with the MJO phase?

Cloud object methodology

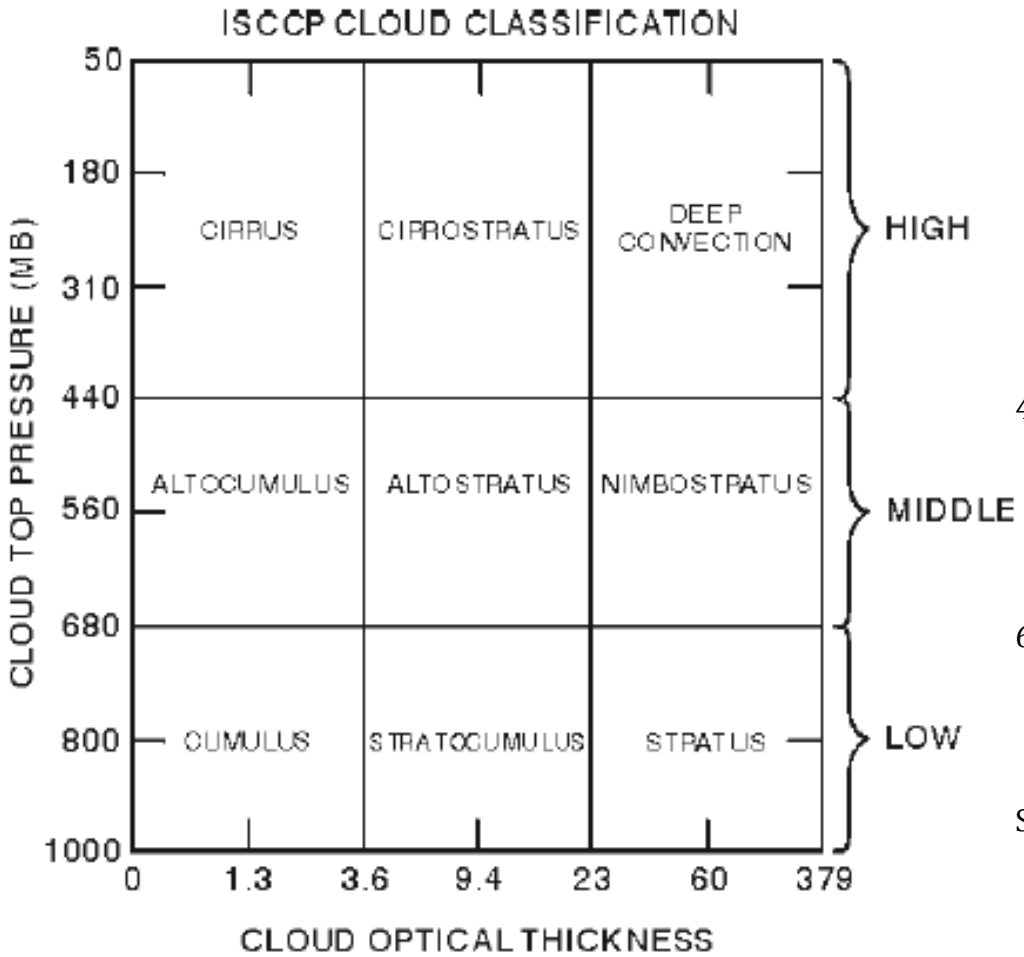
Wielick and Welch (1986)
Xu *et al.* (2005, 2007, 2008); level-2 data

- A contiguous patch of cloudy regions with a single dominant cloud-system type; no mixture of different cloud-system types
- The shape and size of a cloud object is determined by
  - the satellite footprint data
  - the footprint selection criteria
- The identified cloud objects of different types can be further categorized by the large-scale atmospheric conditions based on the Madden-Julian Oscillation (MJO) index in this study





Cloud object selection criteria for different cloud regimes

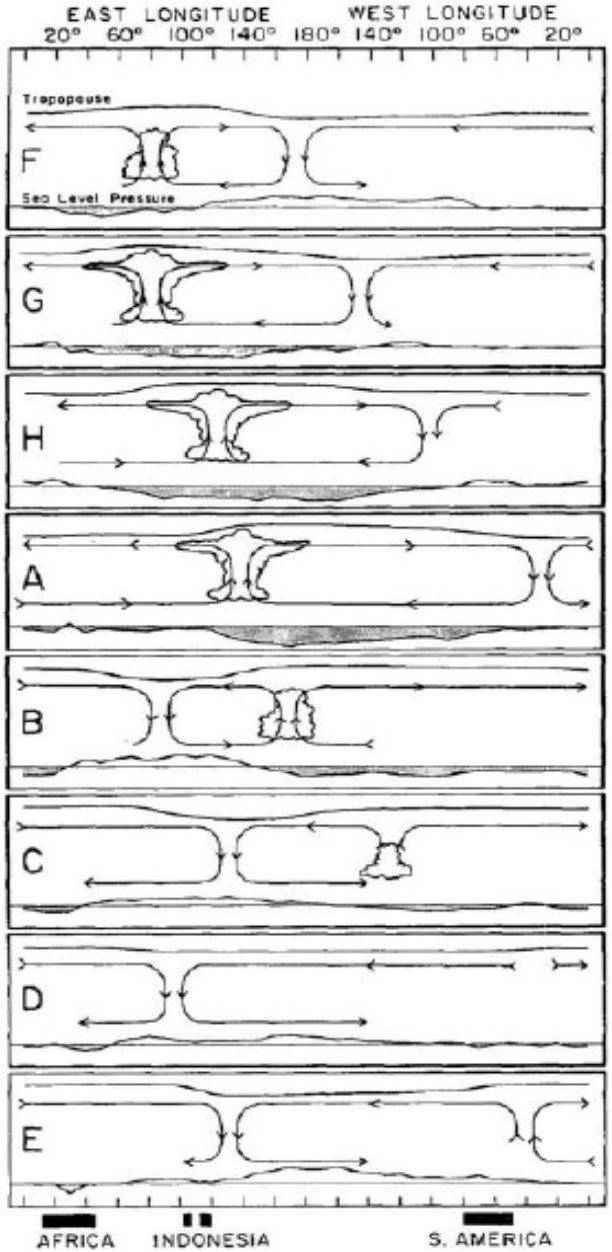


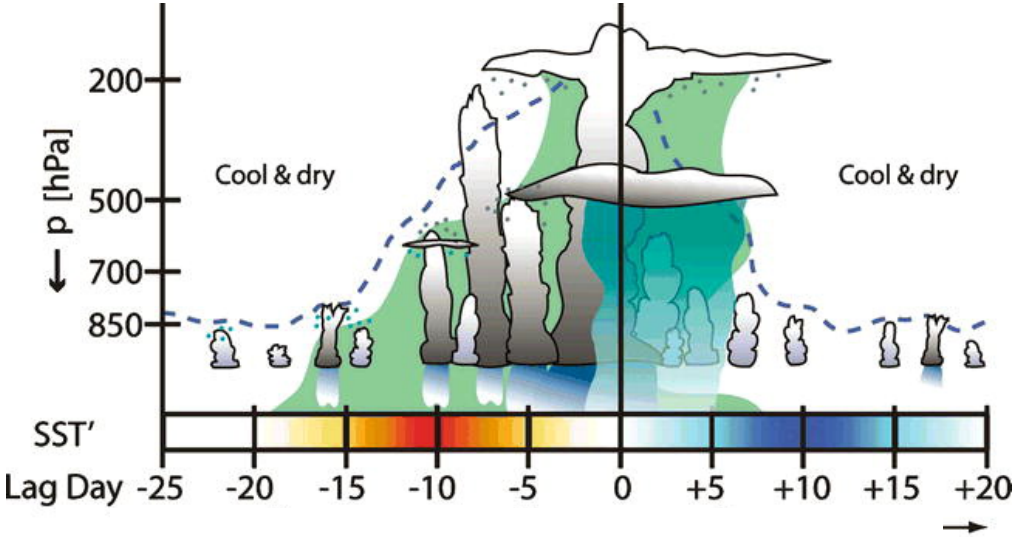
Cloud regime classification used in the cloud object analysis

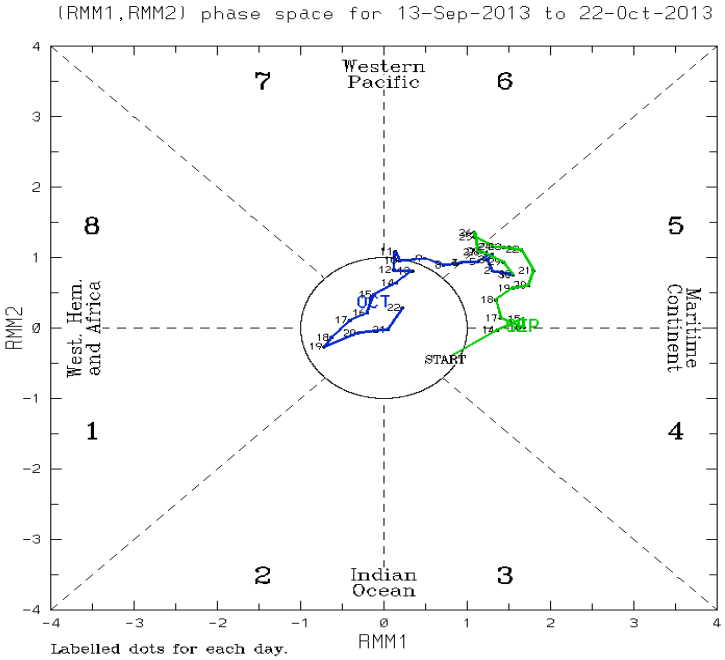
	Cirrus ($\tau < 10$)	Cirrocumulus ($\tau < 10$)	Deep convection ($\tau > 10$); Cirrostratus ($\tau < 10$)
440 hPa			
	Altocumulus	Transition altocumulus	Solid altocumulus
680 hPa			
	Shallow cumulus	Transition stratocumulus	Overcast/solid stratus
Surface			
	0.1	0.4	0.99 1.00

Cloud fraction

Madden-Julian Oscillation (MJO) and MJO index







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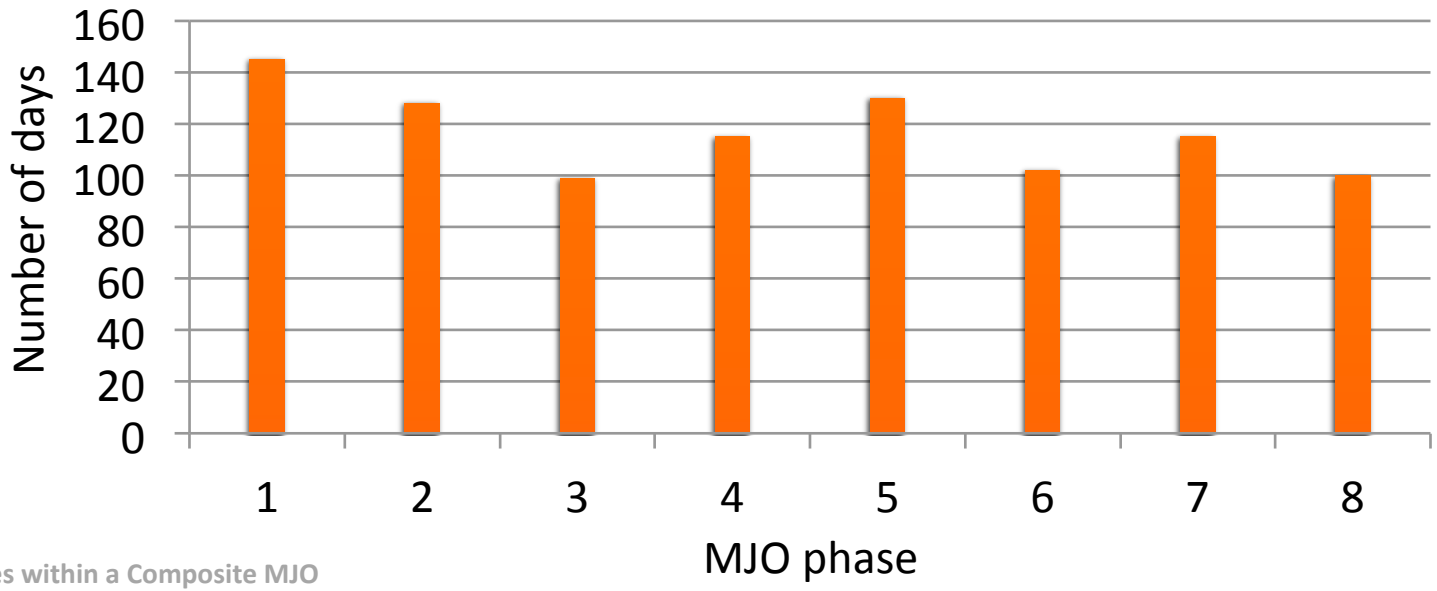
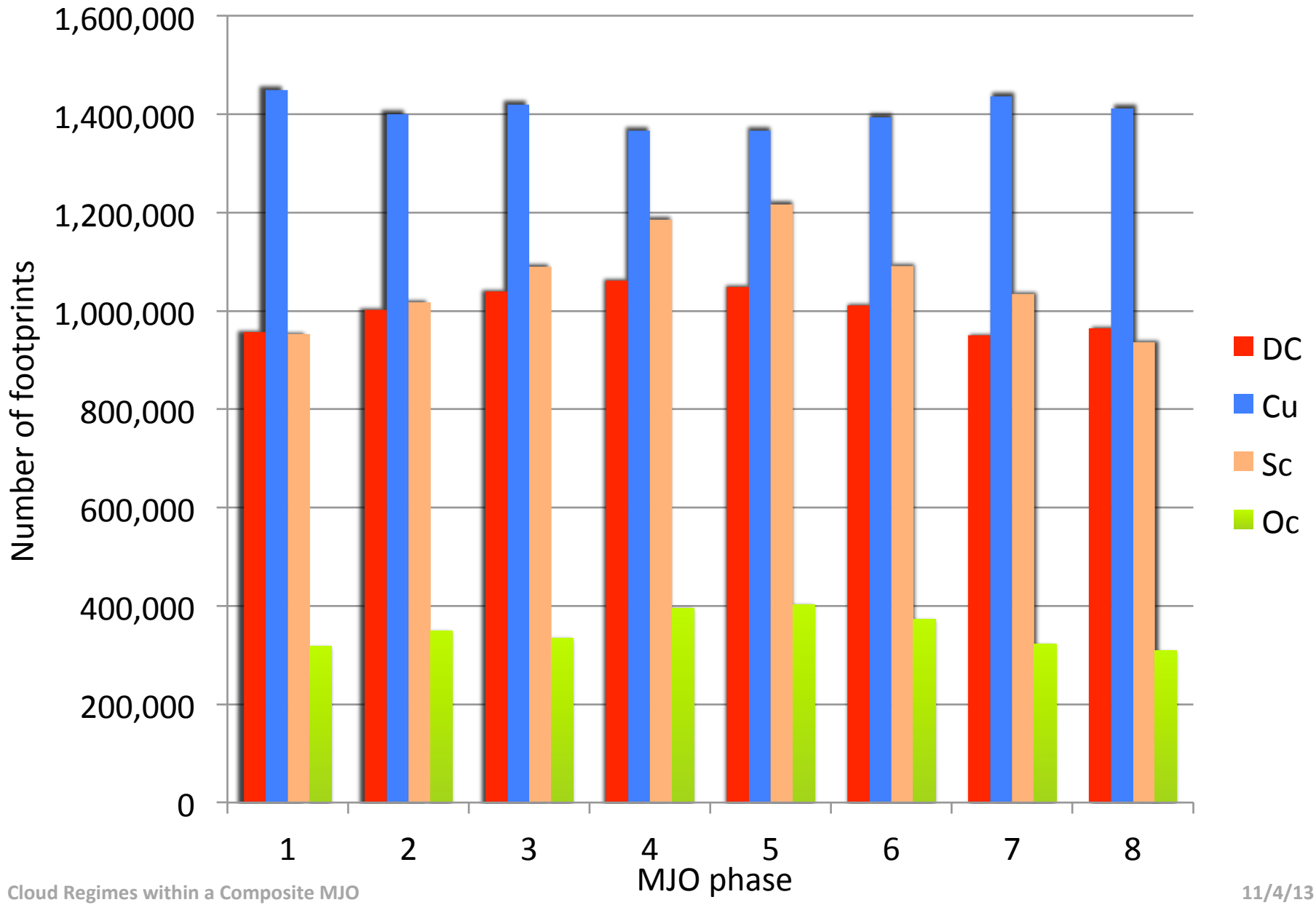
Data sets used in the analysis

- CERES Single Scanner Footprints (SSFs)
  1. Four year data on Aqua: July 2006 – June 2010
  2. 15°S to 15°N latitudinal band only (related to the MJO index)
  3. Four cloud object types: shallow cumulus, stratocumulus, overcast stratus and deep convection
  4. Other six cloud object types (middle and high levels) are being analyzed

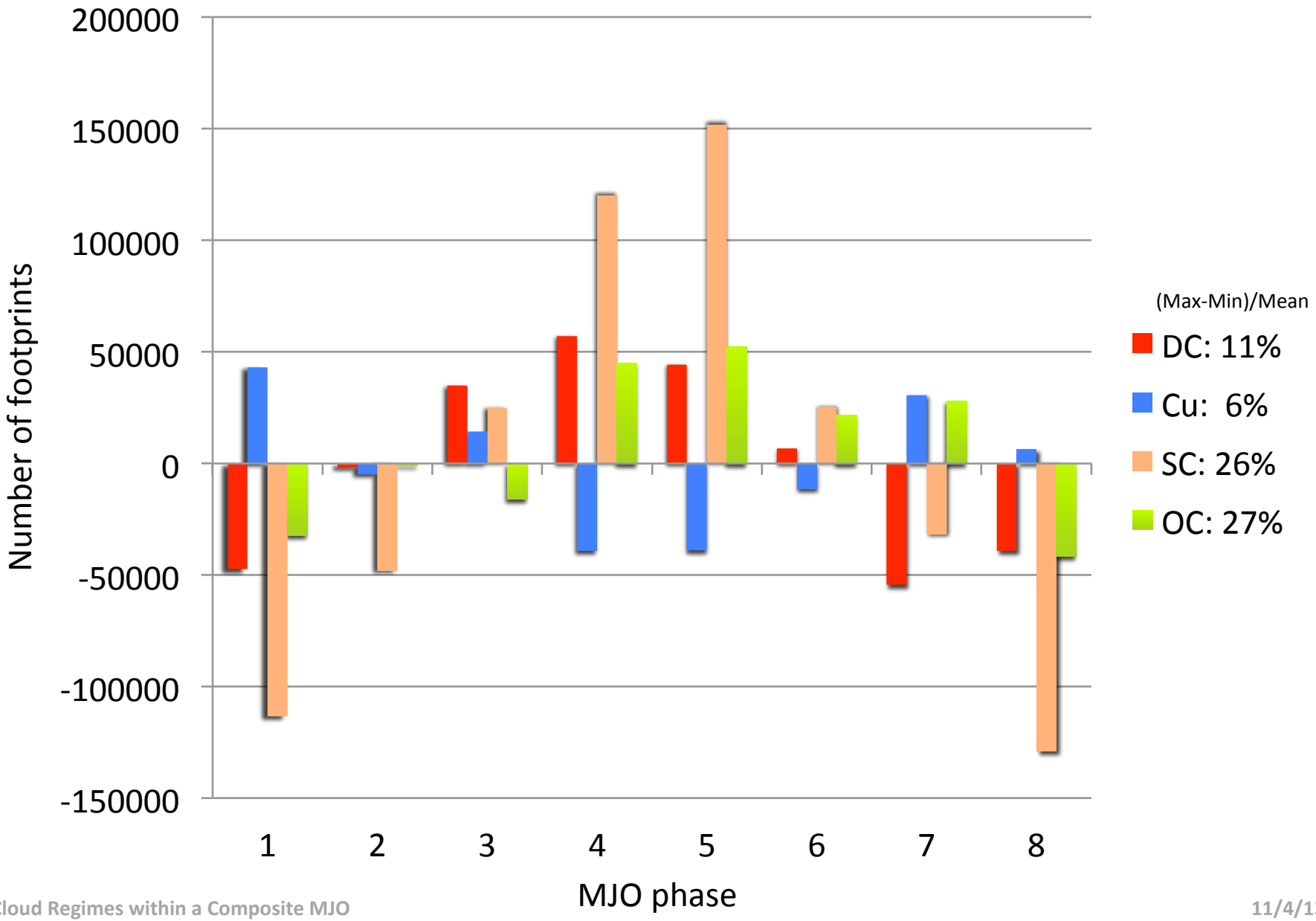
- Real-time Multivariate MJO (RMM) index (combined EOFs of u850, u200 and OLR)
  1. The days with amplitudes of $(RMM1^2+RMM2^2)^{1/2} > 1$ are used; 934 (out of 1461) days
  2. Eight MJO phases and the corresponding numbers of days are shown below
  3. All frequencies of occurrence shown later are normalized by 116.75 days



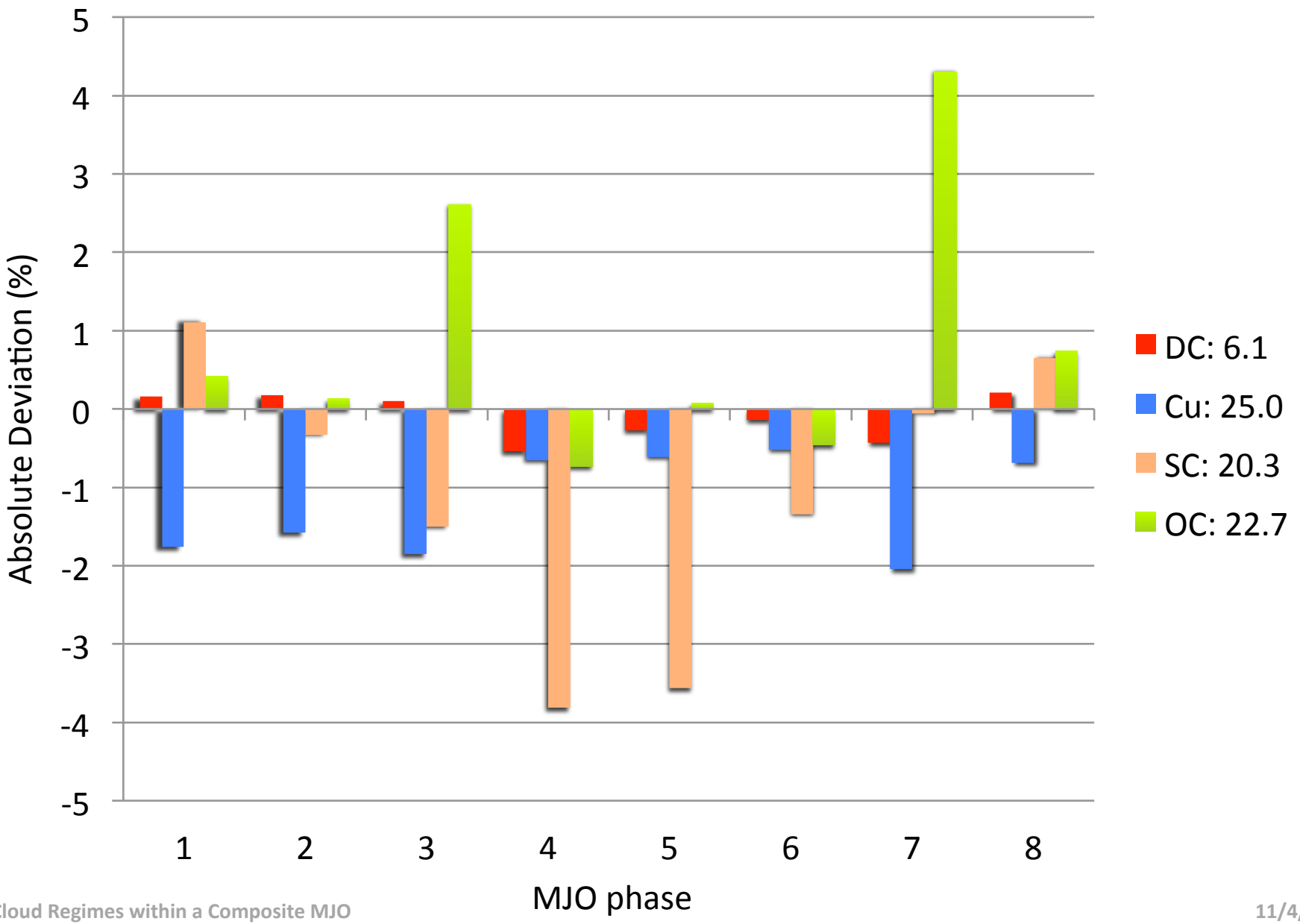
Total numbers of satellite footprints for MJO phases



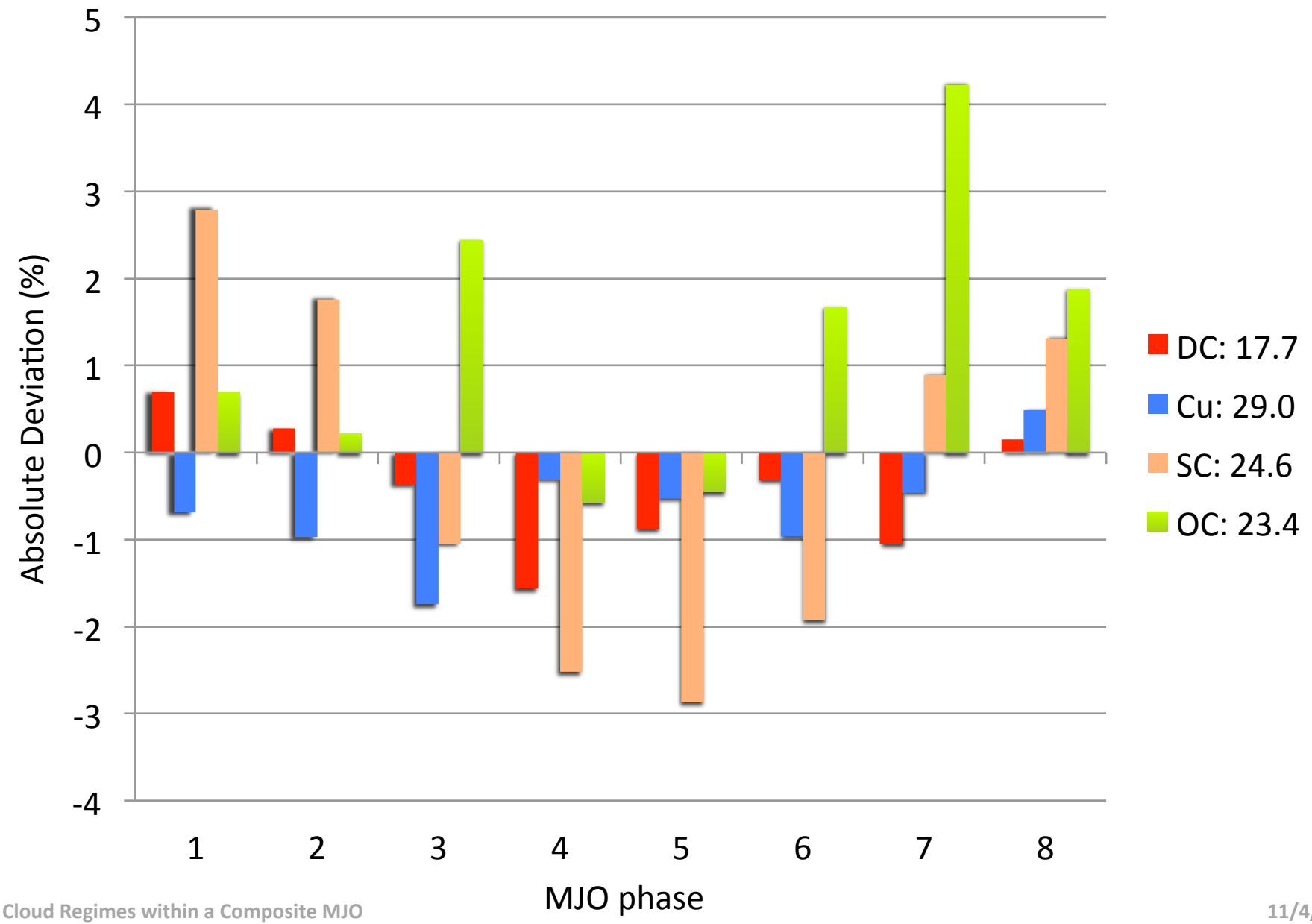
Deviations of satellite footprints for MJO phases



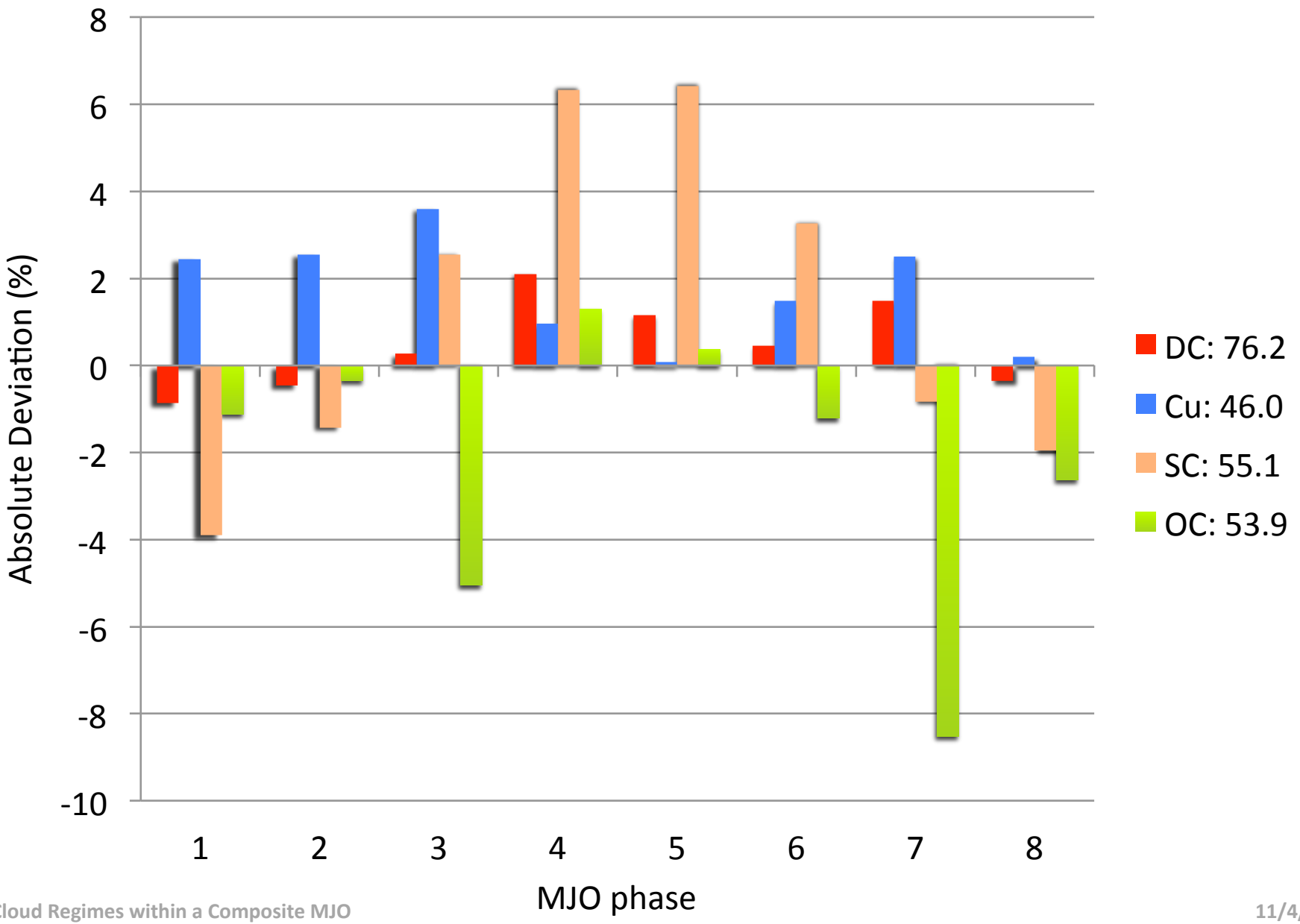
Relative proportion vs. climatology for small size category



Relative proportion vs. climatology for medium size category

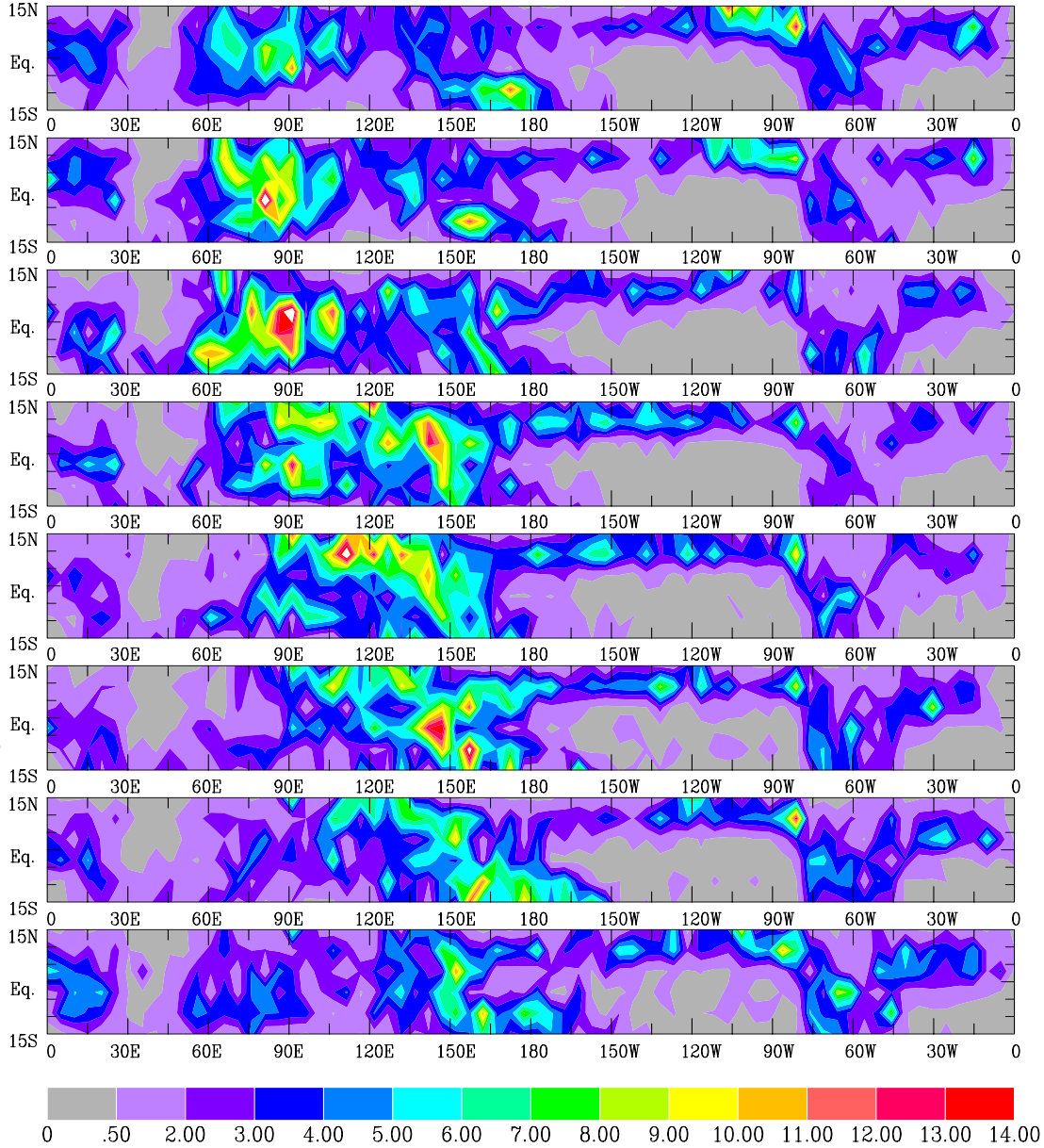


Relative proportion vs. climatology for large size category



Area coverage of deep convective cloud objects

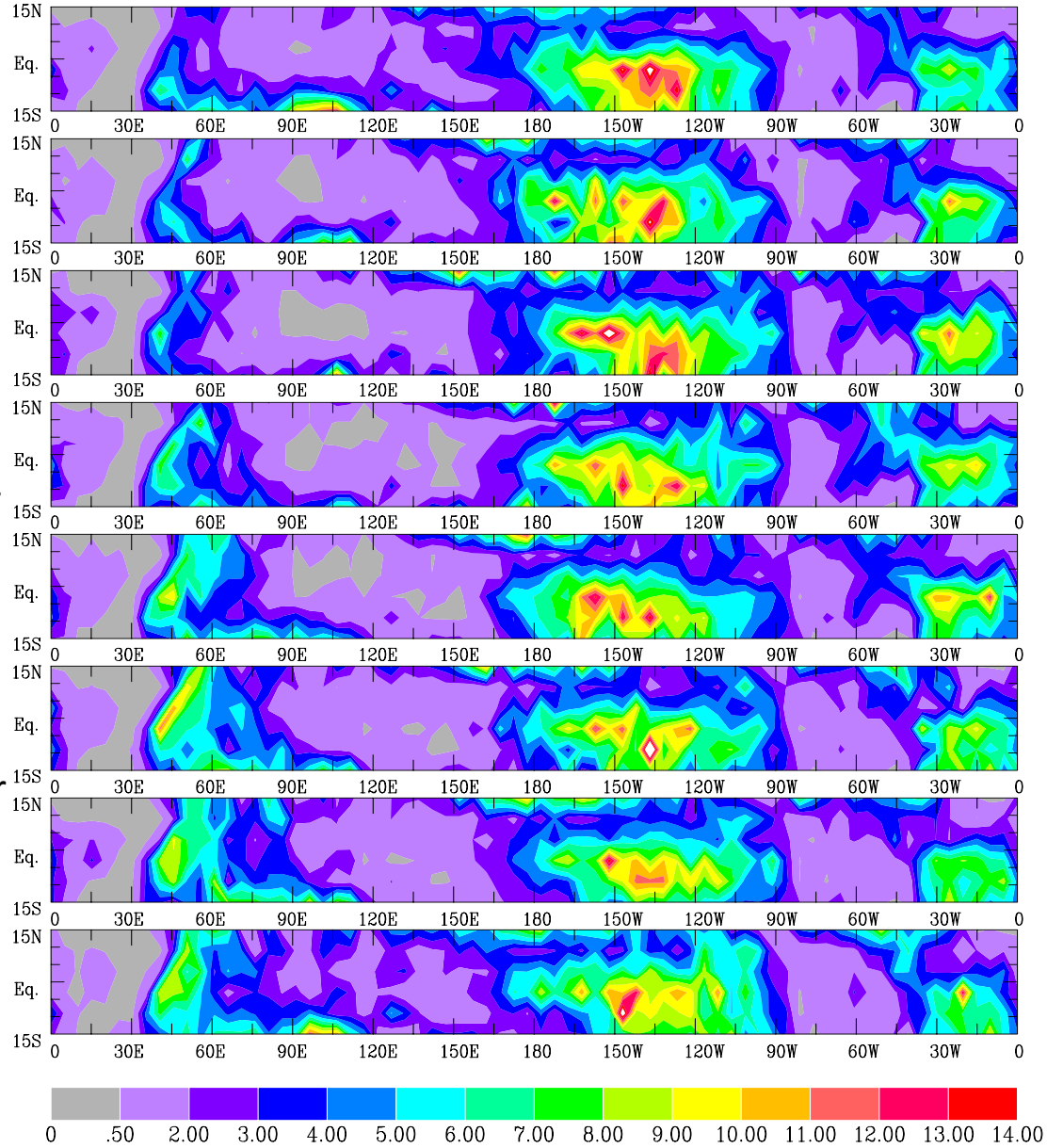
- ✓ Eastward propagation
- ✓ Active convection over maritime continent
- ✓ Dissipation over C. Pac.
- ✓ Most DC cloud objects over India-Pacific
- ✓ Implication for dynamics



Color bar in 10^3 footprints per 5° x5° grid mesh; ~1.1% area coverage

Area coverage of shallow cumulus cloud objects

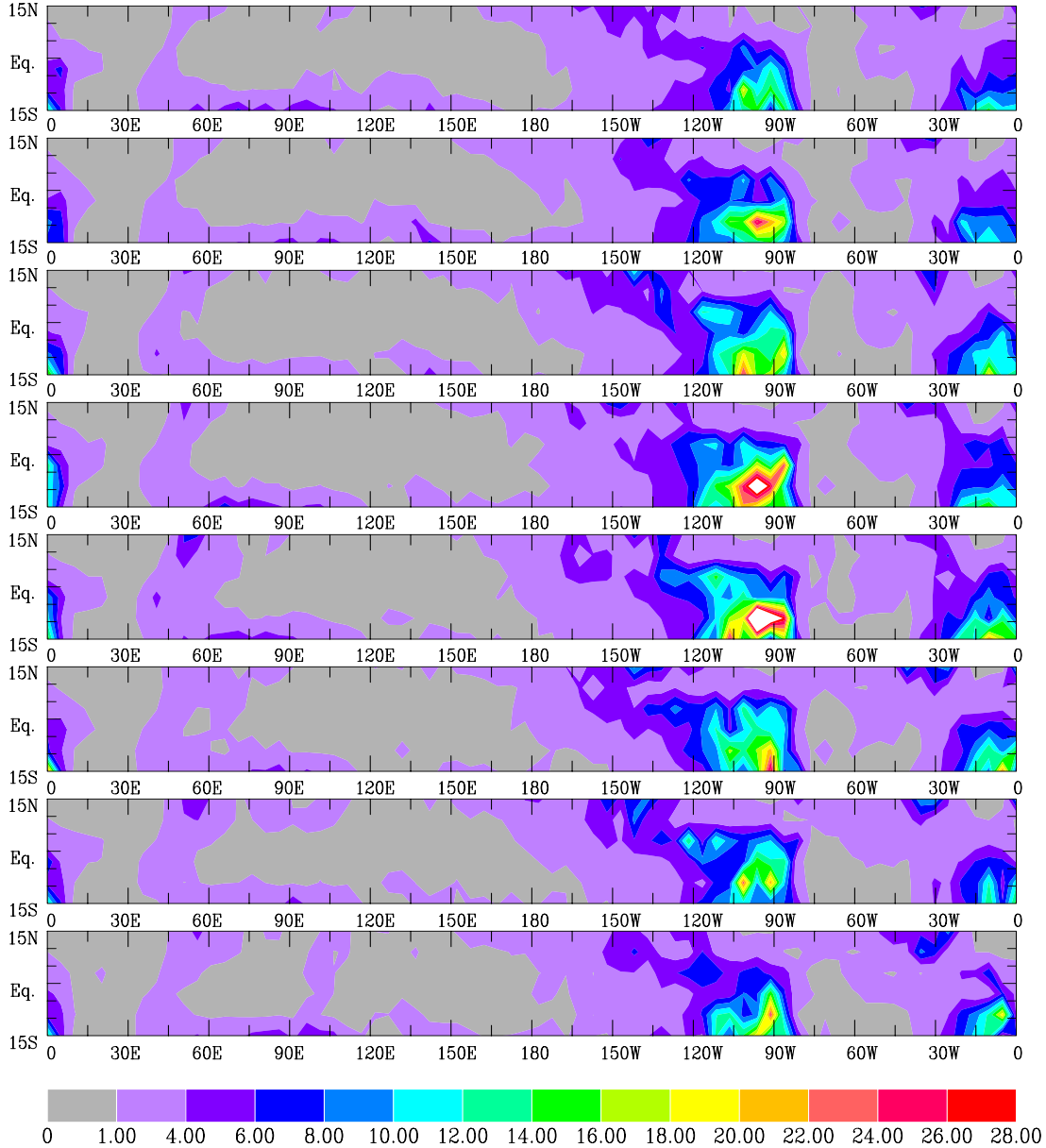
- ✓ Not much propagation
- ✓ Shallow convection over east/central Pacific
- ✓ Strong variations and movements over Indian Ocean
- ✓ No enhancement of shallow convection near DC prior to peak phases



Color bar in 10^3 footprints per 5° x5° grid mesh; ~1.1% area coverage

Area coverage of stratocumulus cloud objects

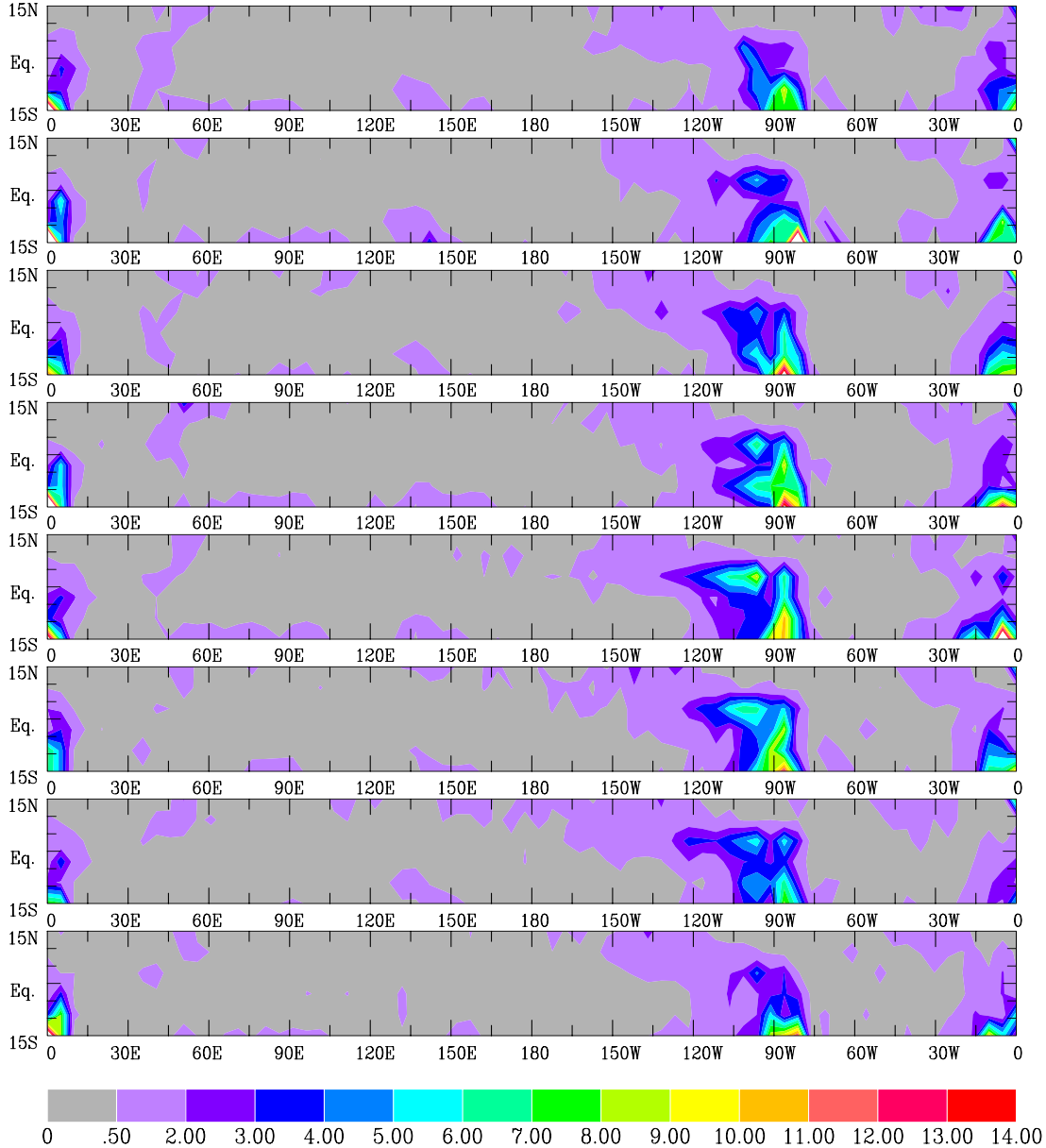
- ✓ Not much propagation
- ✓ Concentrated over east Pacific + Atlantic
- ✓ Enhancement during peak phases due to subsidence associated with Walker circulation
- ✓ East Atlantic lags east Pacific by 1-2 phases



Color bar in 10^3 footprints per 5° x5° grid mesh; ~1.1% area coverage

Area coverage of overcast stratus cloud objects

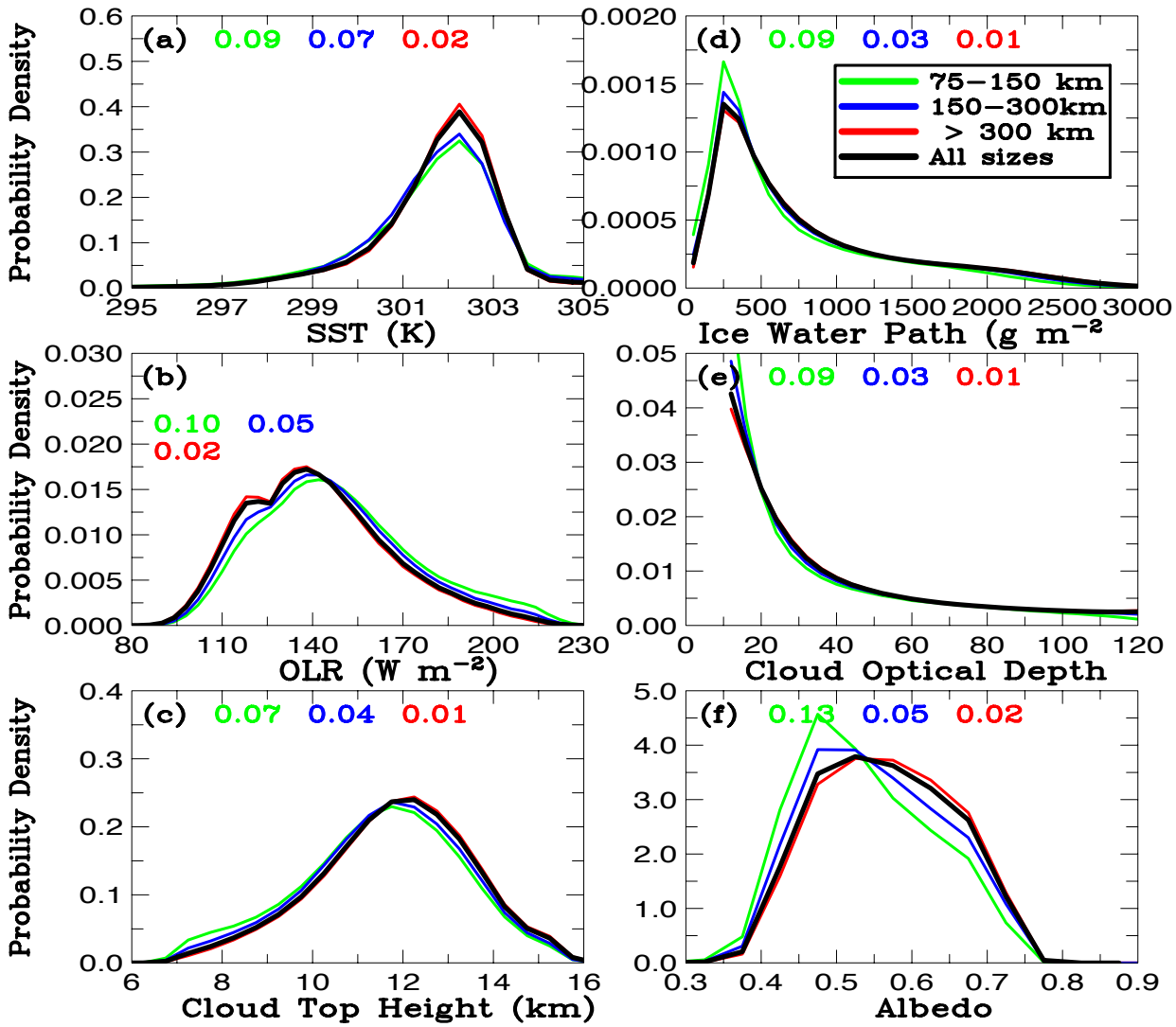
- ✓ Similar to SC in all aspects



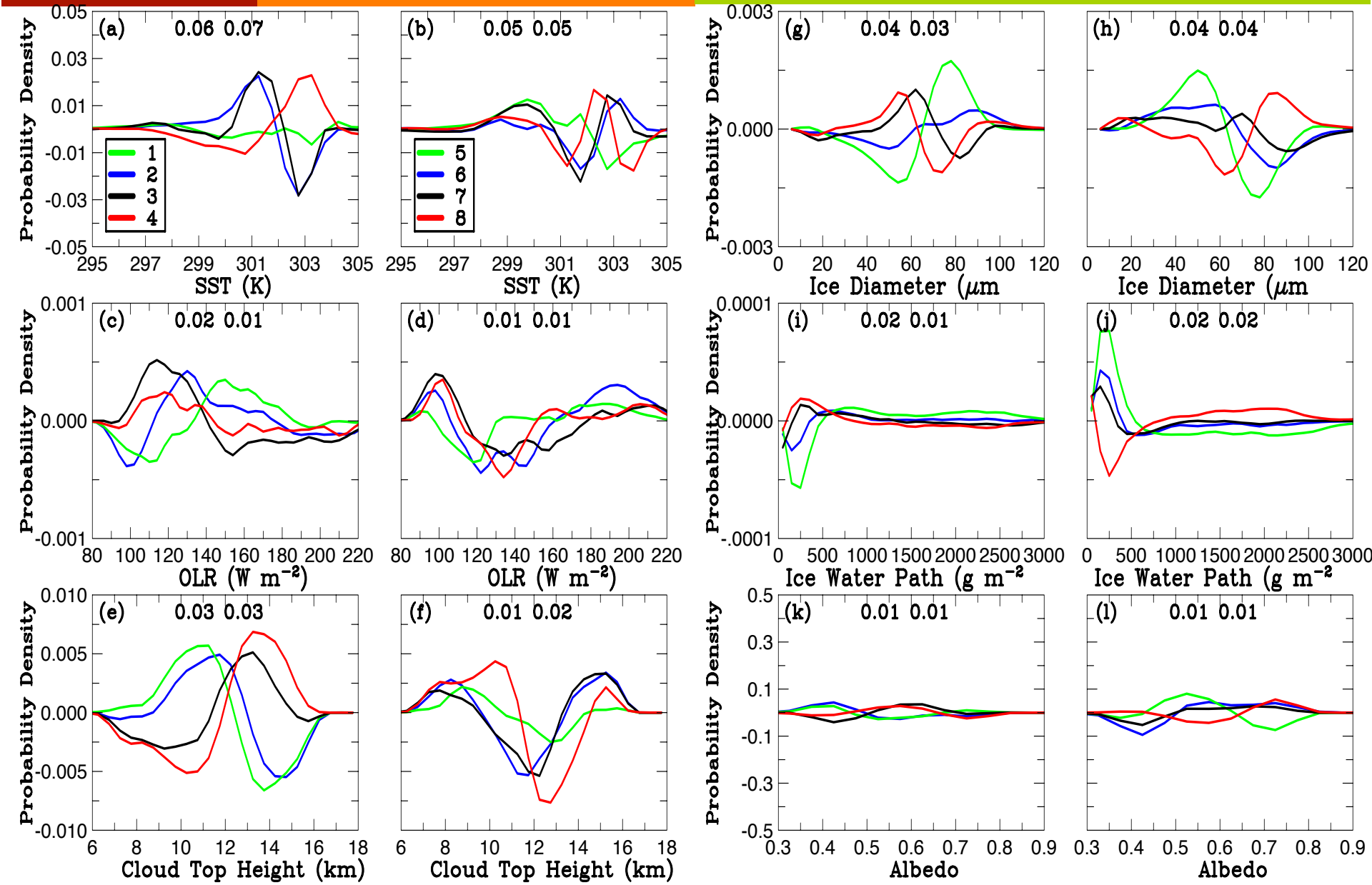
Color bar in 10^3 footprints per 5° x5° grid mesh; ~1.1% area coverage

Variations of cloud and radiative properties during MJO

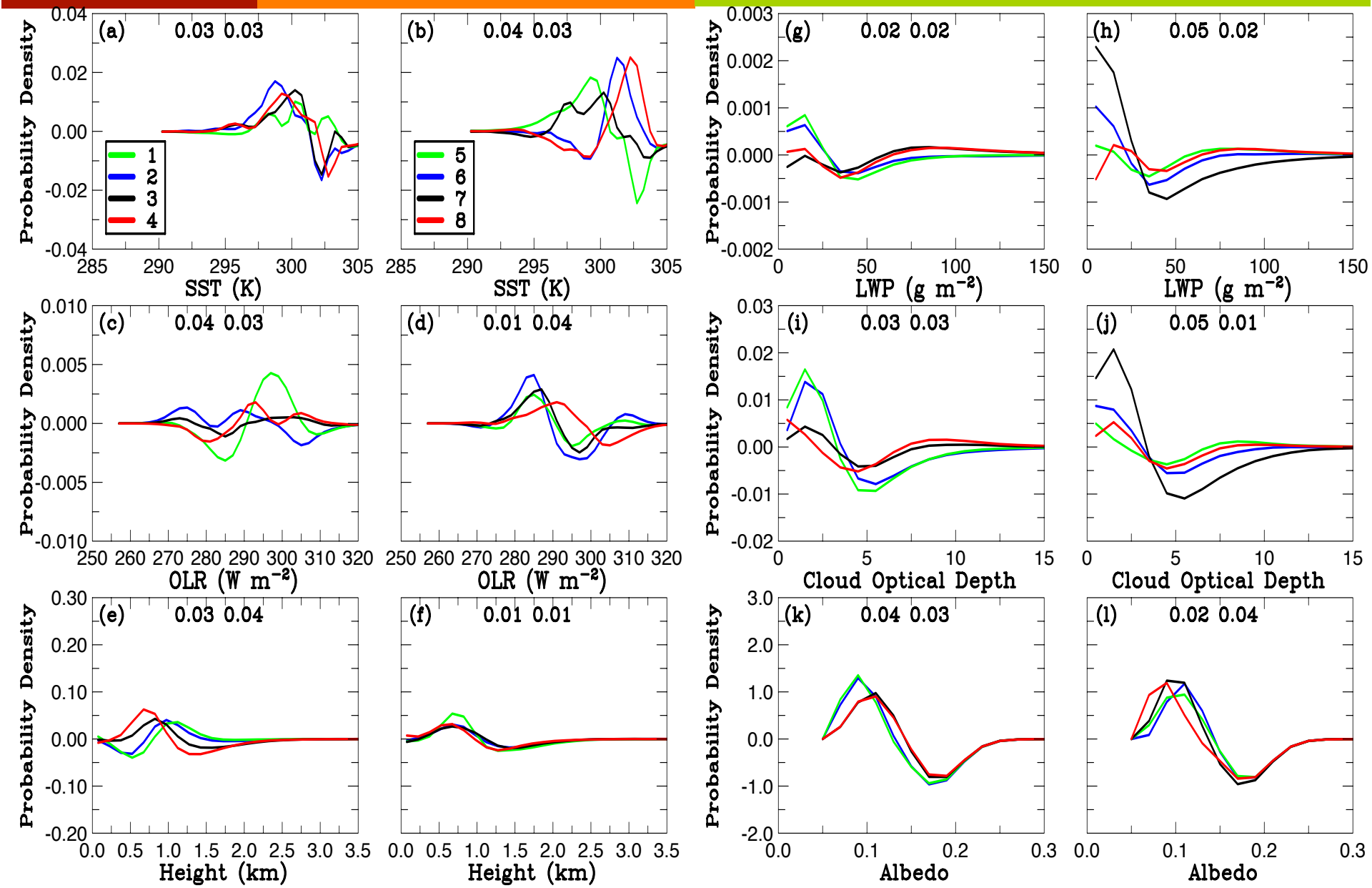
Instead of the entire PDFs for each phase, we will show the deviations of PDF from the all-phase PDFs



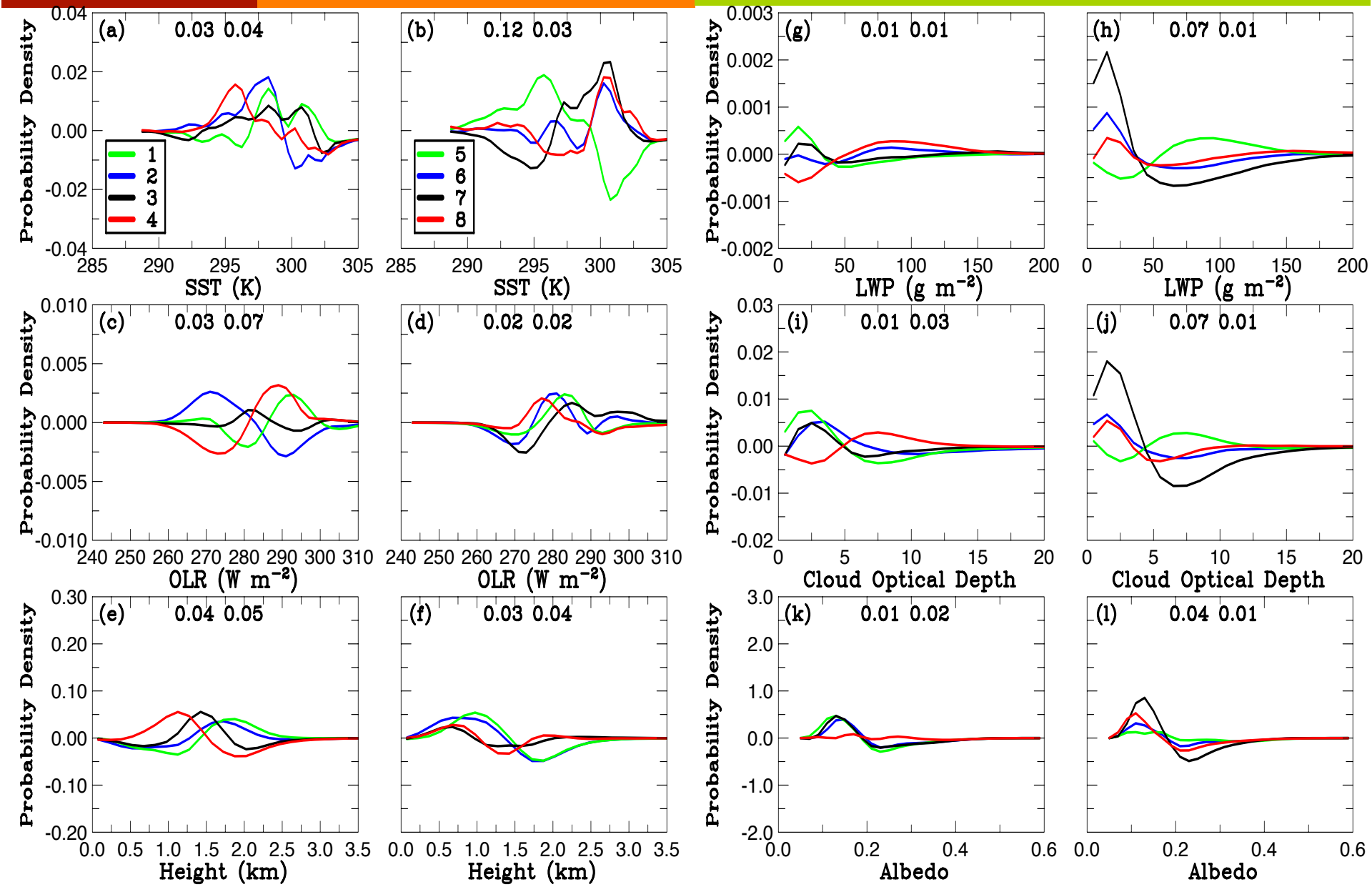
Deep convective cloud object properties



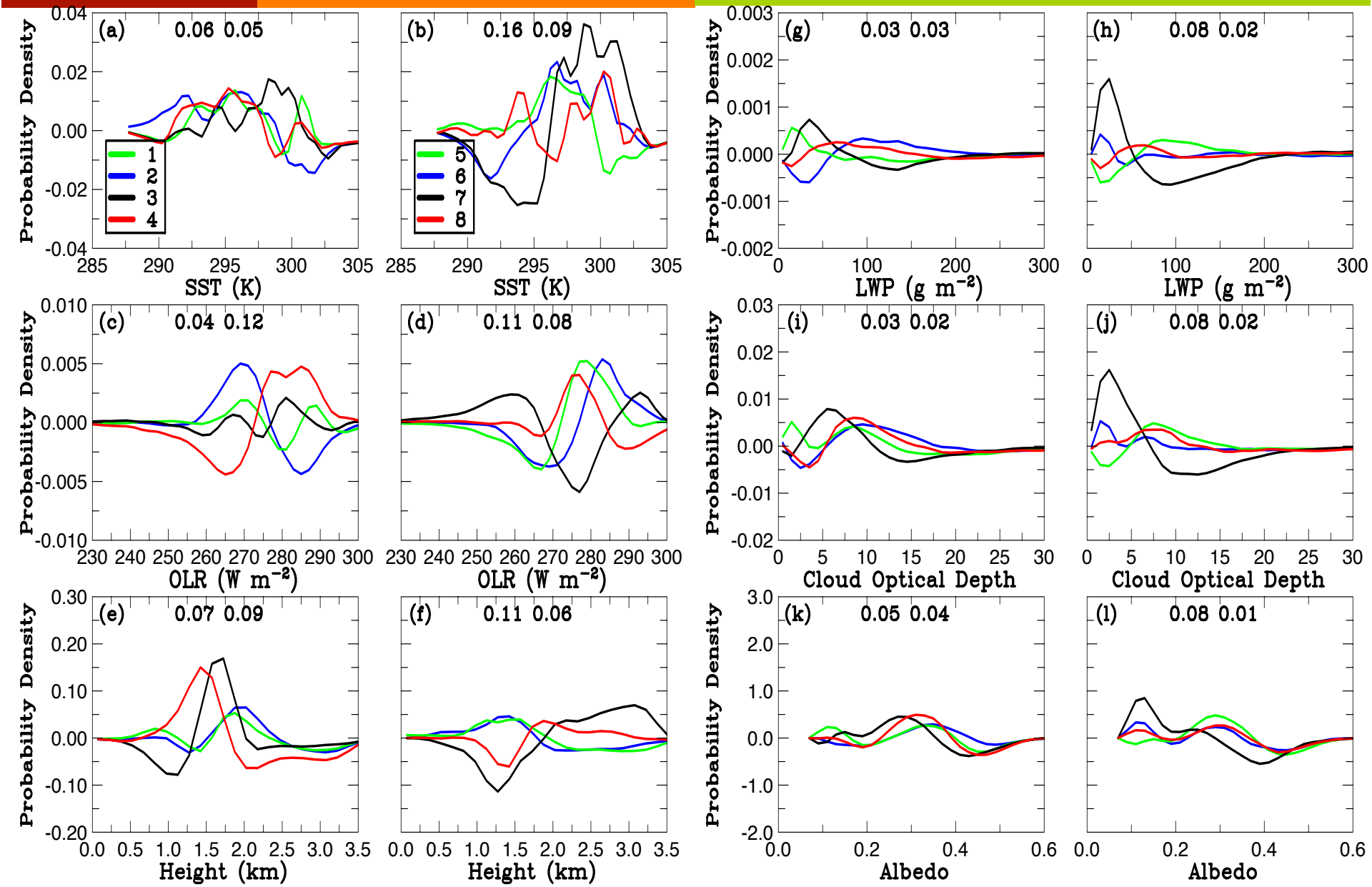
Shallow cumulus cloud object properties



Stratocumulus cloud object properties



Overcast stratus cloud object properties



Summary

- A typical description of MJO cloud population:
  - Extensive deep convection during the mature (3-5) phases
  - Suppressed deep convection during the other phases (1, 7 an 8)
  - Lots of shallow convection during the depressed phases
  - Slightly enhanced shallow convection preceding the deep convection phases
- Qualitatively, this description is correct. But the contrasts between the suppressed and active phases are exaggerated. That is, deep convection is more active than previously thought during the depressed phases. The change from min to max is only 11% for DC, but much larger for SC and OC cloud objects (26-27%).
- Compared to climatology, more large-size cloud objects are present during active phases at the expense of small-size cloud objects. Exceptions are cumulus cloud object during the depressed phases and Overcast cloud objects at Phases 3 and 7.
- There are phase lags between DC and SC/OC cloud objects. The out-of-phase relationship between SC and Cu is pronounced during very active/depressed phases.
- Eastward propagation is only pronounced for DC cloud objects. The frequencies of occurrence for Cu/SC/OC are modulated by the deep convective activities even though the physical locations of these cloud object types are far away from the convective centers.
- Changes in the properties within each cloud type with the MJO phase are relatively small, but some of properties (cloud top height and ice diameter for DC; cloud top height/OLR and albedo for Cu/SC/OC) exhibit significant changes from one phase to another. Phase 7 seems to be very different for Cu/SC/DC cloud object properties.

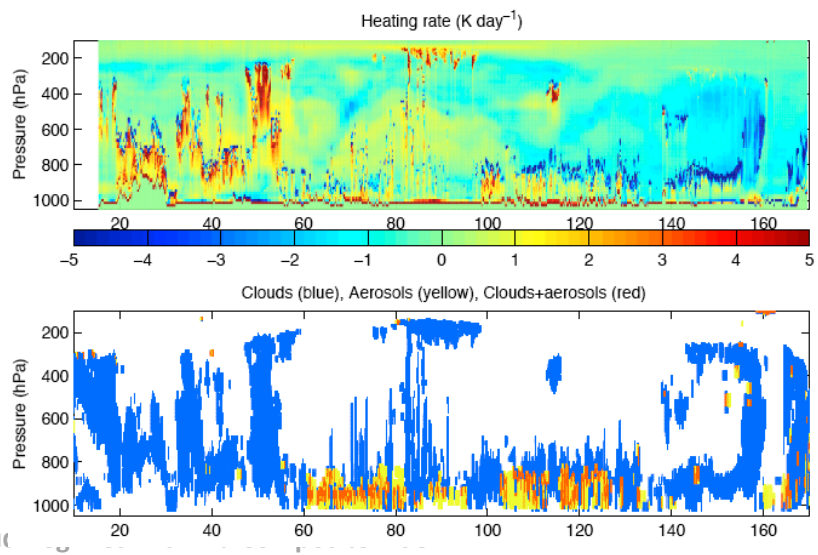
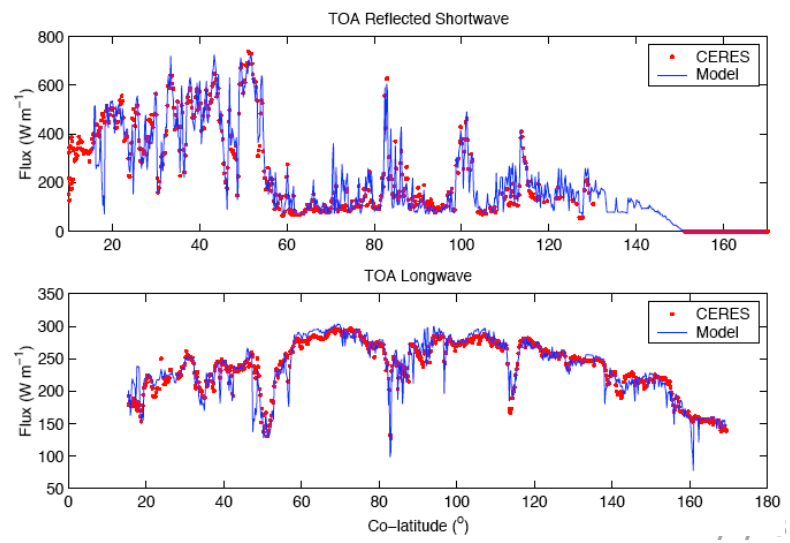
C3M (CCCM) product

- Contains:

1. Merged CALIPSO, CloudSat derived clouds, CERES TOA radiative flux (SW, LW, and WN), MODIS (CERES_ST) derived cloud properties both along CALIPSO-CloudSat ground-track and over the whole CERES footprint,

2. MODIS derived cloud properties by an enhanced cloud algorithm,

3. CALIPSO and MODIS derived aerosol properties

4. Vertical radiative flux profiles computed with CALIPSO (version 3), CloudSat, and MODIS derived cloud properties.

- Data are available from http://eosweb.larc.nasa.gov/PRODOCS/ceres-news/table_ceres-news.html