Madden-Julian Oscillation in the Superparameterized Community Atmosphere Model

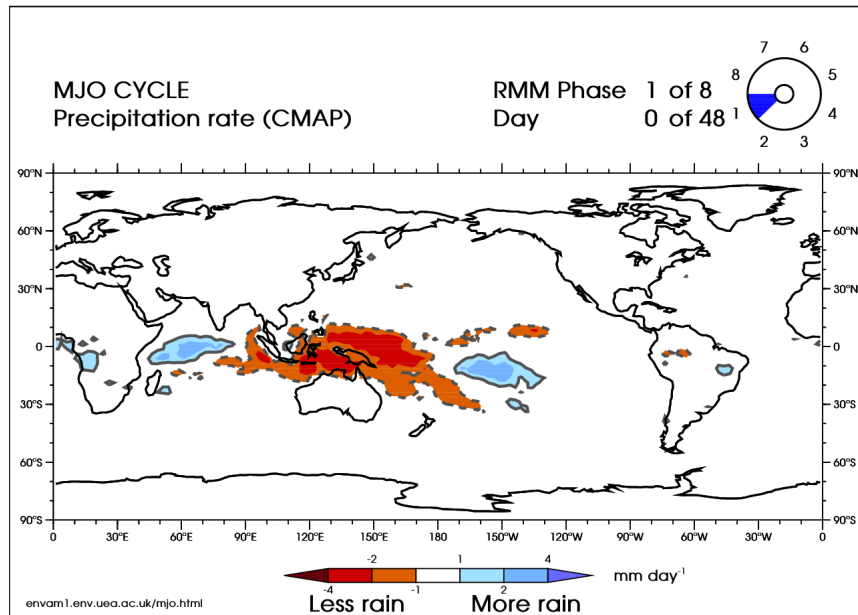Jim Benedict ~ Berkeley National Lab

Dave Randall & Randall Group, CSU
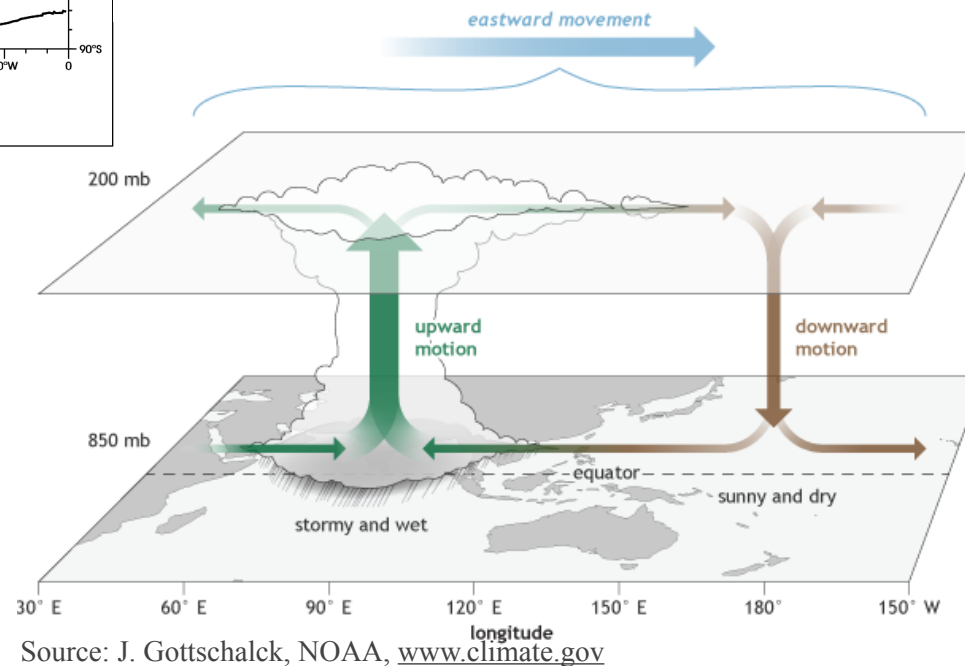Eric Maloney & Maloney Group, CSU
Bill Collins, LBL

CMMAP Semiannual Meeting // Aug. 2015
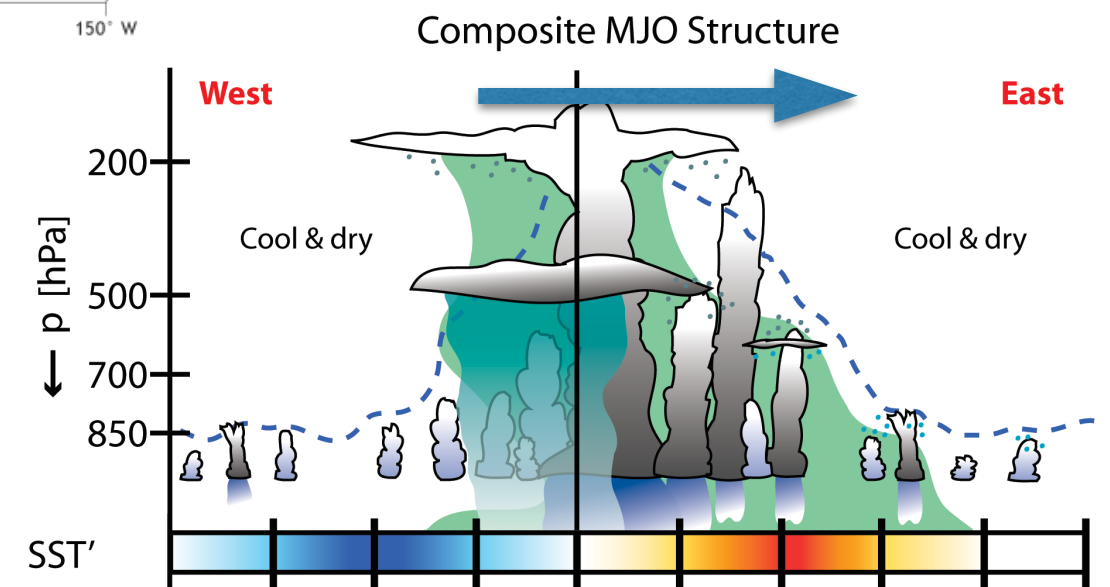
Madden-Julian Oscillation (MJO)

MJO CYCLE
Precipitation rate (CMAP)

RMM Phase 1 of 8
Day 0 of 48

Less rain   More rain   mm day⁻¹

Source: A. Matthews, http://envam1.env.uea.ac.uk/mjo.html

- Cyclic rainy and dry periods (30-90 days) with shifts in wind

- Continent sized

- Slow (5 m/s) eastward movement, mainly across equatorial Indian and Pacific Oceans
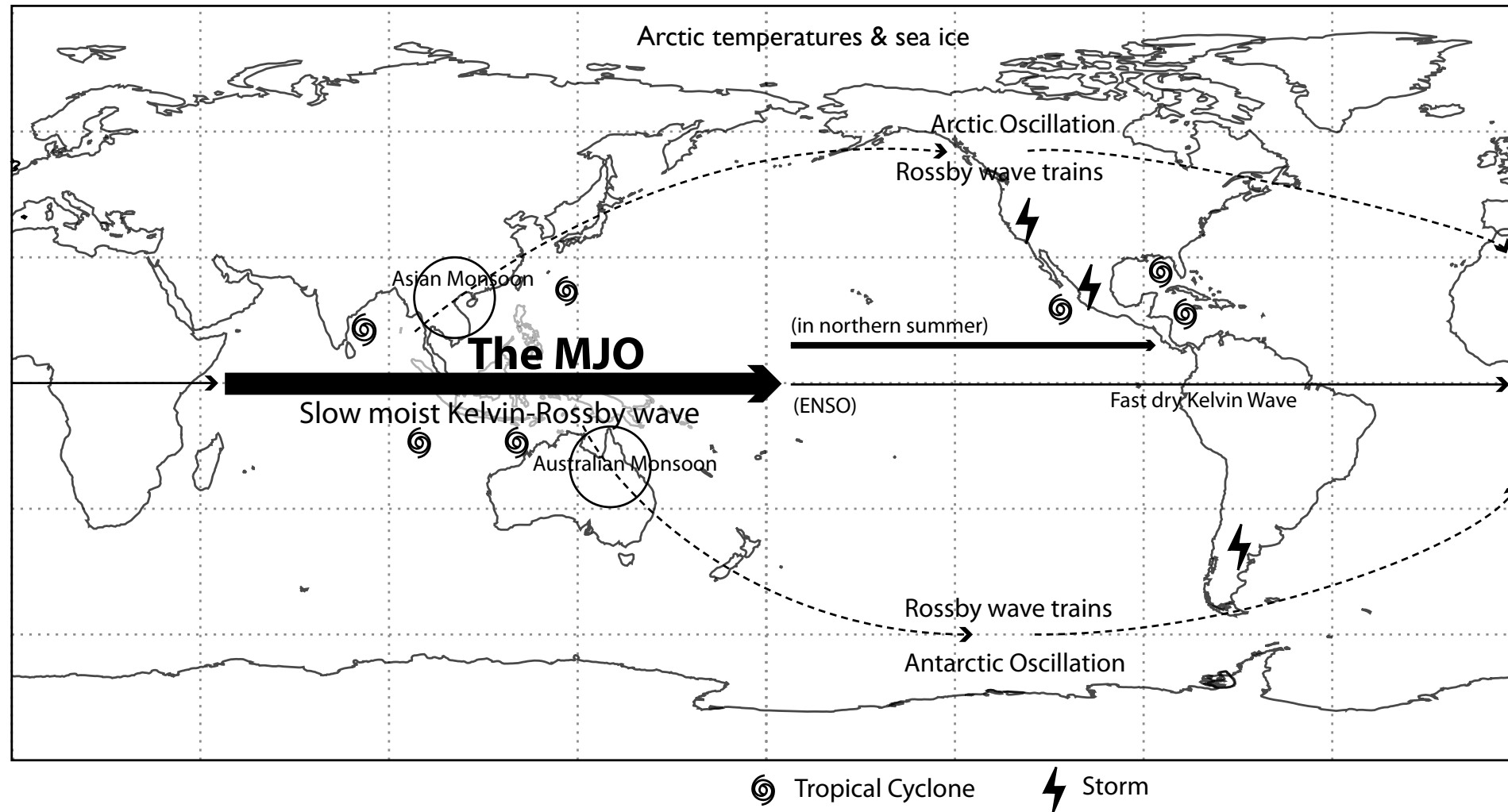
- Irregular initiation

eastward movement

200 mb

upward motion   downward motion

850 mb

equator

stormy and wet   sunny and dry

longitude

Source: J. Gottschalck, NOAA, www.climate.gov

- Mechanisms describing convection onset and eastward movement remain inadequate

- Interaction between convection, ambient moisture, wind, radiation, and surface evaporation is key

- Multi-scale: MJO "envelope" modulates other, smaller waves

Composite MJO Structure

West   East

p [hPa]

Cool & dry   Cool & dry

200
500
700
850

SST'

Source: Adapted from Benedict & Randall (2007)

Why the MJO?

Source: K. Thayer-Calder, adapted from Lin et al. (2006)

- ‣ MJO has significant local and global impacts
- ‣ Most conventional climate models struggle to simulate the MJO
- ‣ Weather and climate predictability suffers without accurate MJO
- ‣ MJO: A testbed to expose flaws in our understanding of clouds

SPCAM & MJO: Timeline

1971: MJO discovered

1999: Multiscale modeling framework in climate science pioneered

2001: Superparameterization (SP) of CAM

2005: SPCAM found to produce realistic MJO signal

2008-2009: Many physical aspects of SPCAM's MJO found to closely resemble observations (prescribed SSTs)

2010-11: Further improvements to MJO simulation when SPCAM is coupled to simplified or dynamical ocean models

2013-14: SPCAM predicts more frequent and intense MJOs in a warming climate
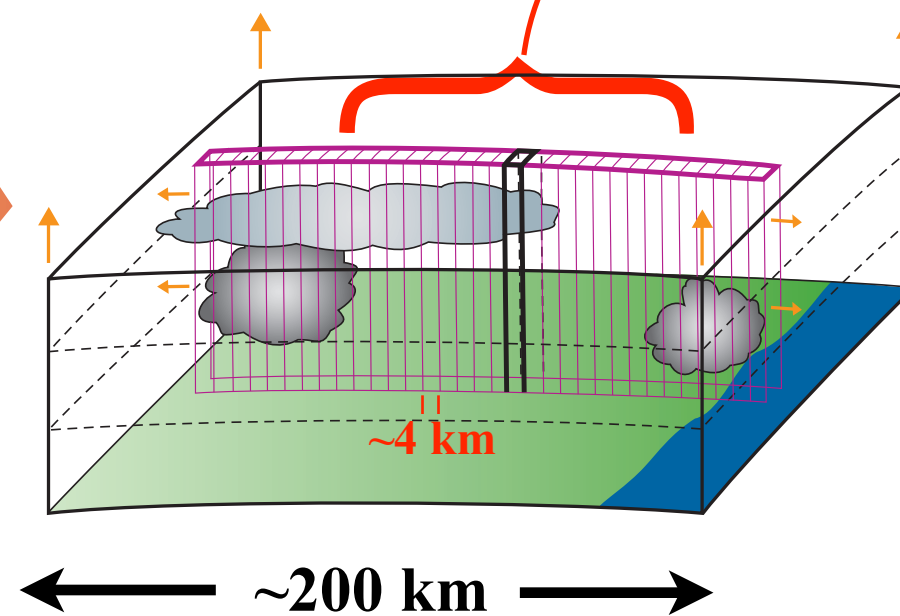
2014-2015: Moisture advection and cloud-radiative feedbacks found to be critical to MJO existence in SPCAM
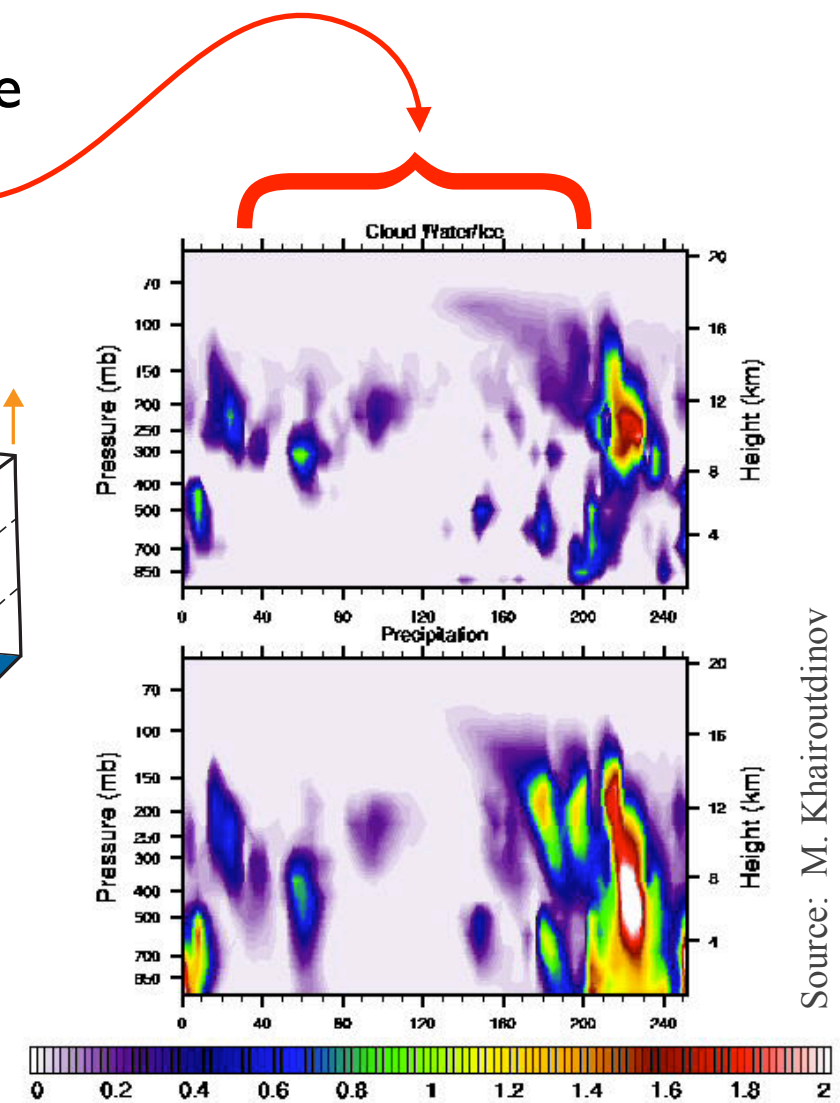
Superparameterization (SP)

‣ Parameterization: Statistical theory that attempts to explain the general behavior of an unresolved process (e.g., a cumulus cloud)

‣ SP: Replaces cloud-related parameterizations by embedding a cloud-resolving model into each climate model grid cell

‣ SP allows clouds and their environment interact in a more nature manner

Source: UCAR

Source: M. Khairoutdinov
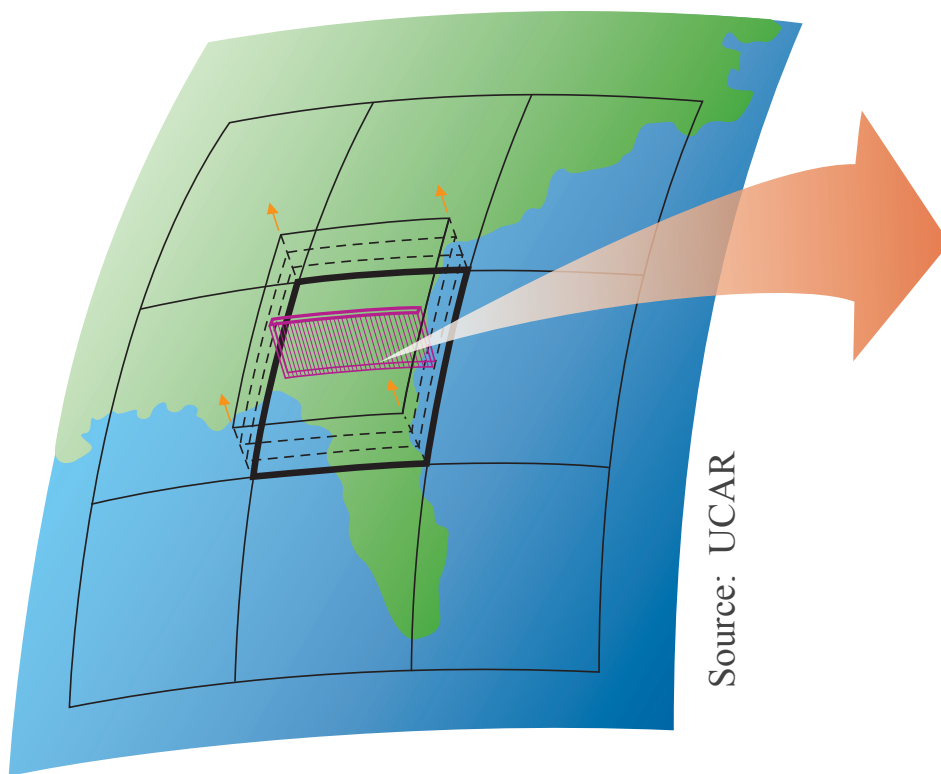
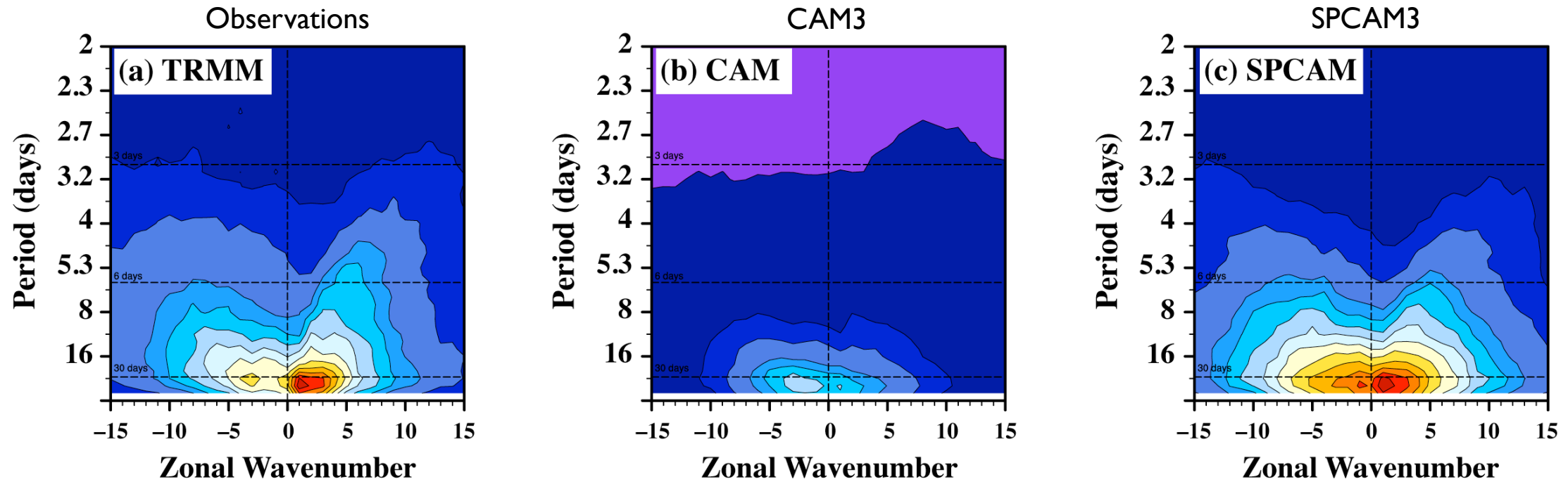Within each climate model grid cell…   …is a "curtain-shaped" high-resolution cloud-resolving model…   …that explicitly simulates clouds and precipitation.
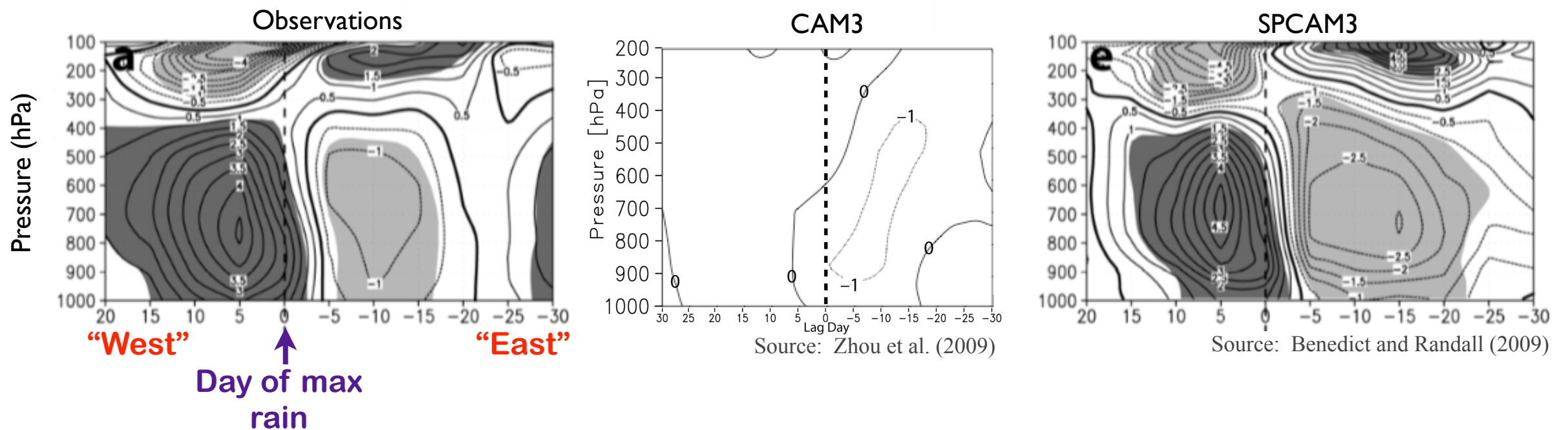
Selected Findings

Tropical Rainfall Power Spectra (Symmetric)

Source: Benedict et al. (2013)

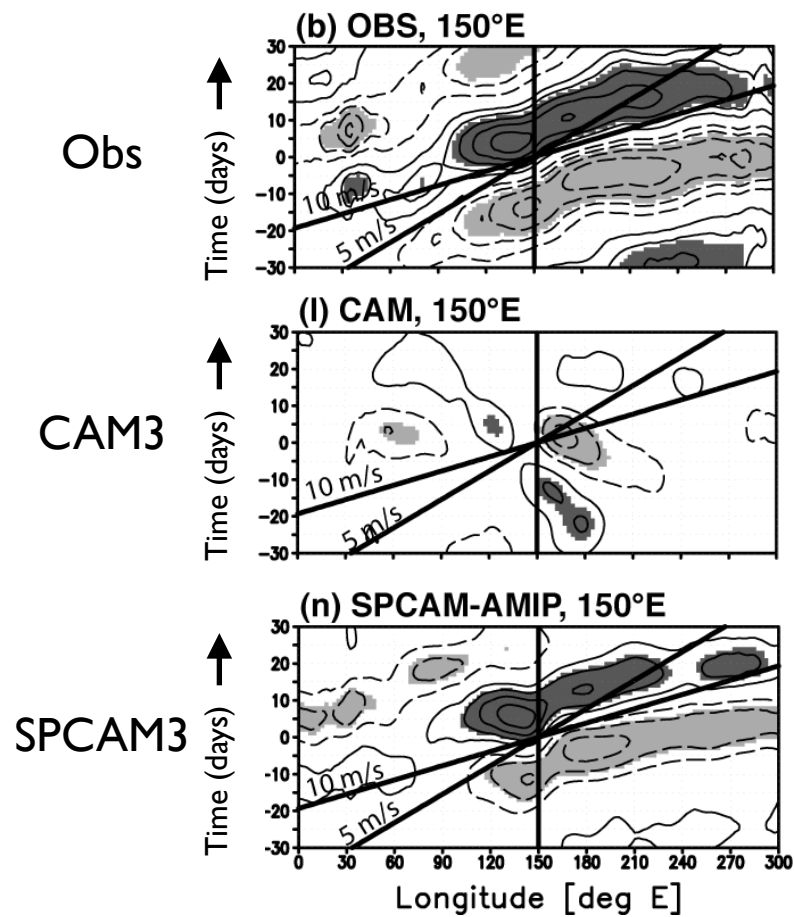## Lag Composite Cross-section of Zonal (West-East) Wind Anomalies

Source: Zhou et al. (2009)

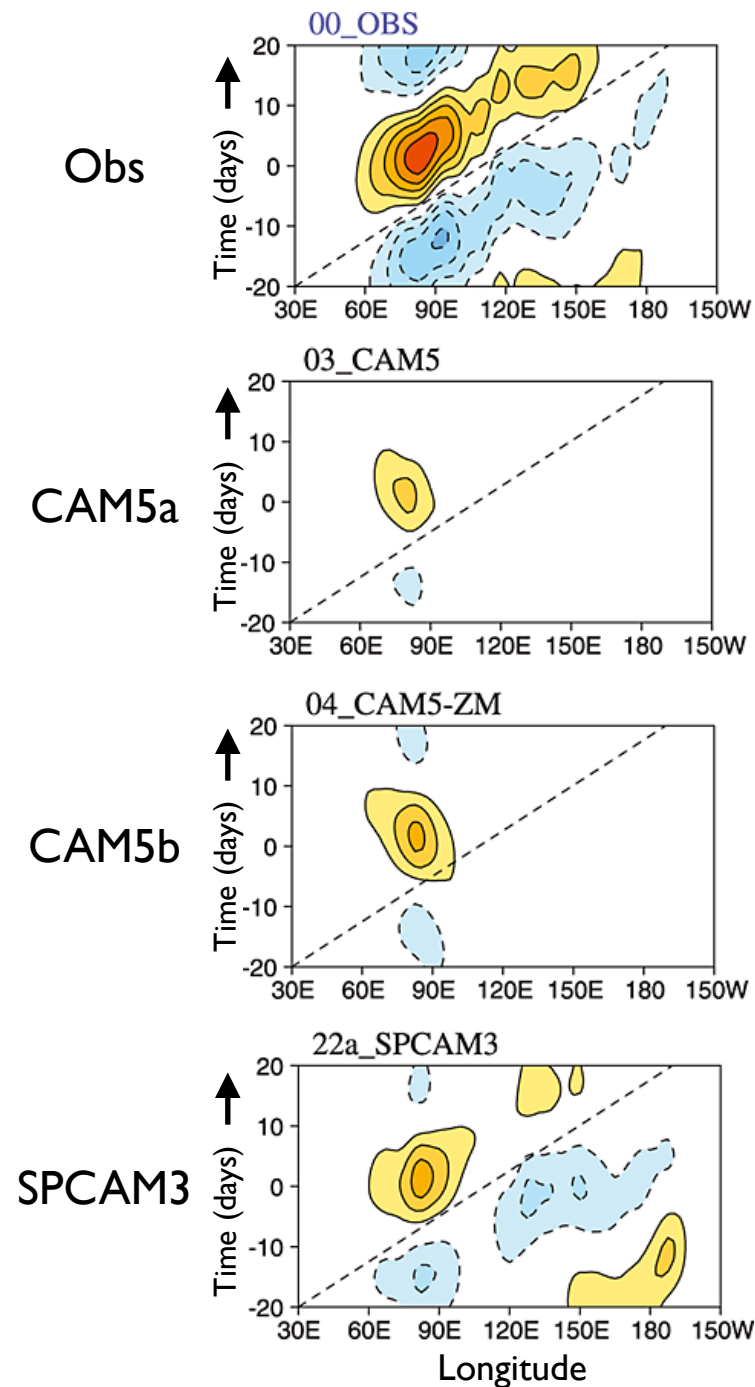Source: Benedict and Randall (2009)

Selected Findings

Lag correlation:
Rain based at 150°E
and zonal (west-east) wind

Lag auto-correlation:
Rainfall based at 90°E

Source: Benedict et al. (2014)

Source: Jiang et al. (2015)

Compared to various versions of CAM (and most other conventional climate models), SPCAM produces more realistic MJO-related…

- Rainfall, wind, temperature, and moisture patterns

- Longitudinal dependence of MJO patterns

- **Vertical profiles of condensational heating**

- **Moisture advection**

- **Longwave radiation-precipitation feedbacks**

Selected Findings

Lag correlation:
OLR based at 90°E and zonal wind
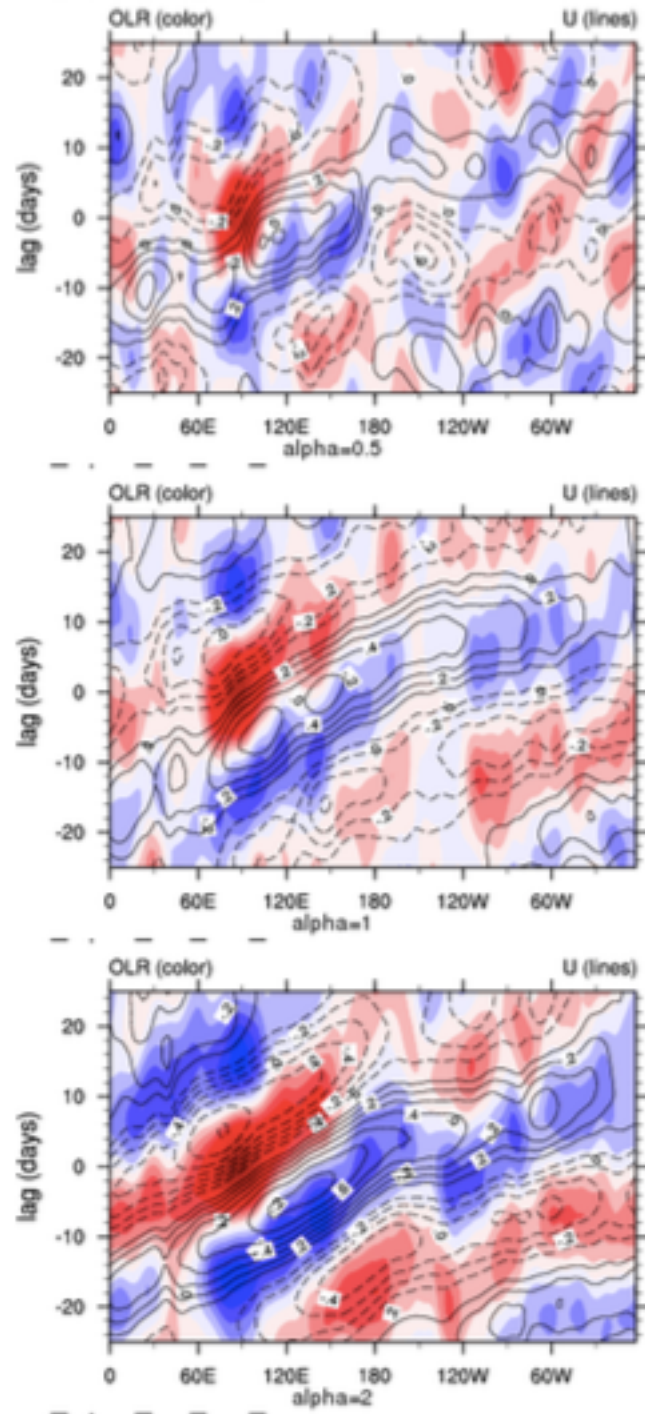
Moisture advection strength…

Weaker

Default

Stronger

Source: Pritchard & Bretherton (2014)

‣ (Left) Pritchard & Bretherton (2014): MJO propagation in SPCAM suffers when moisture advection associated with near-equatorial rotational flow is artificially damped…

‣ (Right) Suggests MJO in SPCAM is not critically reliant on mesoscale cloud organization

‣ Results support moisture mode instability theory
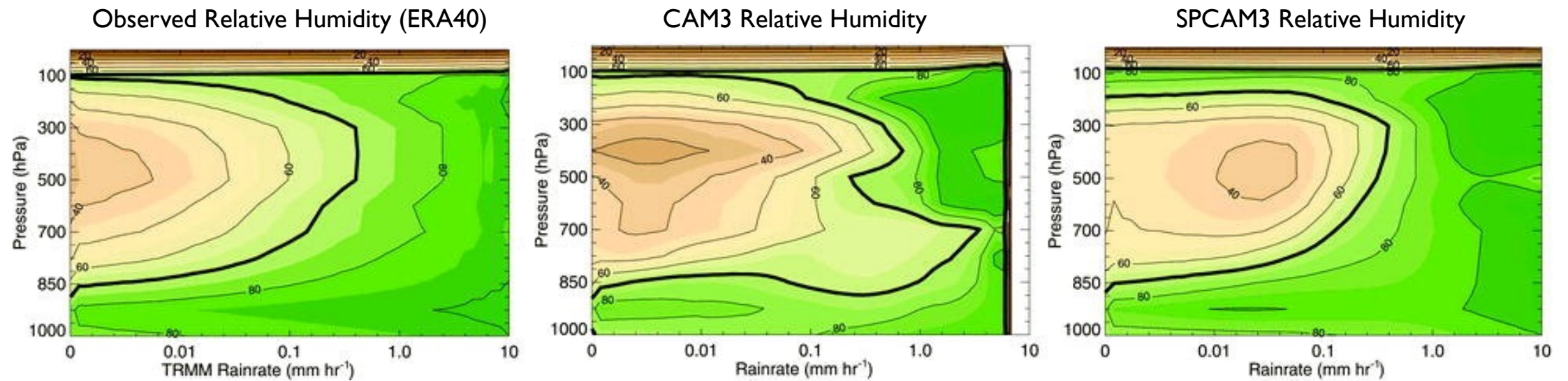

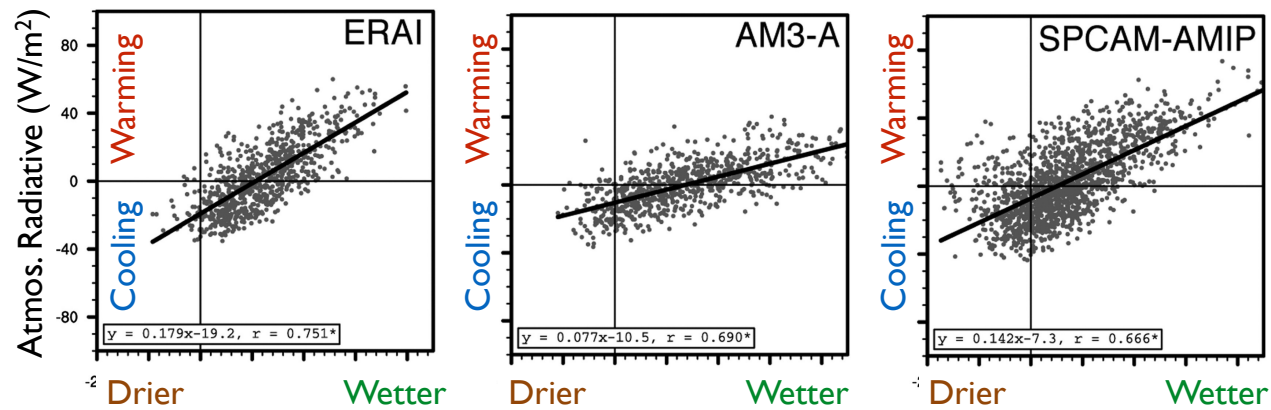b) Control SPCAM (32x1)
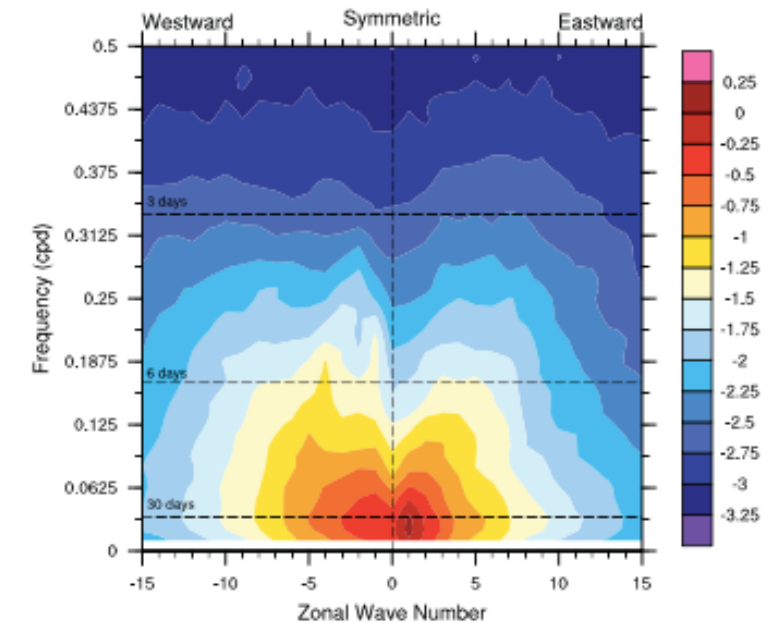
d) Micro-CRM (8x1)
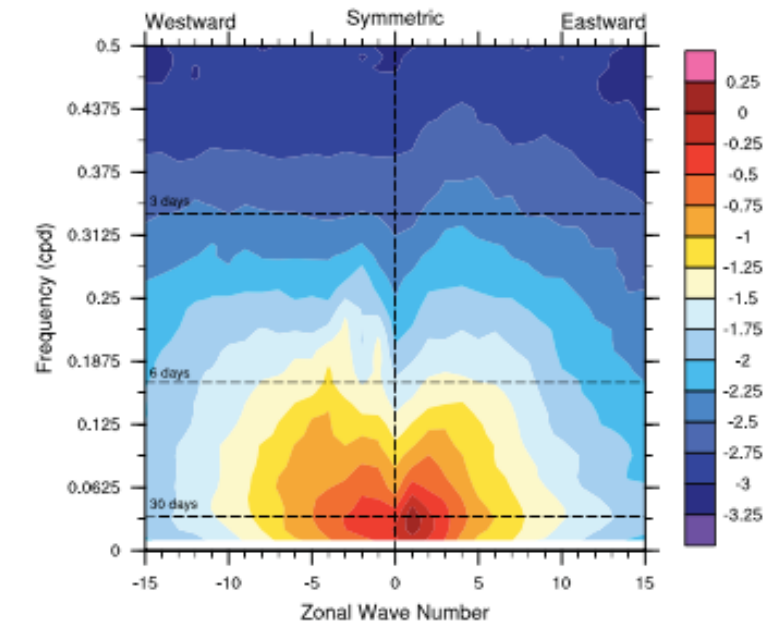
Primary Explanations

Why does the SPCAM excel at simulating the MJO?

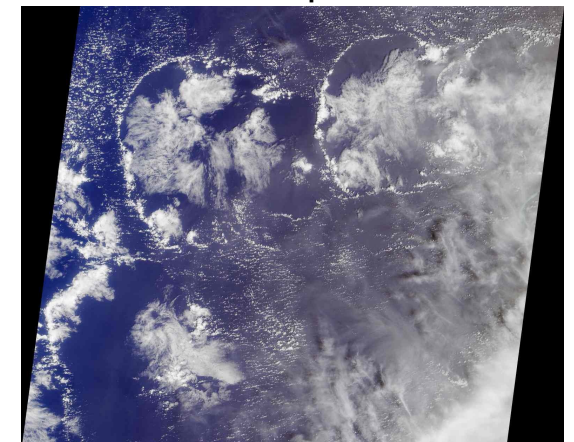**(1) SPCAM produces humidity-rainfall relationship closer to observations**

Observed Relative Humidity (ERA40)   CAM3 Relative Humidity   SPCAM3 Relative Humidity

Source: Thayer-Calder & Randall (2009)

(2) SPCAM has improved cloud-radiation feedbacks

ERAI   AM3-A   SPCAM-AMIP

$y = 0.179x - 19.2, \ r = 0.751^*$ $y = 0.077x - 10.5, \ r = 0.690^*$ $y = 0.142x - 7.3, \ r = 0.666^*$

Source: Benedict et al. (2014)

(3) SPCAM has more realistic mesoscale cloud organization and temporal "memory"

Tropical cloud organization, from space

Source: NASA MODIS

Adding Complexity: Slab Ocean

- ‣ Previous results employ the common practice of using prescribed SSTs that cannot respond to atmospheric forcing

- ‣ MJO simulations in SPCAM improve further when the atmosphere is coupled to even a highly simplified responsive ocean (slab ocean)

- ‣ Additional MJO improvements when fully dynamical ocean model employed (Charlotte's talk next)

Lag correlation:
OLR index based at 120°E and zonal wind
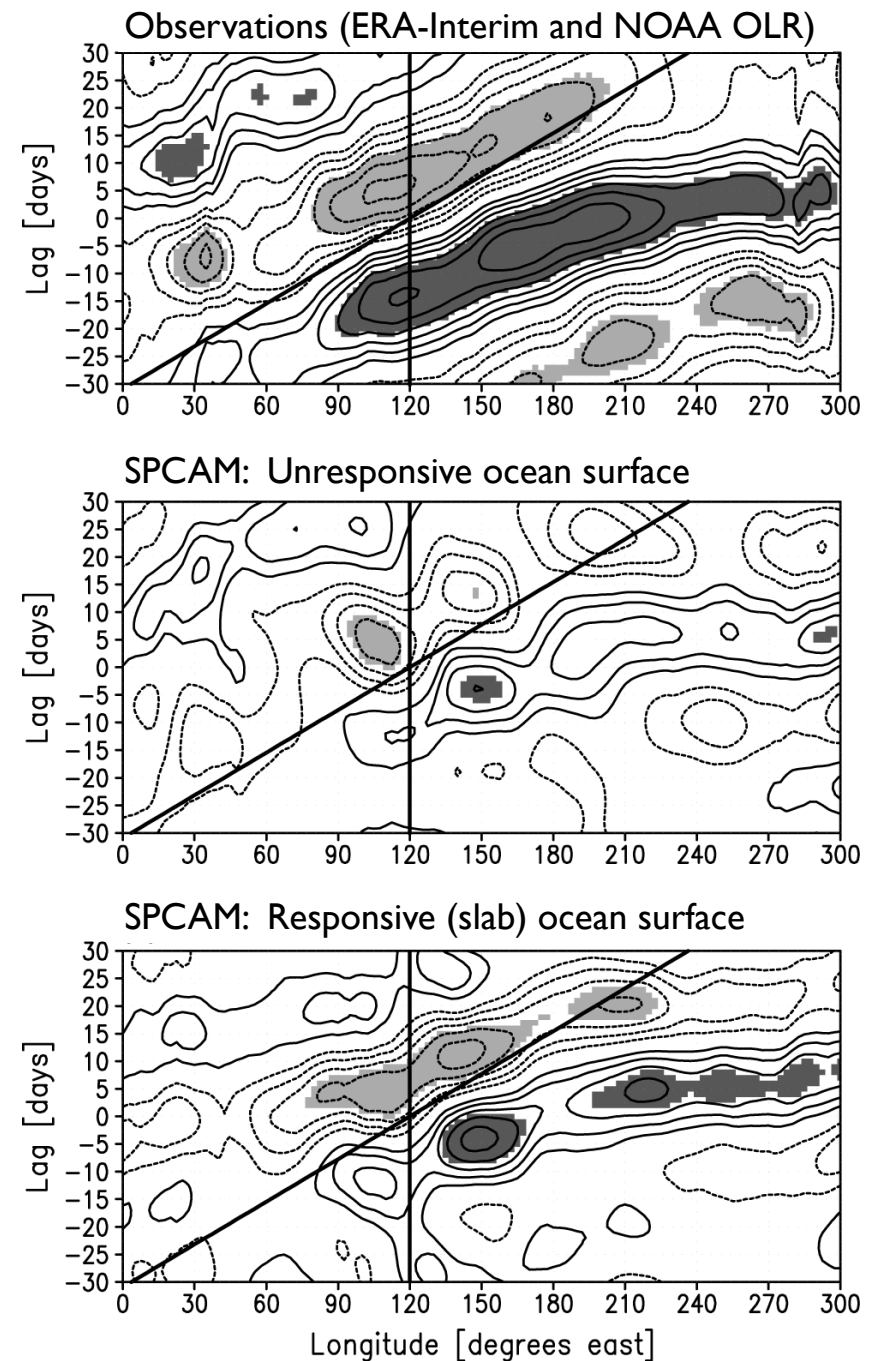
Source: Benedict & Randall (2011)

Summary

- The Madden-Julian oscillation (MJO) has broad impacts on weather and climate

- Our understanding of several key aspects of the MJO is insufficient. Many current climate models cannot accurately simulate the MJO.

- Superparameterization (SP), pioneered and advanced by CMMAP members, can dramatically improve the simulated MJO

- SP allows clouds and their environment to interact in a more natural manner and permits more realistic cloud life cycles and organization

- Coupling the atmosphere to a more realistic ocean model further improves the MJO in the SP framework