The MJO in Uncoupled and Coupled Versions of the Superparameterized CAM/CCSM

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Photo: RICO, courtesy B. Stevens

Part I

Effects of a slab ocean model on a superparameterized GCM (SP-CAM)

- In earlier 19-yr SPCAM AMIP simulation, SSTs were not allowed to respond in a natural manner to surface fluxes

- Interactions between the atmospheric boundary layer and oceanic mixed layer can substantially impact MJO structure and propagation
    - Krishnamurti et al. (1988), Zhang and McPhaden (1995), Zhang (1996), Jones and Weare (1996), Lau and Sui (1997), Hendon and Glick (1997), Shinoda et al. (1998), Yoneyama et al. (2008)

- How does MJO structure, intensity, and propagation change in the SPCAM if we allow tropical SSTs to respond to anomalous surface fluxes?

Data Sources

- **Simulated data: Two 5-year time segments of SPCAM daily output**
  - Time span: 1999 – 2004
  - First 5-year segment: SPCAM AMIP simulation ("CTL")
  - Second 5-year segment: new SPCAM simulation that is identical to the first except for the inclusion of a slab-ocean model (Waliser et al. 1999) used to predict SST anomalies that are coupled to the atmosphere ("SOM"):

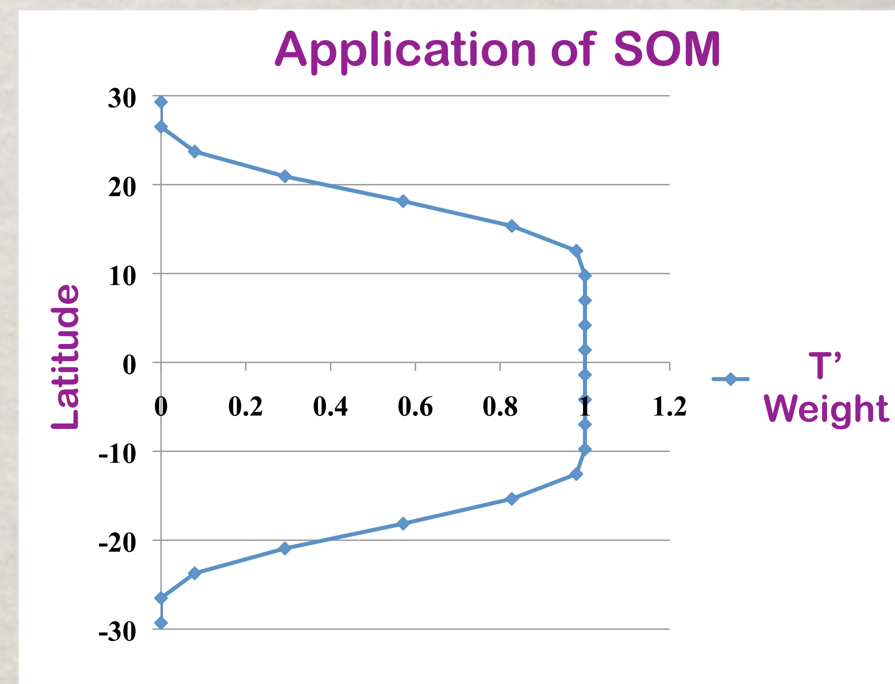
Departure of SST from (daily) prescribed value

Departure of total surface flux from smoothed climatology

Damping coefficient: (50 days)$^{-1}$

$$\frac{dT'}{dt} = \frac{F'}{\rho C H} - \gamma T'$$

Time- and space-dependent ocean mixed layer depth

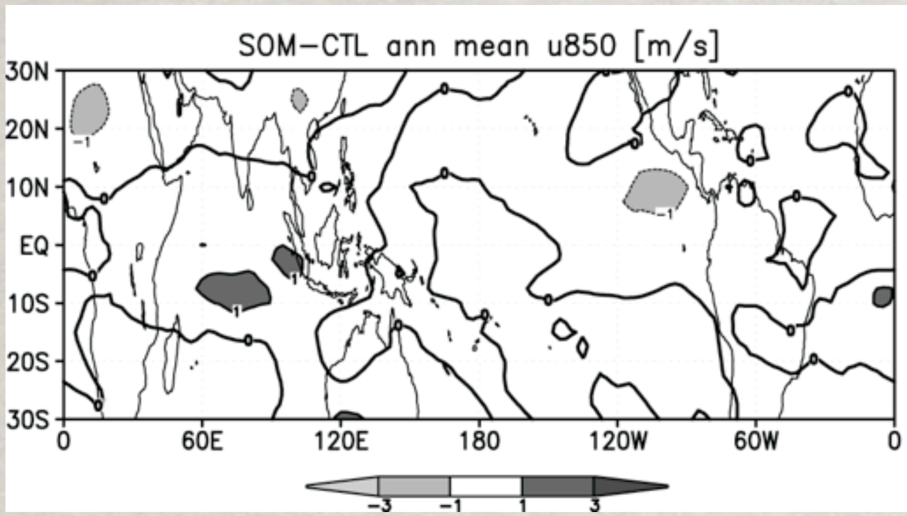


- **Validation data:**
  - ECMWF-Interim Reanalysis (ERAI): dynamic and thermodynamic variables
  - GPCP: rainfall
  - NOAA satellites: OLR, SST

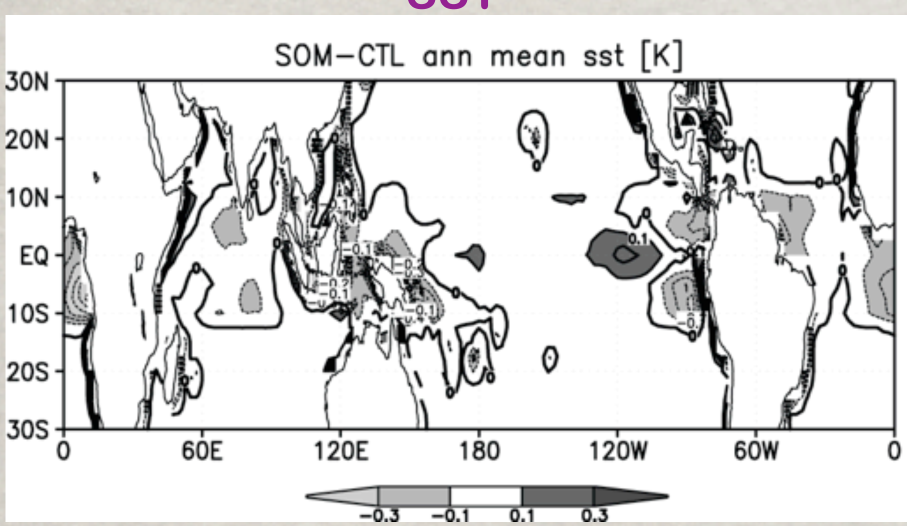
Selected Results: The Basics

SOM–CTL, ANNUAL MEAN

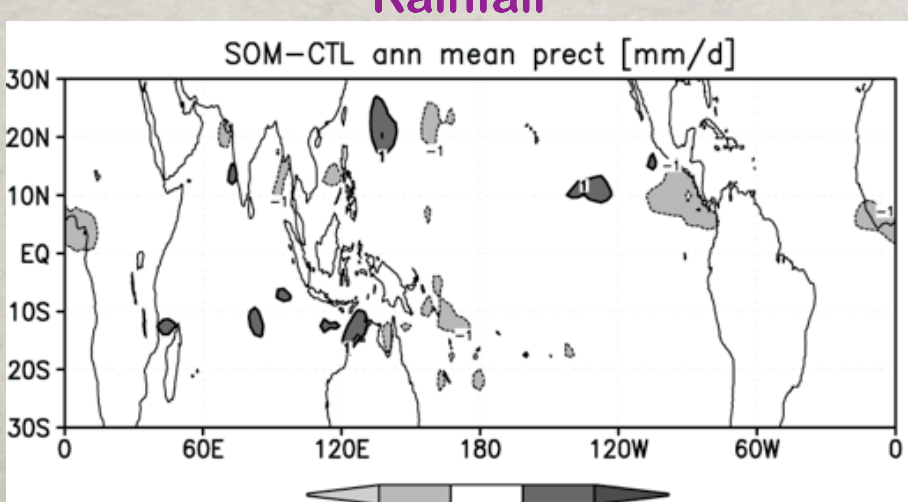
850 hPa zonal wind



SST



Rainfall



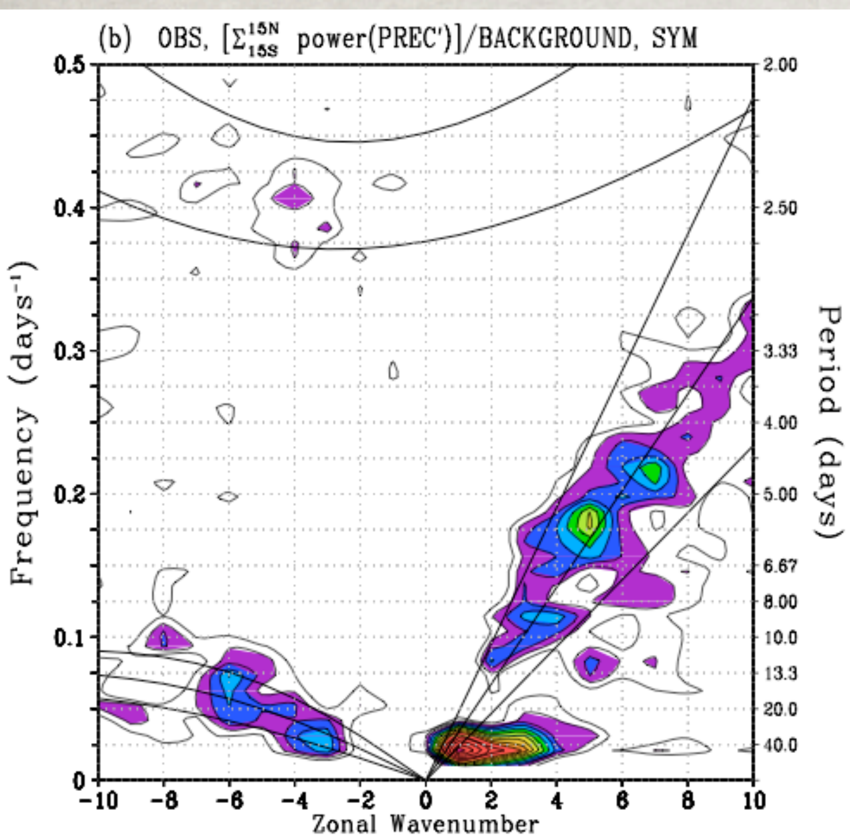
- No significant differences of global energy budget between standard CAM, uncoupled SPCAM, and coupled SPCAM

- Mean state differences are small → we can infer that changes to MJO structure can be mainly attributed to effects of slab-ocean model

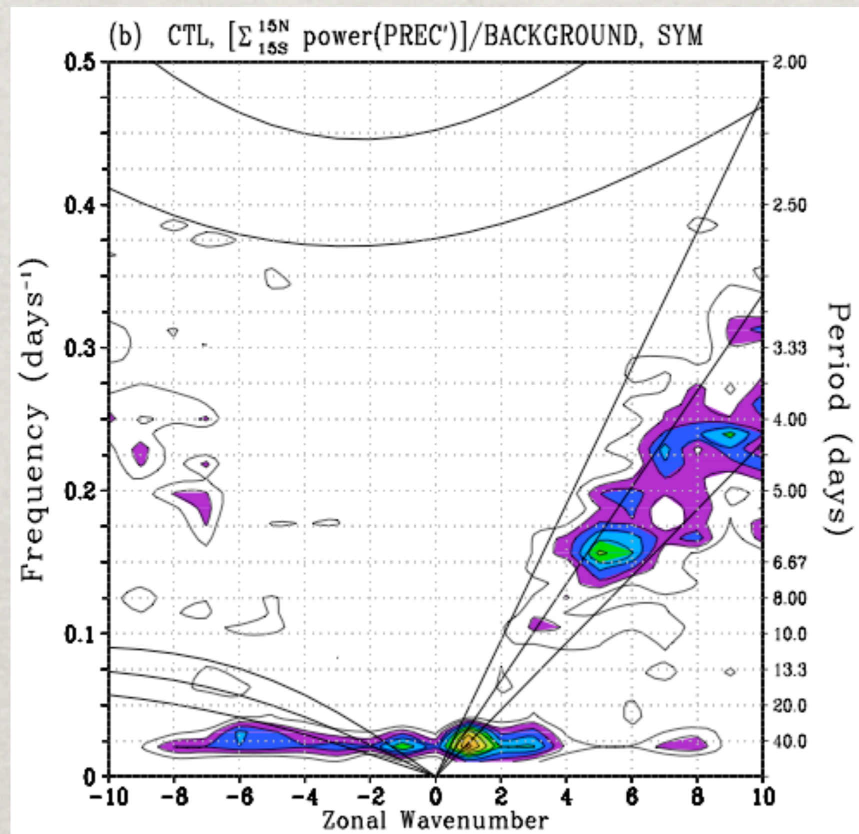
Selected Results: Spectral Analysis

- **SOM indicates more realistic distribution of low-frequency power, improved Kelvin and equatorial Rossby wave signals, and a larger east-west power ratio**

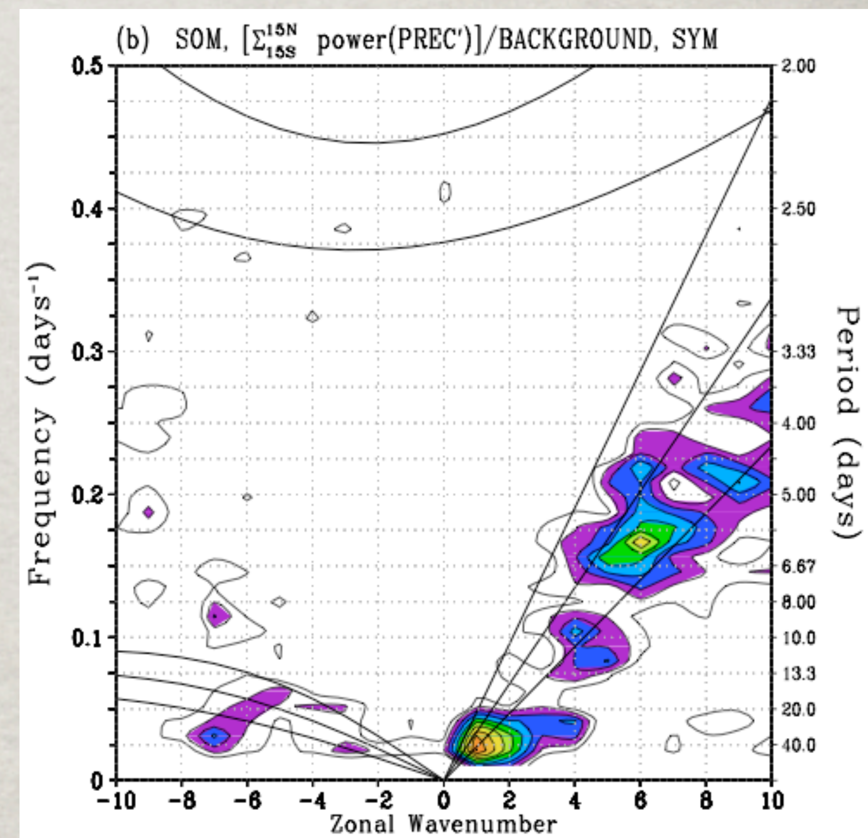
GPCP Rain



CTL Rain



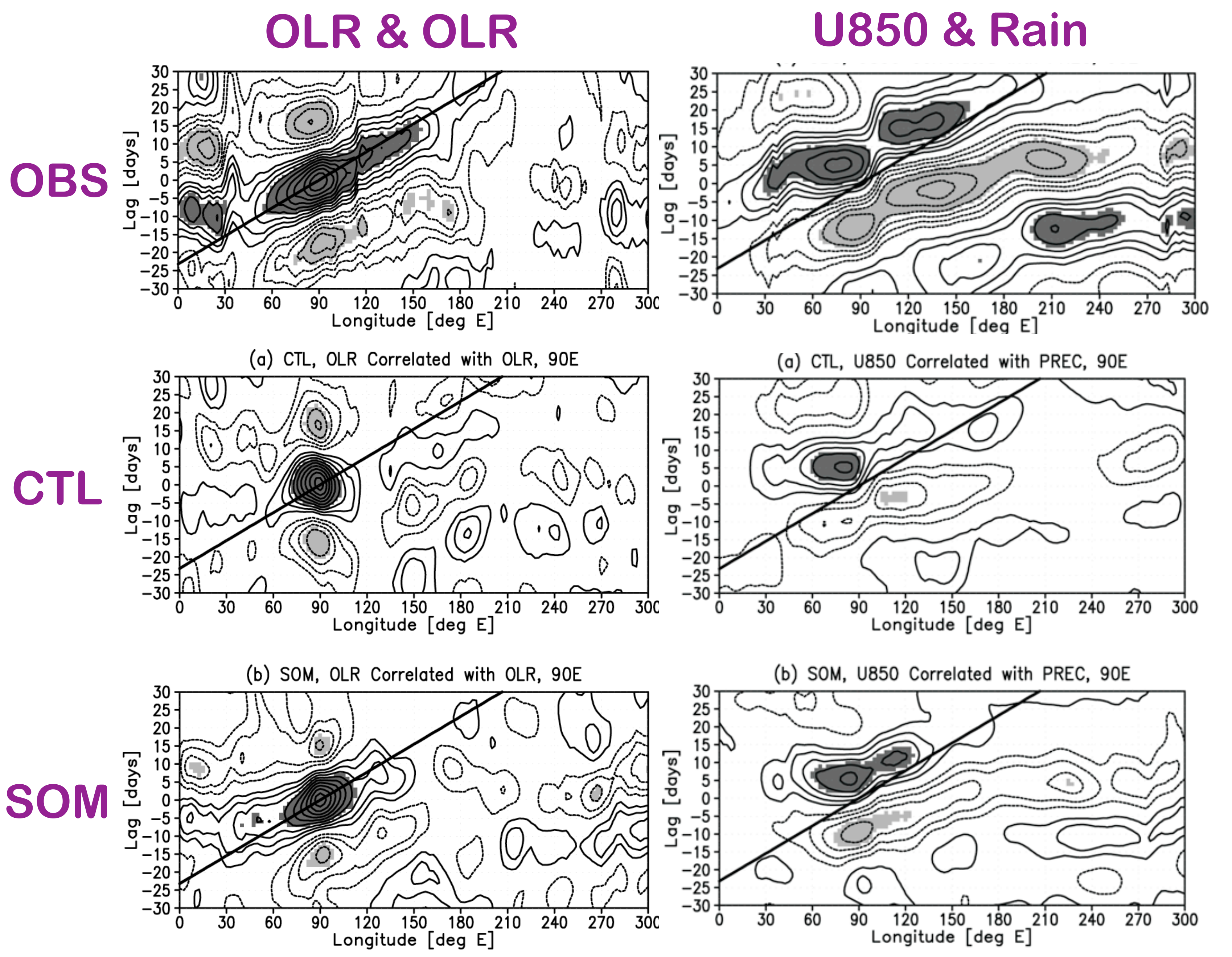
SOM Rain



Ratios of Eastward to Westward MJO Spectral Power

	Precipitation	OLR	U850
Observations	2.7	3.1	5.9
CTL	1.3	1.7	2.6
SOM	1.7	2.1	3.5

Selected Results: Lag Correlation 1

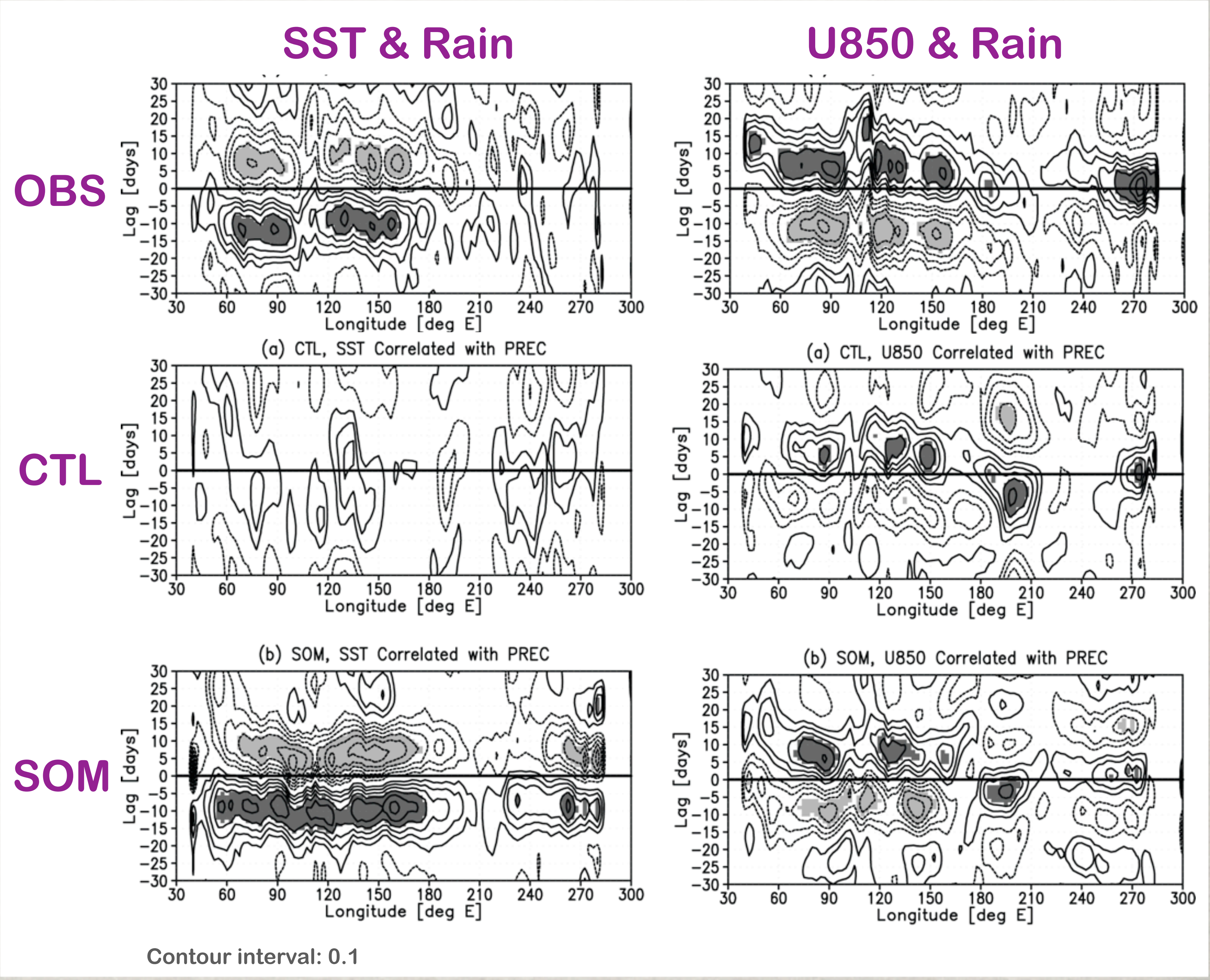


Contour interval: 0.1

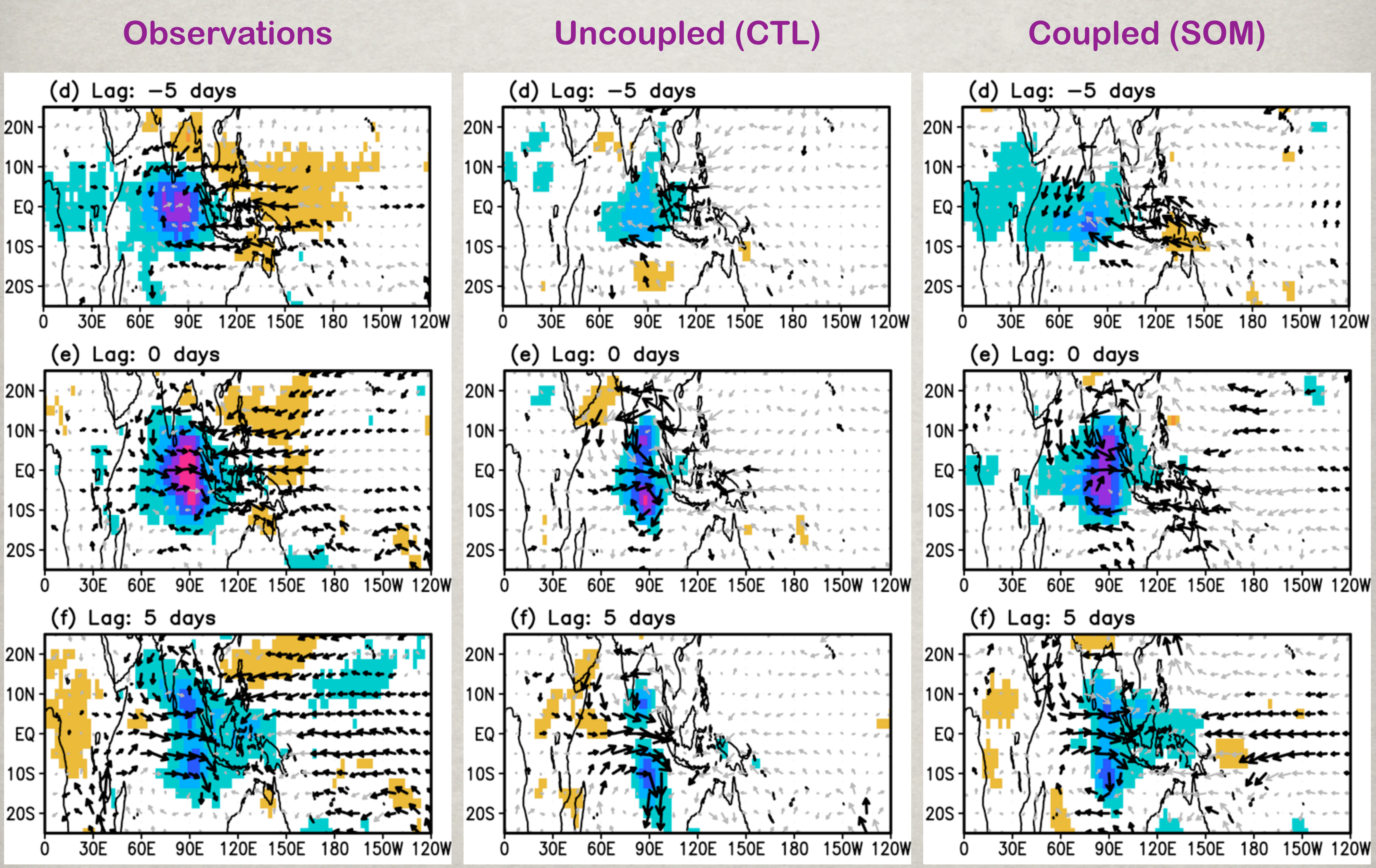
- 20-100-day filtered signals
- SOM: Greater MJO signal coherence
    - MJO convection remains organized over a larger space-time domain
- Couplet of leading easterlies-trailing westerlies
    - improved relationship between convection and dynamics

Selected Results: Lag Correlation 2

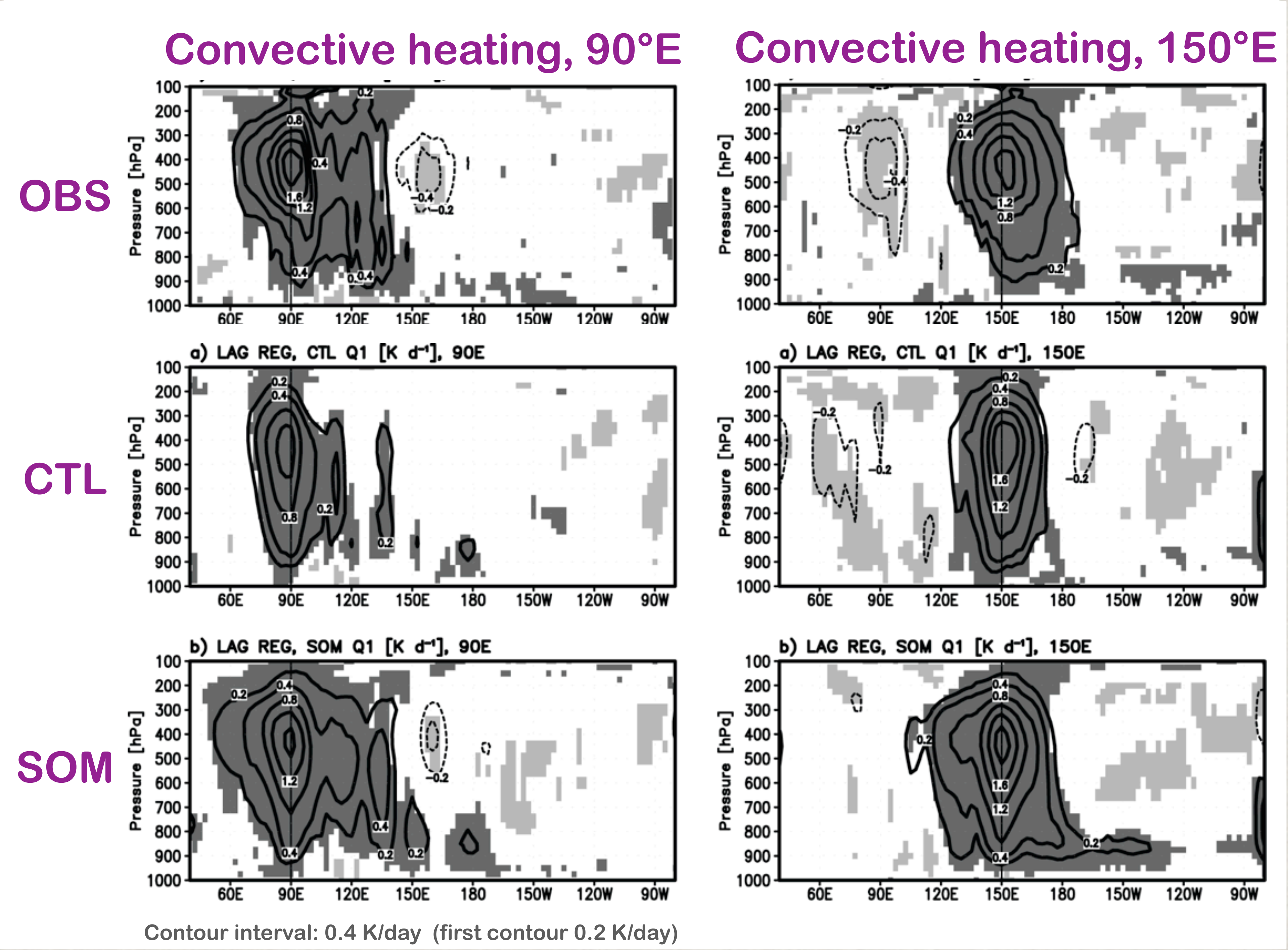
- 20-100-day filtered signals
- Substantially more realistic SST structure in SOM (expected)
- Improved coupling of low-level zonal winds over a larger spatial domain in SOM



Selected Results: Lag Regression



Selected Results: Lag Regression



- **SOM: Improved structure and intensity of convective heating in Indian Ocean region (as well as many other variables)**
- **West Pacific MJO too strong in SOM**

Discussion: Moist Static Energy Budget

- Timeseries of spatially averaged regression values

$$\left\langle \frac{\partial m}{\partial t} \right\rangle \approx -\left\langle \omega \frac{\partial m}{\partial p} \right\rangle - \langle \mathbf{v} \bullet \nabla m \rangle + \mathrm{LH} + \langle \mathrm{LW} \rangle$$

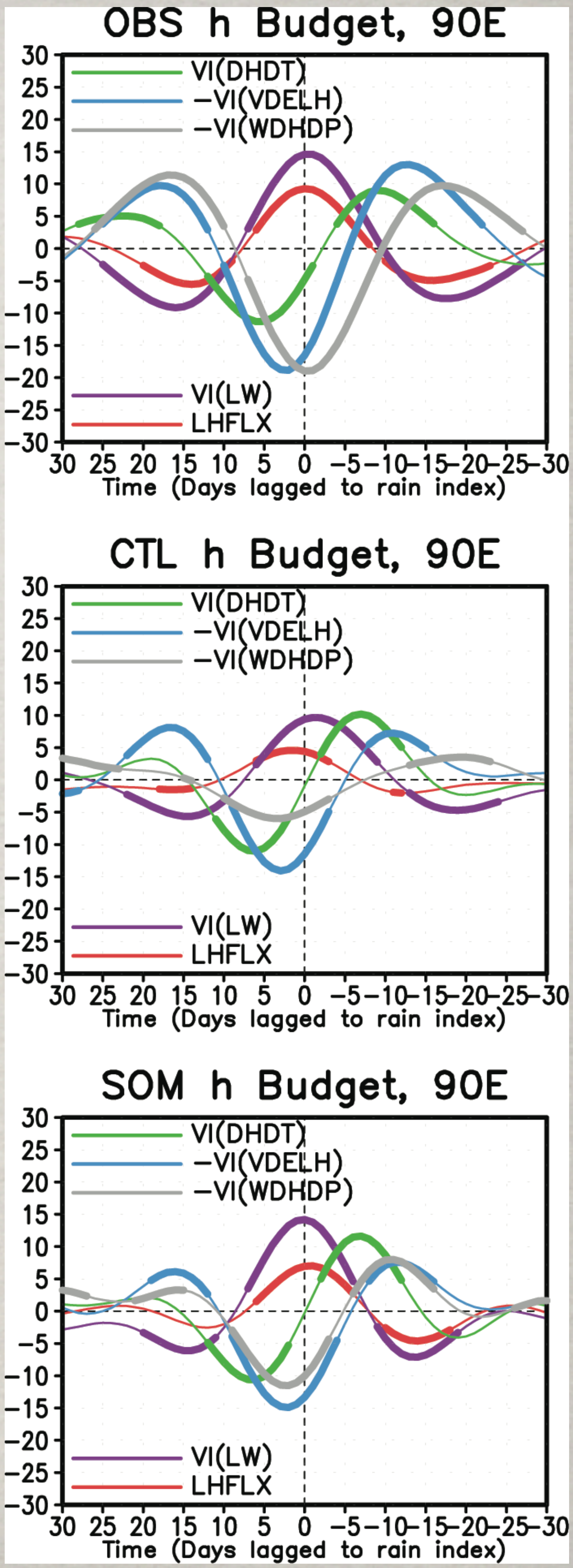
- **Coupling changes surface latent heat flux profiles**
  - **Weaker SLHF 1-3 weeks ahead of max rainfall**
  - **Peak SLHF shifts to earlier time in SOM compared to CTL**

- **Coupling changes vertically integrated vertical h advection profiles**

Max rain: 124 W m^{-2}

Max rain: 61 W m^{-2}

Max rain: 70 W m^{-2}



Part I: Conclusions

- The uncoupled SPCAM simulation reveals an improved MJO representation compared to the standard CAM
    - more realistic structures of winds, moisture, heating, and advection in the composite MJO (Benedict and Randall 2009, Zhu et al. 2009)

- Compared to the uncoupled SPCAM, the MJO in the coupled SPCAM is more realistic
    - improved spectral and physical MJO structures, coupling between convection and dynamics
    - improved signal coherence and eastward propagation

- Exact reasons for differences seen in SPCAM-SOM remain elusive
    - most notable differences in structures of low-level moisture convergence, surface latent heat flux, and vertically integrated vertical h advection

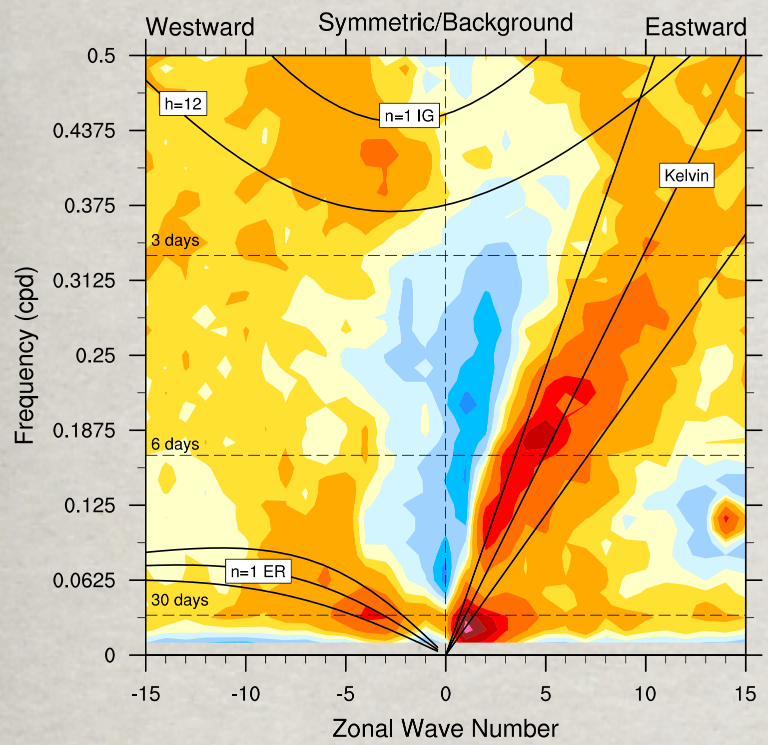
Part II

Effects of superparameterization on a fully coupled GCM (SP-CCSM)

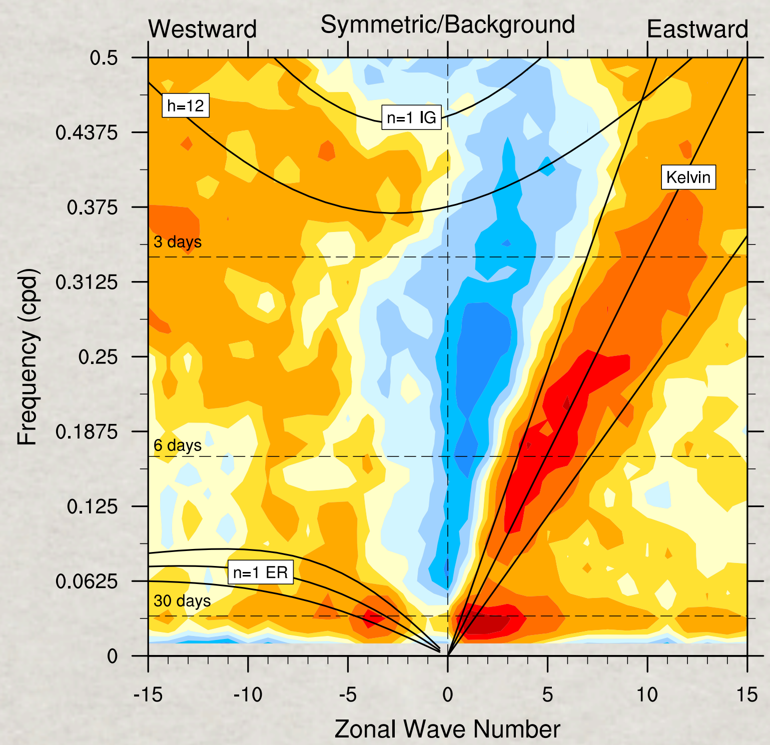
- SP applied to NCAR's Community Climate System Model (SP-CCSM)
  - Atmosphere: CAM version 3.0, T42 spatial truncation
  - Ocean: POP, 3°x5° horizontal resolution, ocean at rest at initialization
- Integration: 23 years, only years 4-23 are analyzed
- Mean tropical SST biases similar between CCSM and SP-CCSM... ~1°C

Selected Results: Symmetric Equatorial Waves

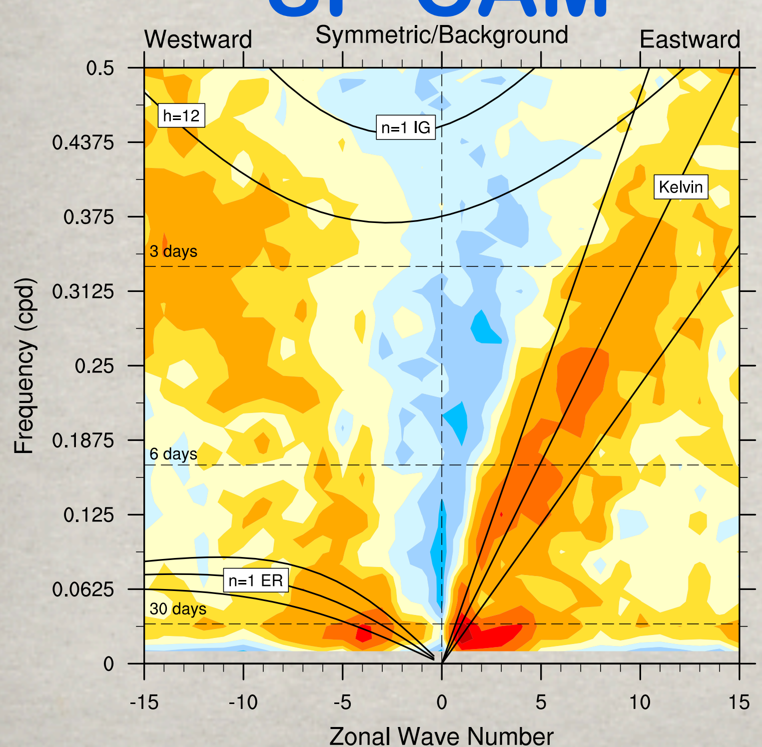
OBS



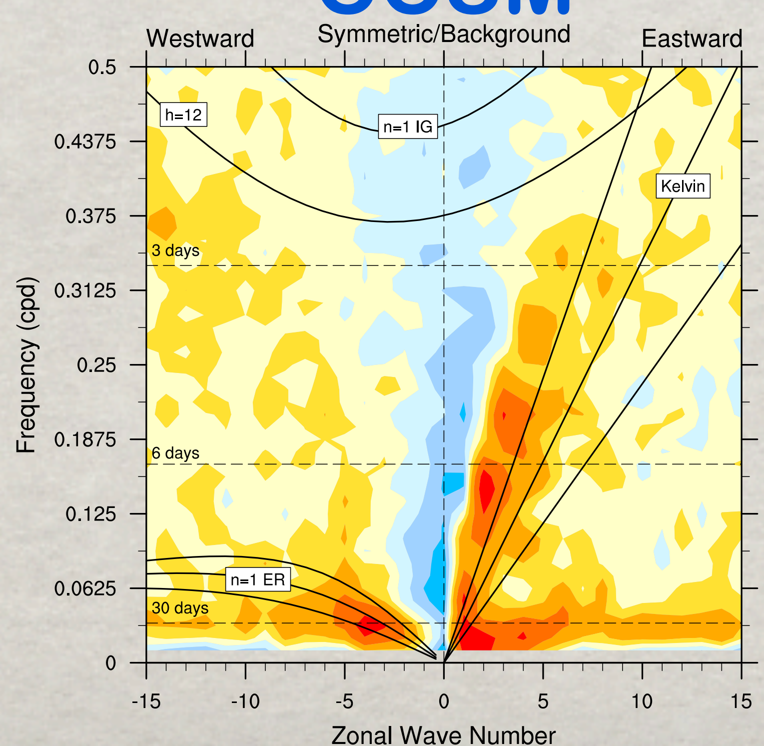
SP-CCSM



SP-CAM



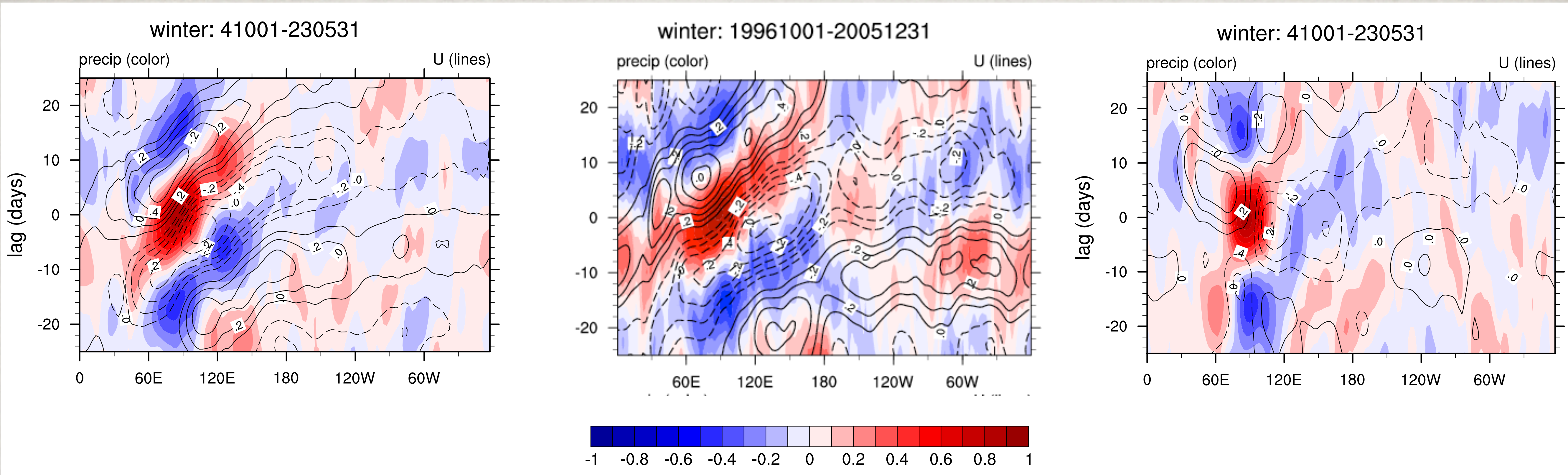
CCSM



- More robust MJO spectral signal in SP-CCSM
- Slower and more robust Kelvin wave behavior in SP-CCSM

Selected Results: Lag Correlation

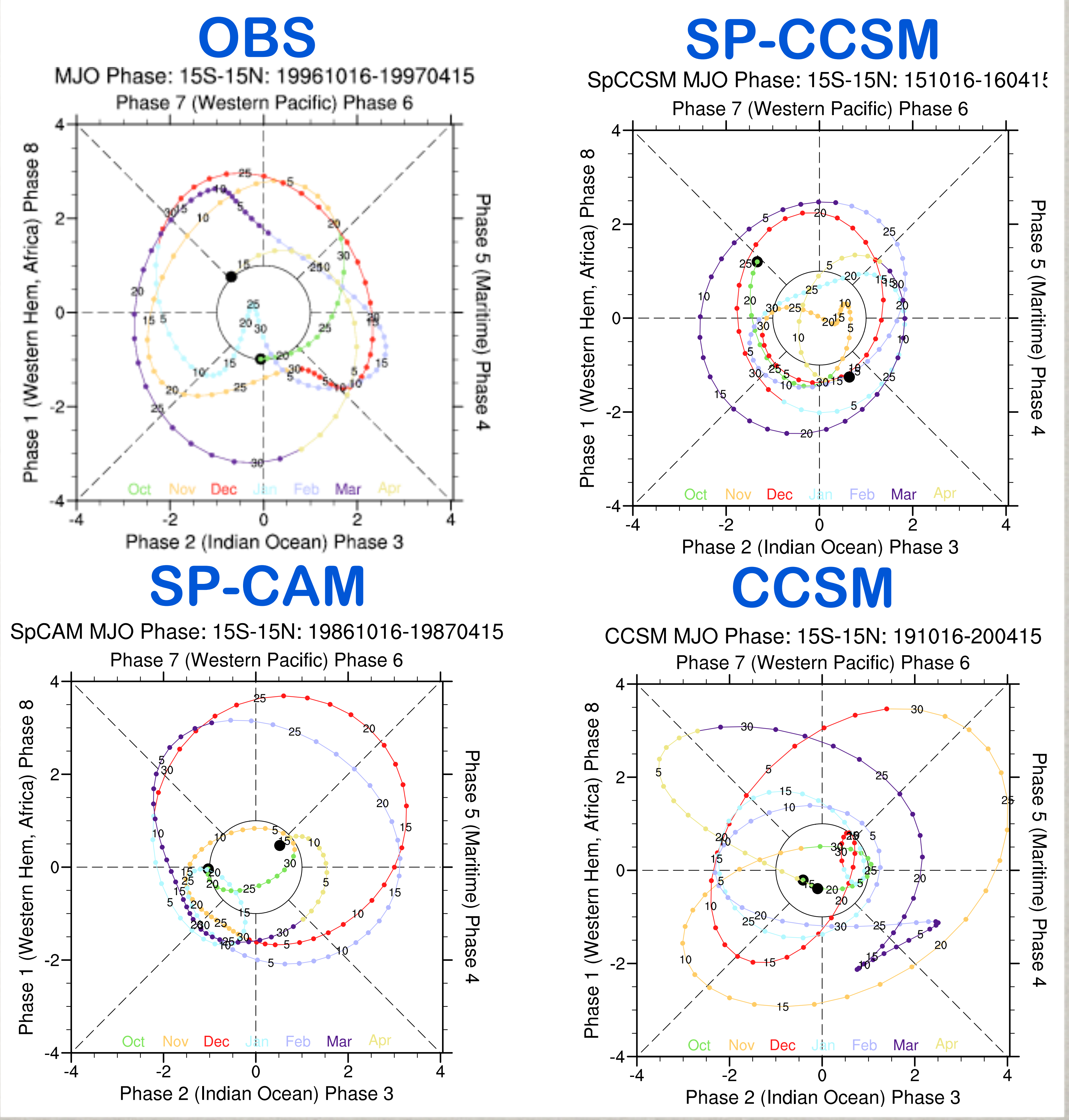
SP-CCSM | **OBS** | **CCSM**



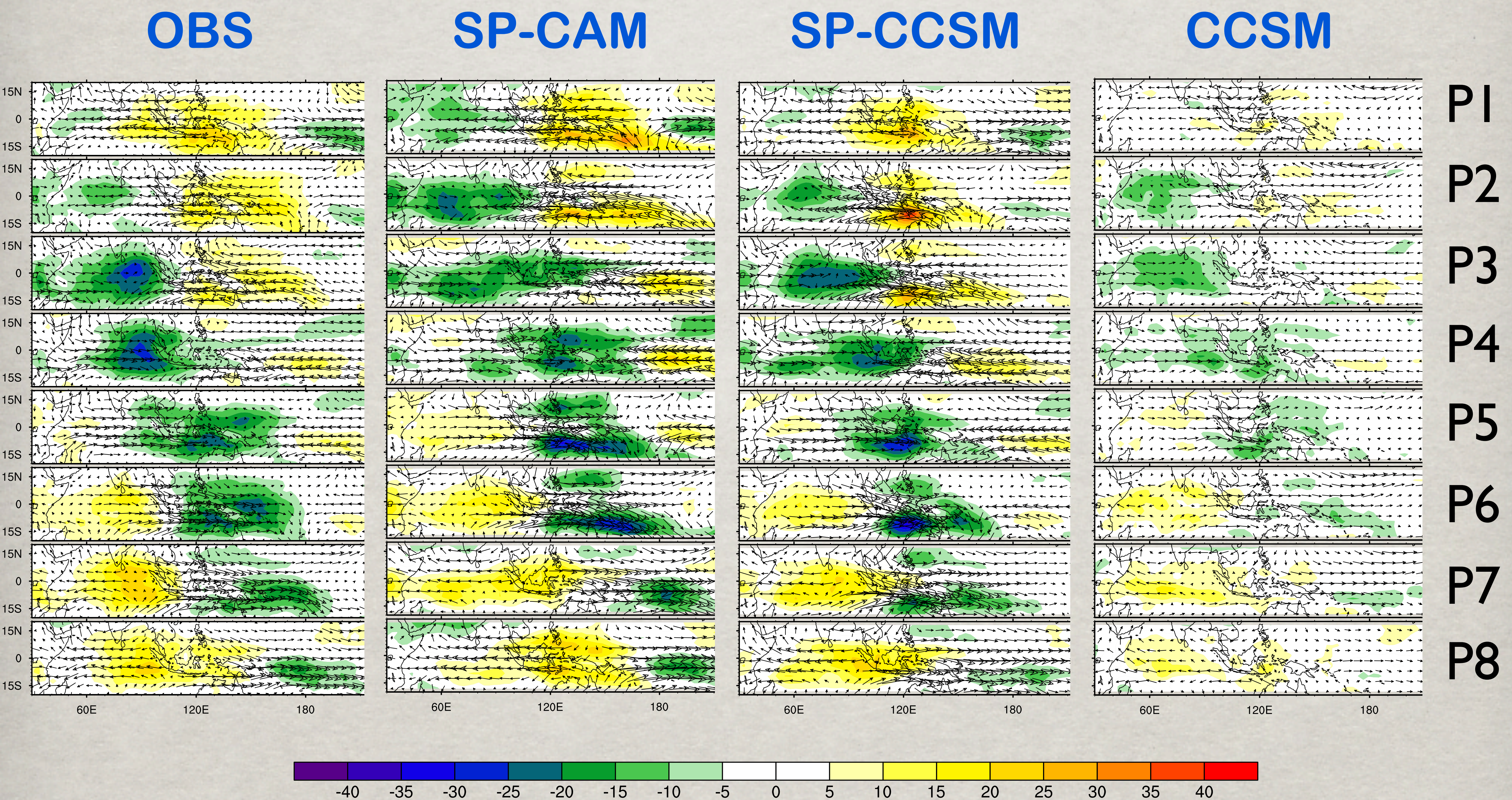
- 20-100-day filtered rainfall and U850 correlated with filtered Indian Ocean rainfall (~10°S-10°N, 75°-100°E)
- SP-CCSM indicates more realistic propagation of coupled signal

Selected Results: MJO Phase Space

- Representative behavior of MJO based on combined PC1 and PC2, single boreal winter (Wheeler & Hendon 2004)
- Basis EOFs are generated for each model and qualitatively resemble observed EOF structures



Selected Results: Nov-Apr Composite ISO



Phase-composite 20-100-day OLR [W m^{-2}]

Main Conclusions

- Coupling the SP-CAM to a slab ocean model results in greater MJO signal coherence (convection-dynamics), improved eastward propagation, a more realistic vertical structure

- Utilizing superparameterization in the CCSM shows similar improvements

- Big Picture:
  - Kelvin wave shift toward smaller equivalent depths appears linked to SP, not atmos-ocean coupling
  - Equatorial Rossby wave signal improved when some form of atmos-ocean coupling is used
  - MJO eastward propagation is clarified through use of atmos-ocean coupling
  - MJO spectral power increases both through SP or atmos-ocean coupling

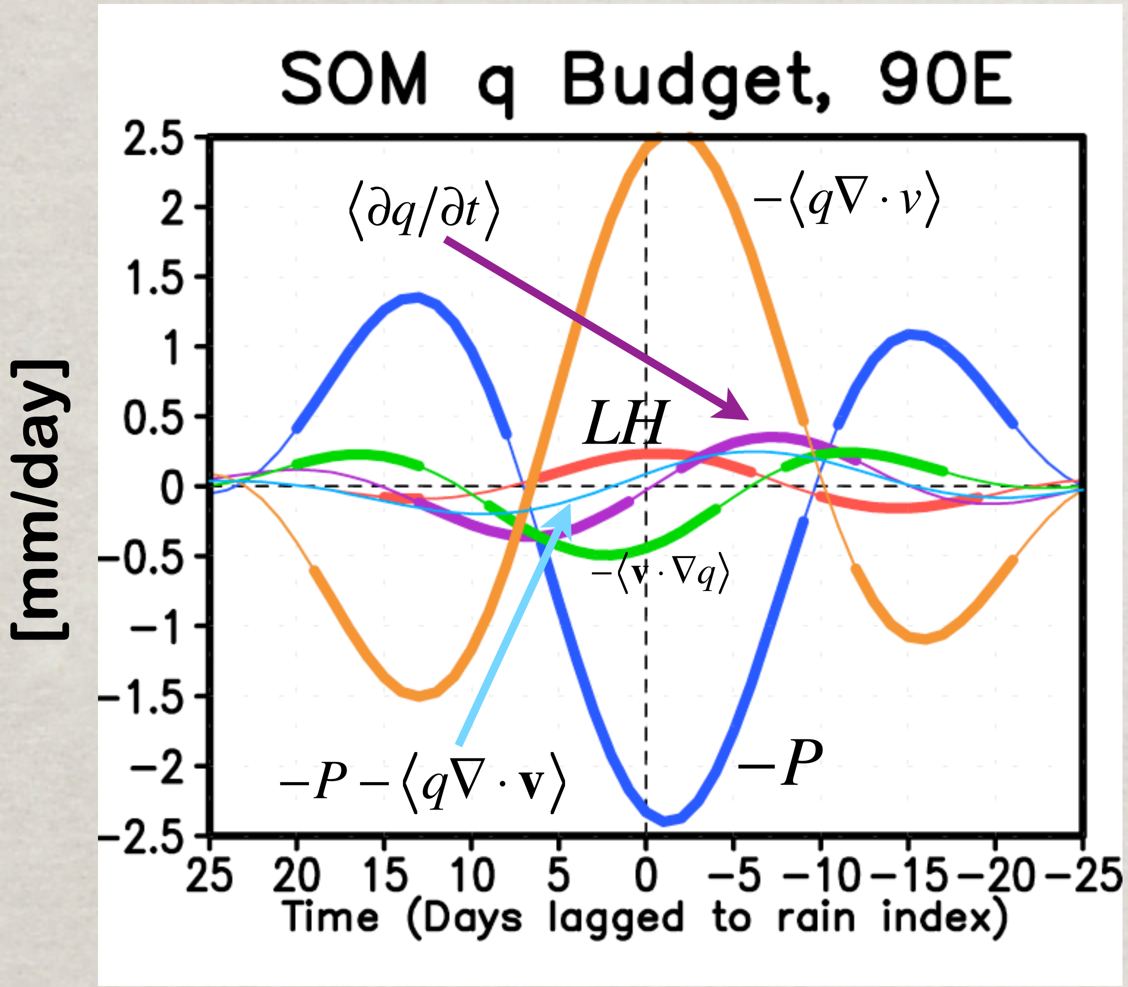
- Further work required to pinpoint mechanisms related to changes in ISV behavior in SP-CAM/CCSM

Thank you... questions/comments?

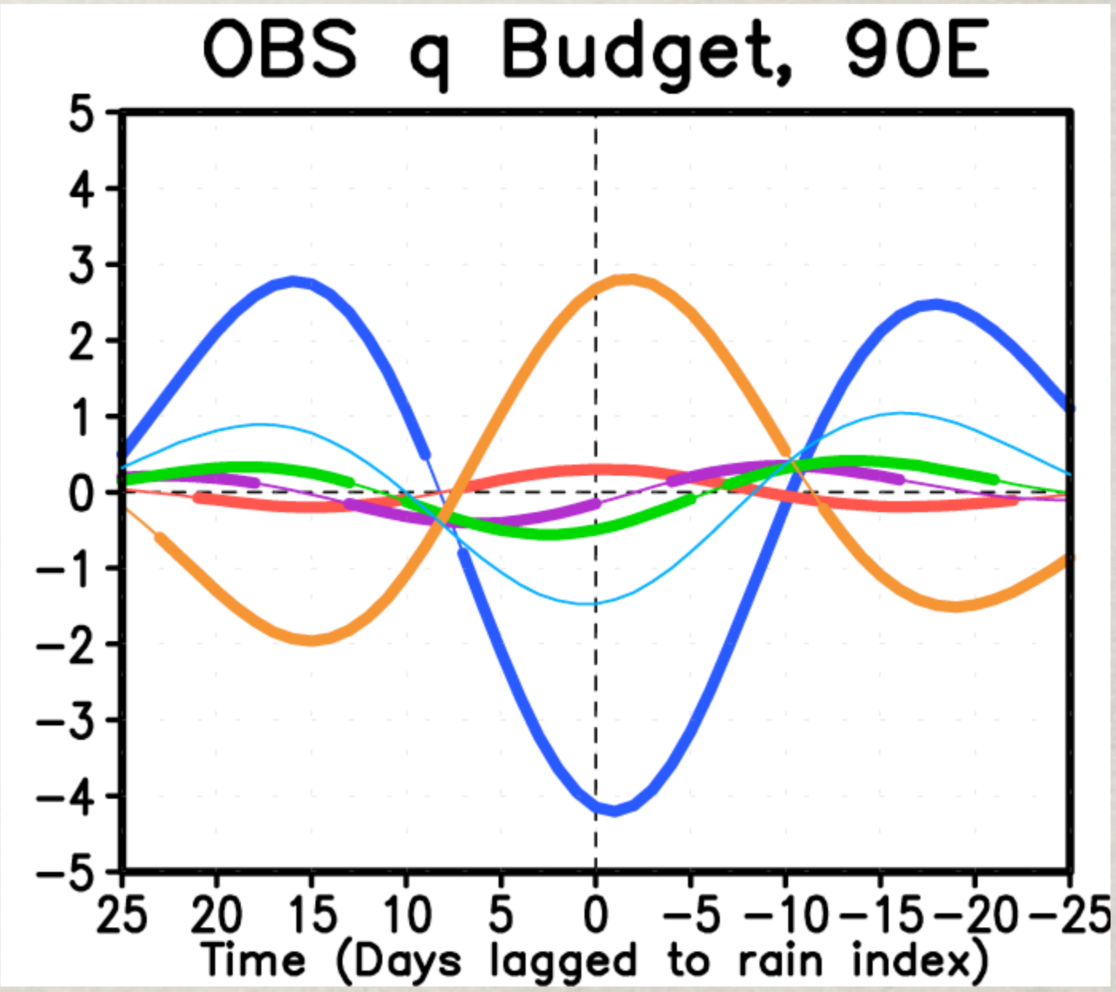
Photo: RICO, courtesy B. Stevens

q Budget, 90°E

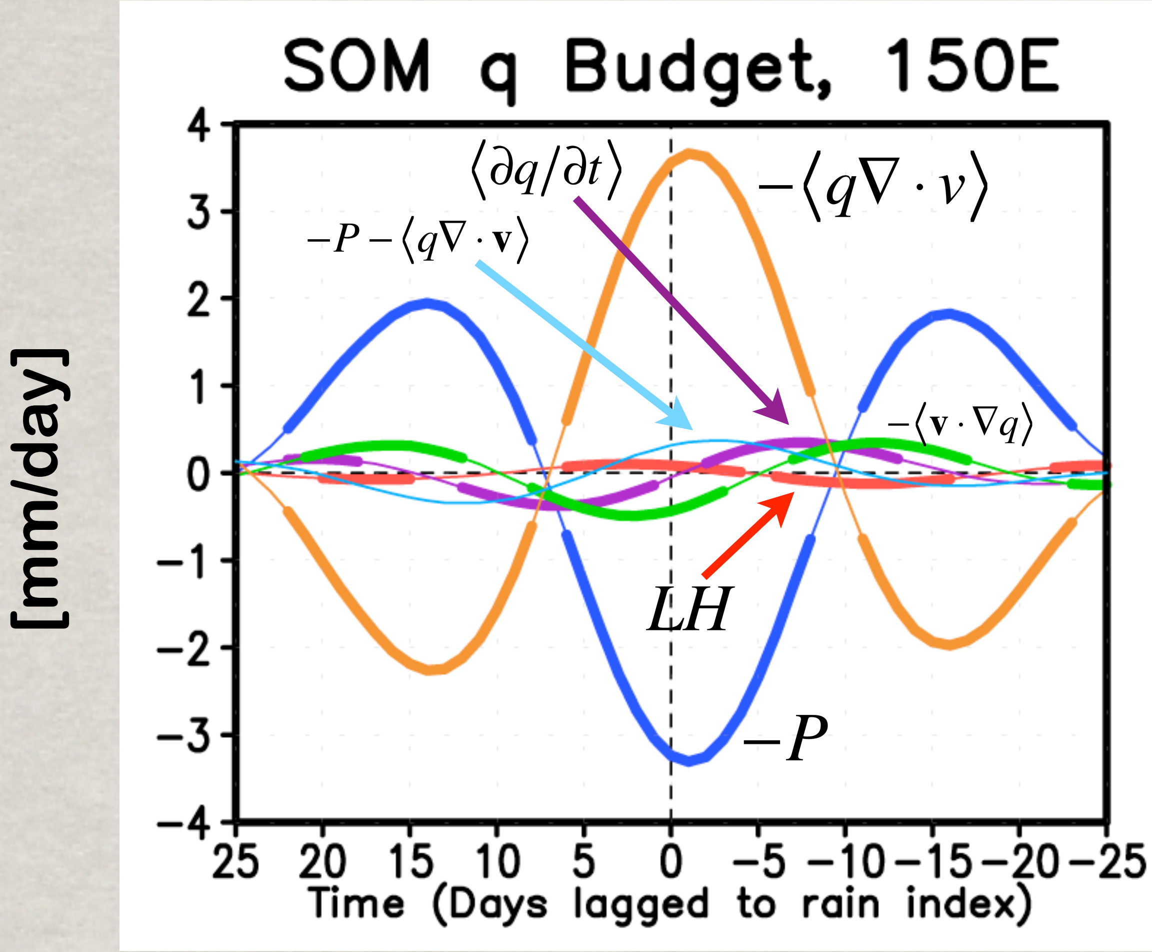
Coupled SPCAM

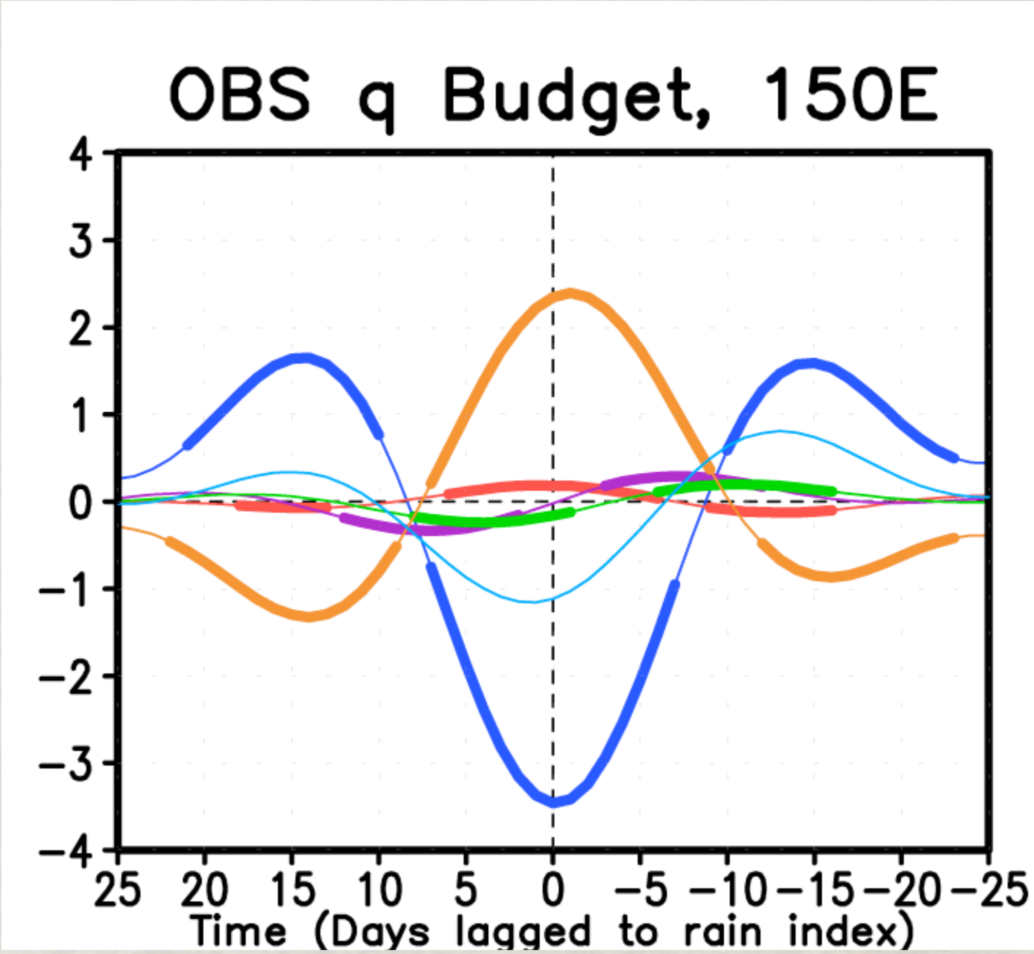


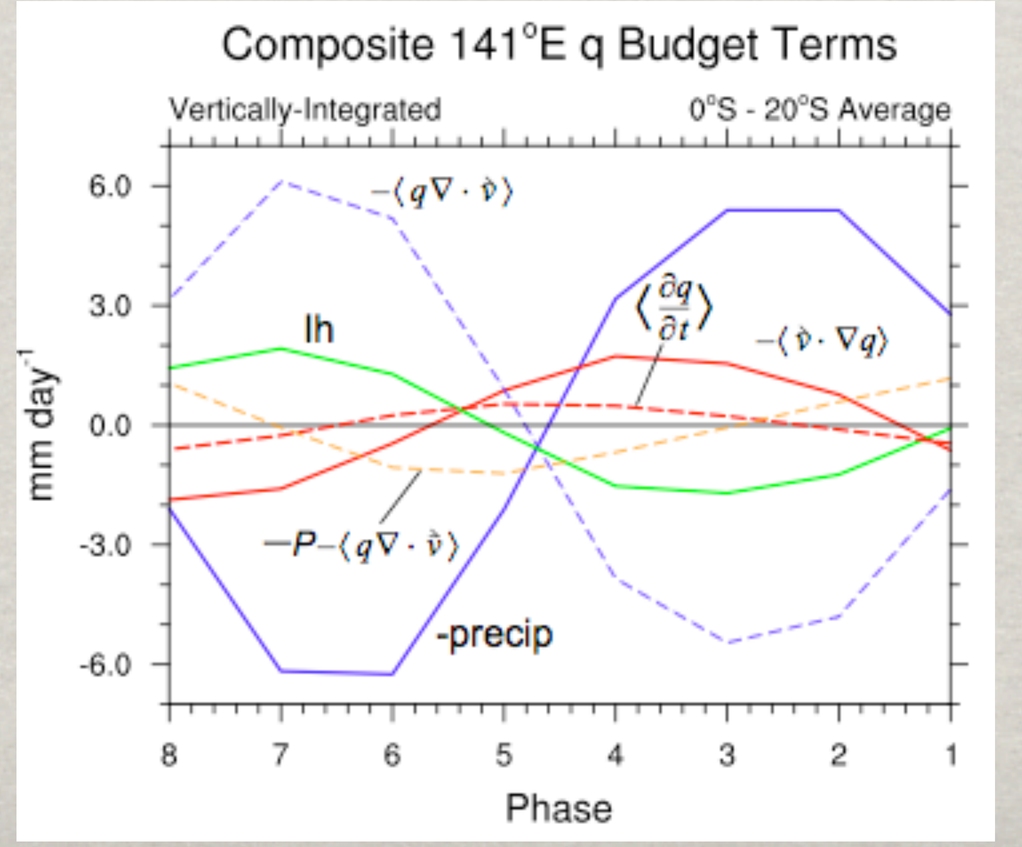
Reanalysis



q Budget, 150°E



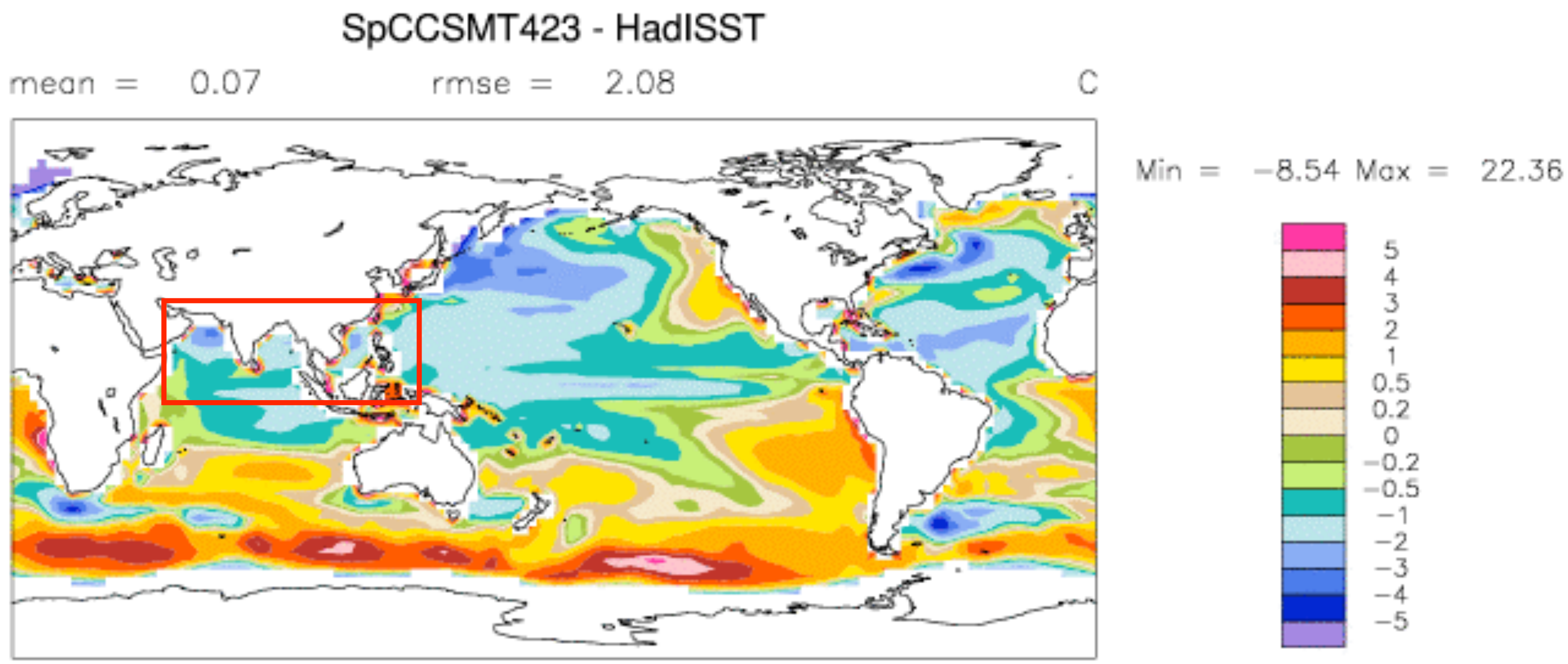




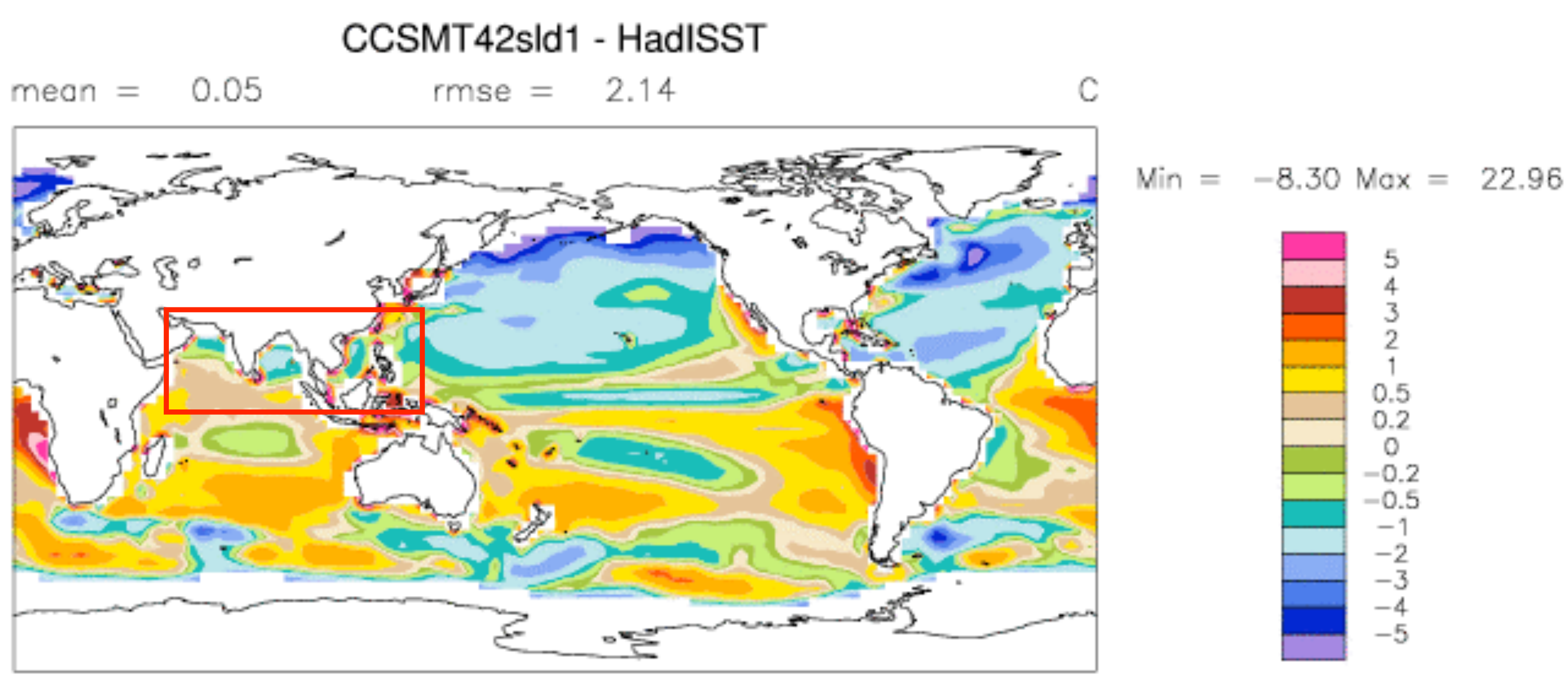
Maloney et al. 2009, JAMES

SST

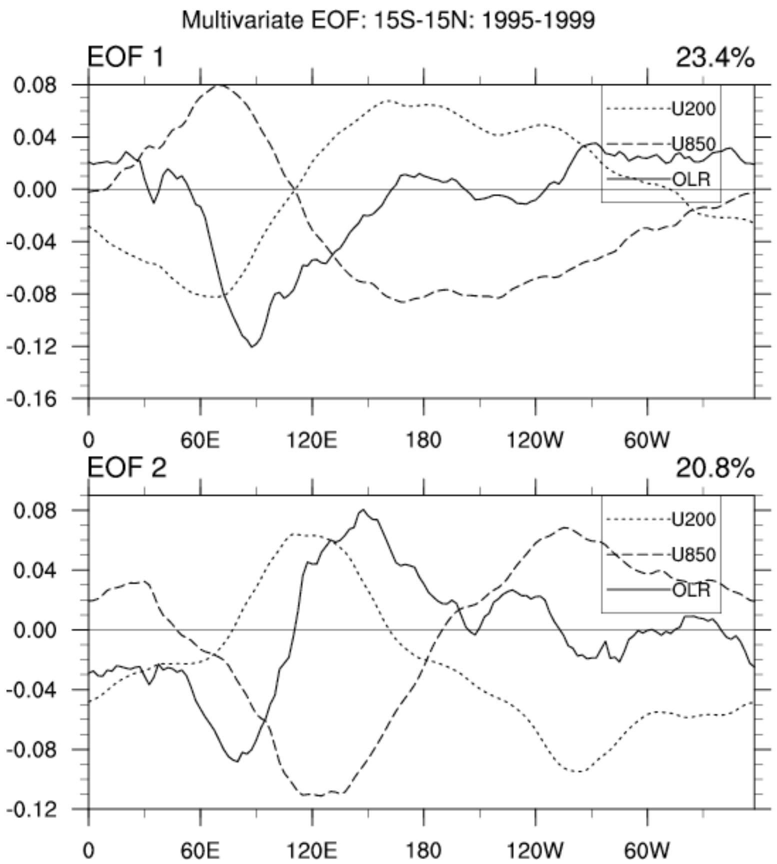
SpCCSM



CCSM

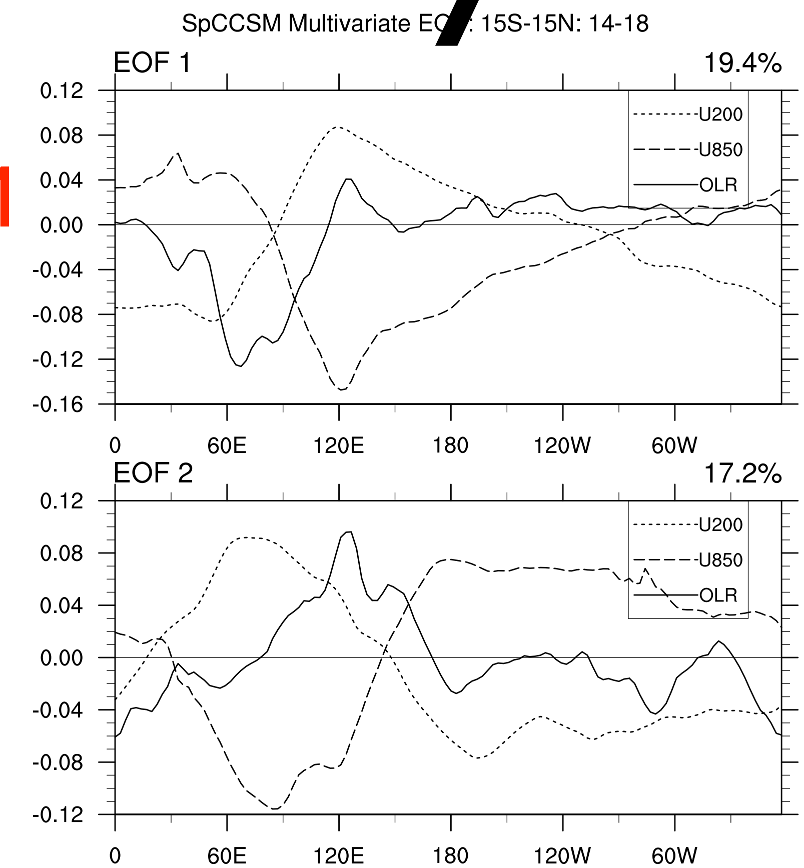


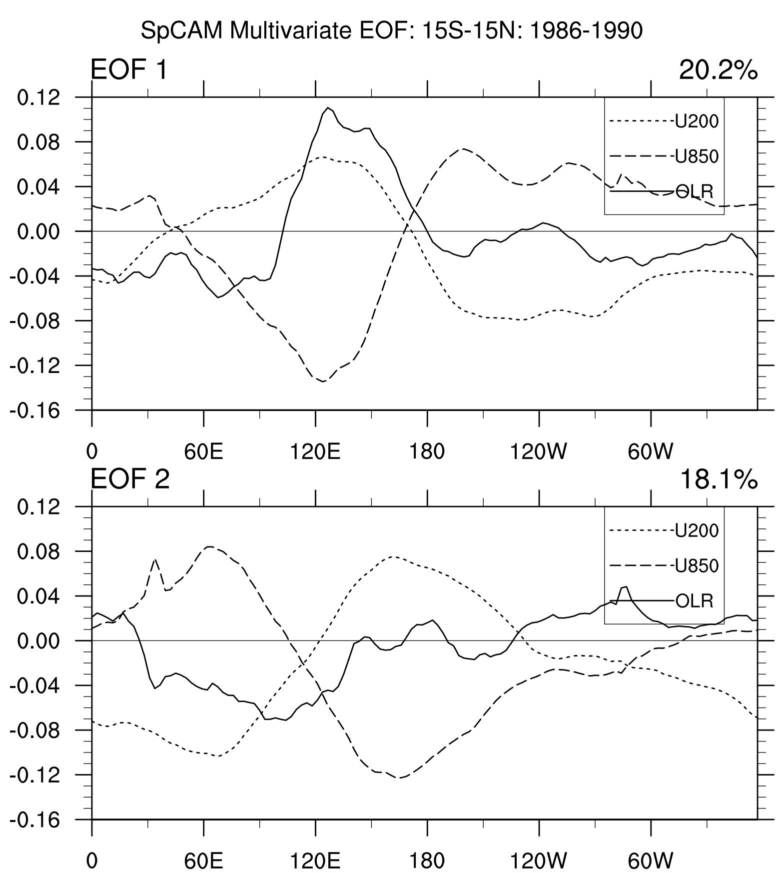
Multivariate EOF Analysis



OBS

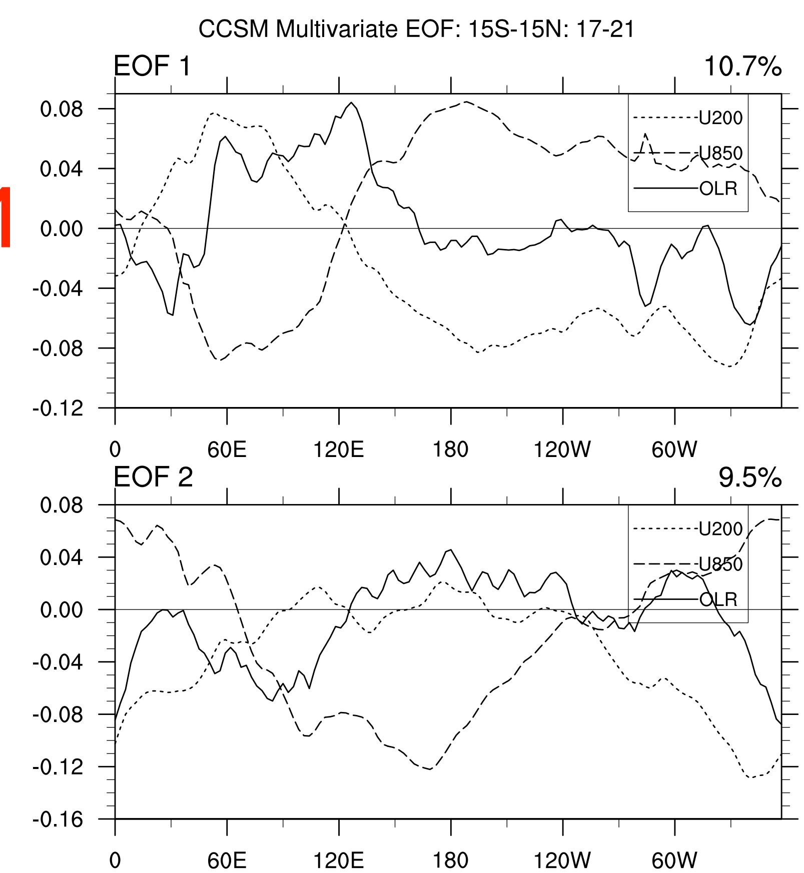
SpCCSM



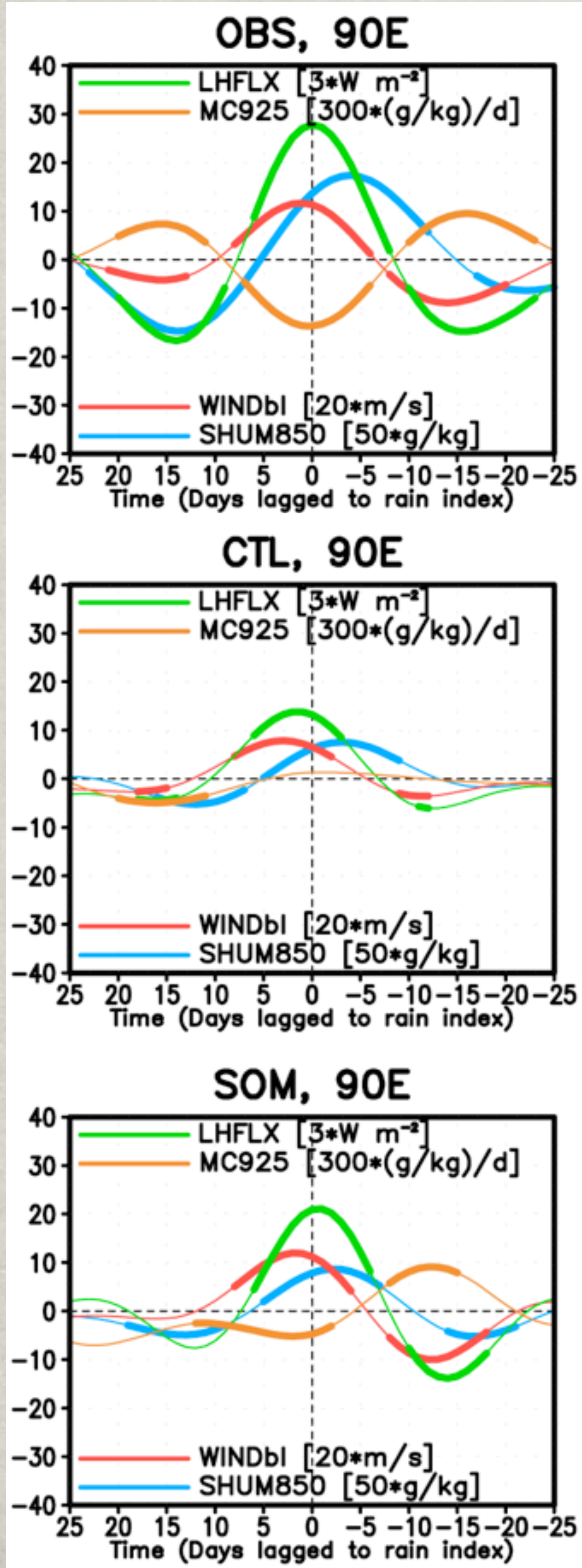


SpCAM

CCSM



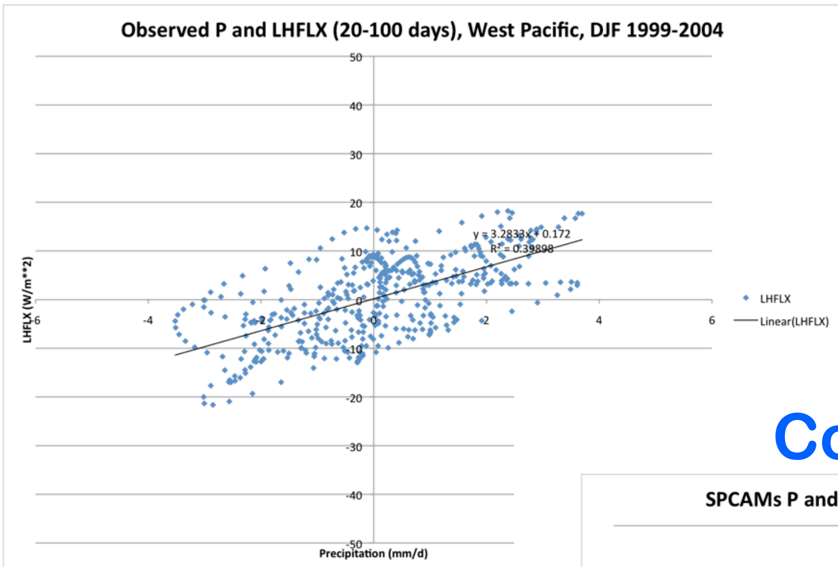
Discussion: Mechanisms



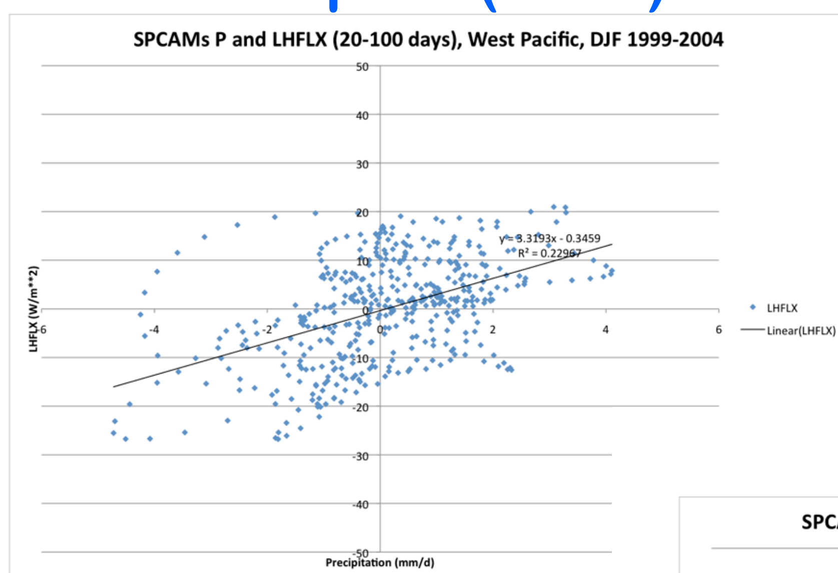
- Timeseries of spatially averaged regression values
  - Index: standardized rainfall at 90°E
  - Spatial average: 10°x10° box, centered on 90°E and Equator
  - Unified y-axis (for comparison)
- CTL: Before Day –10, no significant relationships between most low-level variables
- Improved phasing of low-level variables—moisture convergence, insolation, SSTs—promotes coherent MJO eastward propagation and more realistic convective intensity for Indian Ocean MJO events in the SOM

Discussion: Surface Latent Heat Fluxes

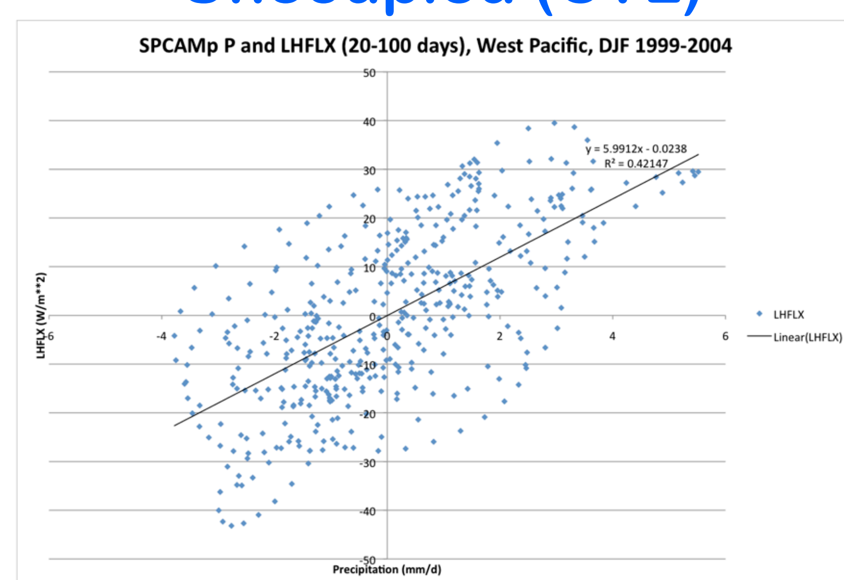
GPCP/OAFlux



Coupled (SOM)



Uncoupled (CTL)



- In both Indian and West Pacific basins, sensitivity of SLHF to rainfall is largest in CTL, and SOM is closer to observations

- 20-100-day filtered rainfall vs. SLHF
- Daily snapshots, DJF only
- West Pac domain: 15°S-10°N, 120°-180°E