Effects of a Slab Ocean Model on MJO Structure in the SPCAM

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Motivation and Research Questions

- In 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
  - 1 Sep 1999 – 31 Aug 2004
  - First 5-year segment taken from SPCAM AMIP simulation (“CTL”)
  - Second 5-year segment taken from a 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”):

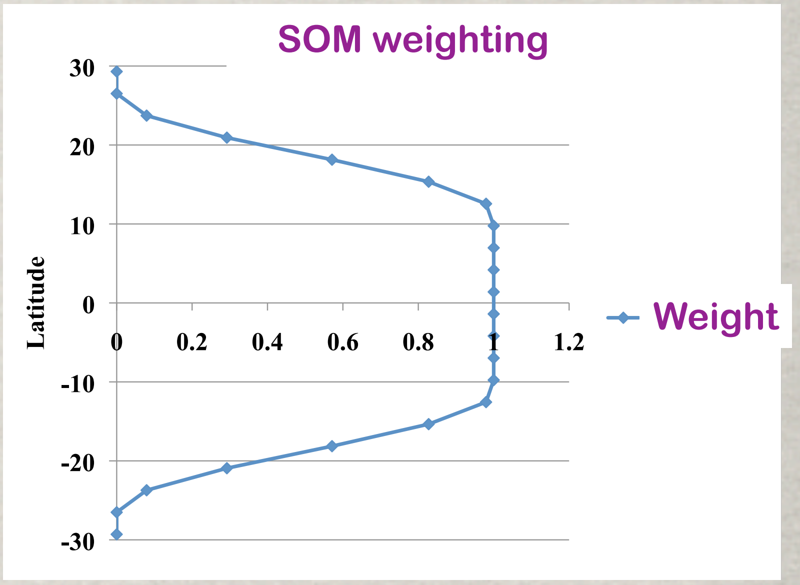
Departure of SST from (daily) prescribed value

Departure of total surface flux from smoothed climatology

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

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

Time- and space-dependent ocean mixed layer depth

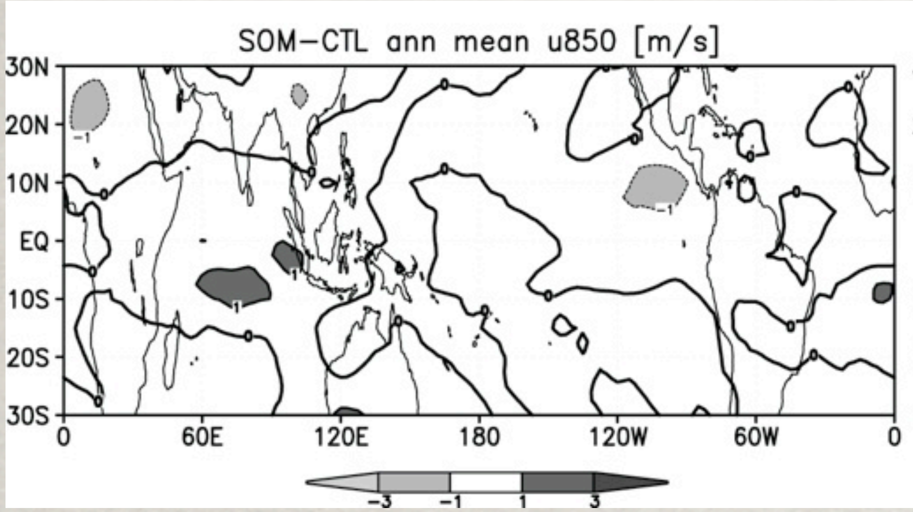


- Validation data:
  - ECMWF-Interim Reanalysis (ERAI): dynamic and thermodynamic variables
  - GPCP: rainfall
  - NOAA satellites: OLR, SST
  - TRMM Microwave Imager (TMI): Total column water

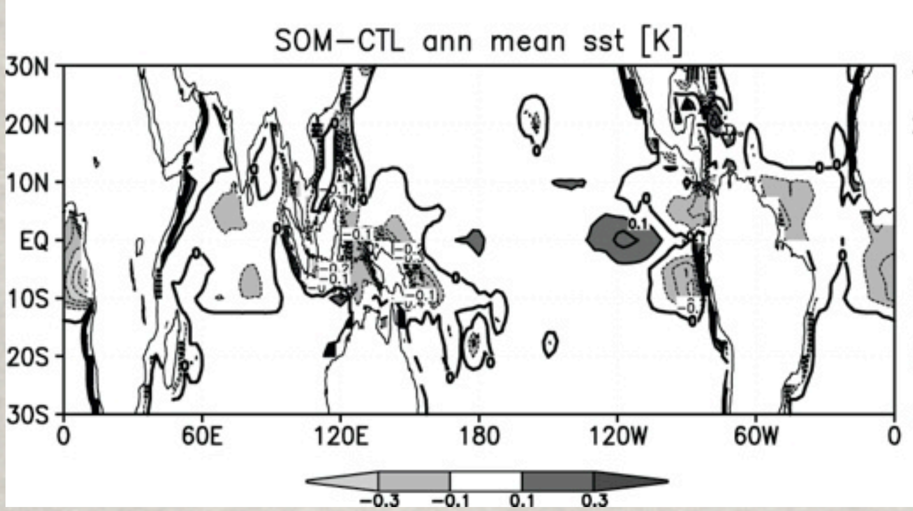
Selected Results: The Basics

SOM–CTL, ANNUAL MEAN

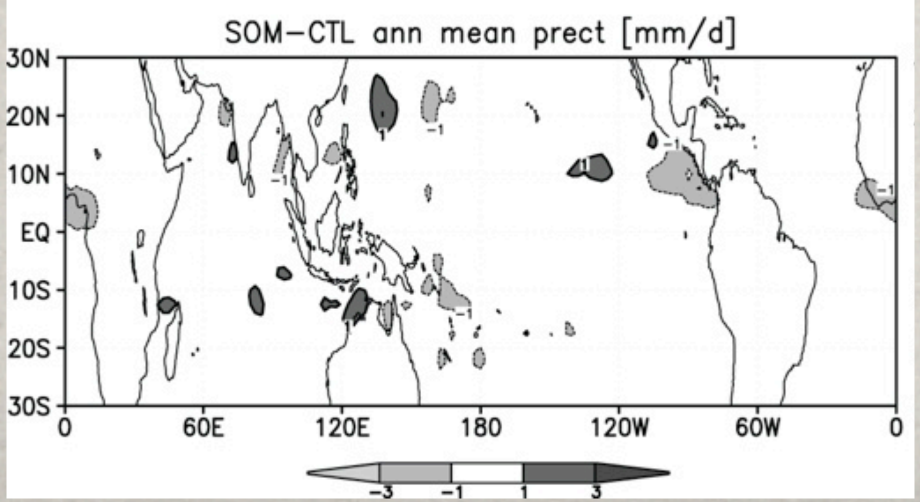
850 hPa zonal wind



SST



Rainfall



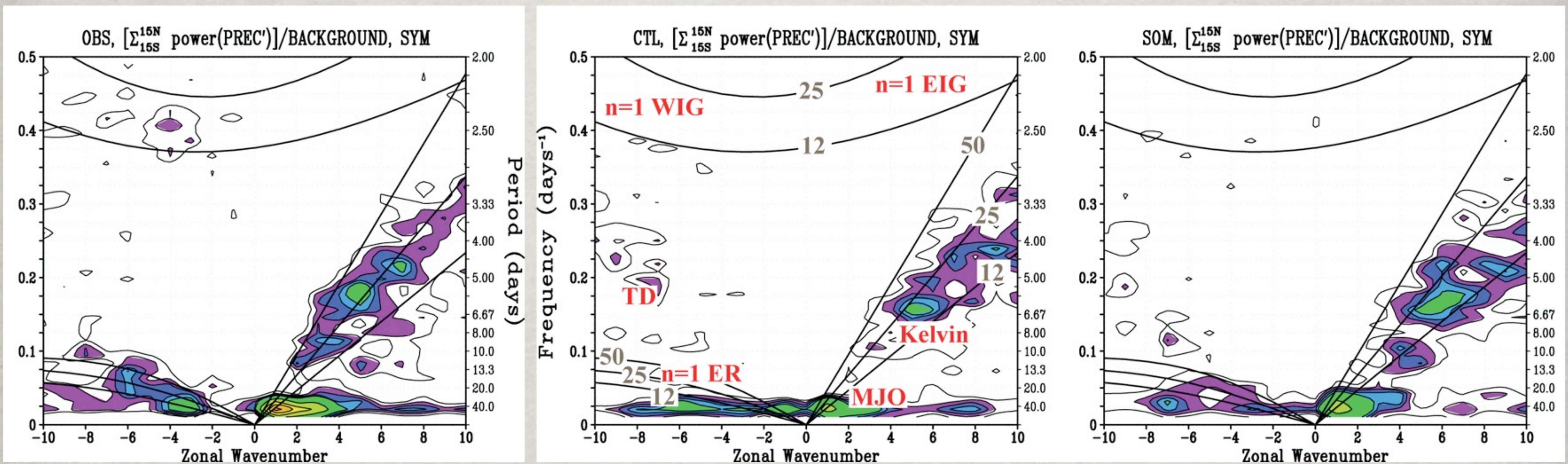
- No significant differences of global energy budget between standard CAM, uncoupled SPCAM, and coupled SPCAM

- 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 Rossby signals, and a larger east-west power ratio

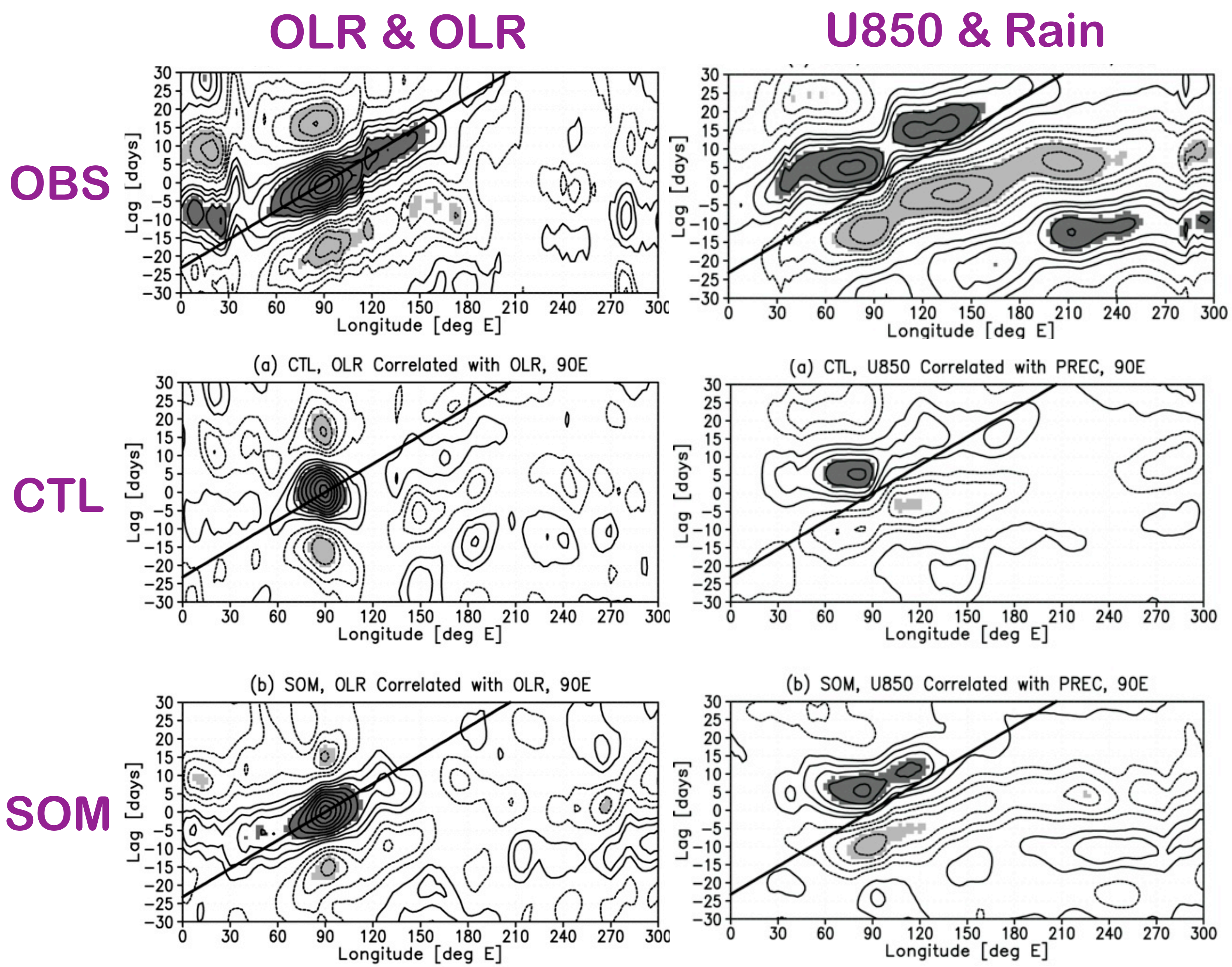
Obs Rain | CTL Rain | SOM Rain



Ratios of Eastward to Westward MJO Spectral Power

	Precipitation	OLR	U850	U200
Observations	2.7	3.1	5.9	7.4
CTL	1.3	1.7	2.6	3.7
SOM	1.7	2.1	3.5	4.0

Selected Results: Lag Correlation 1

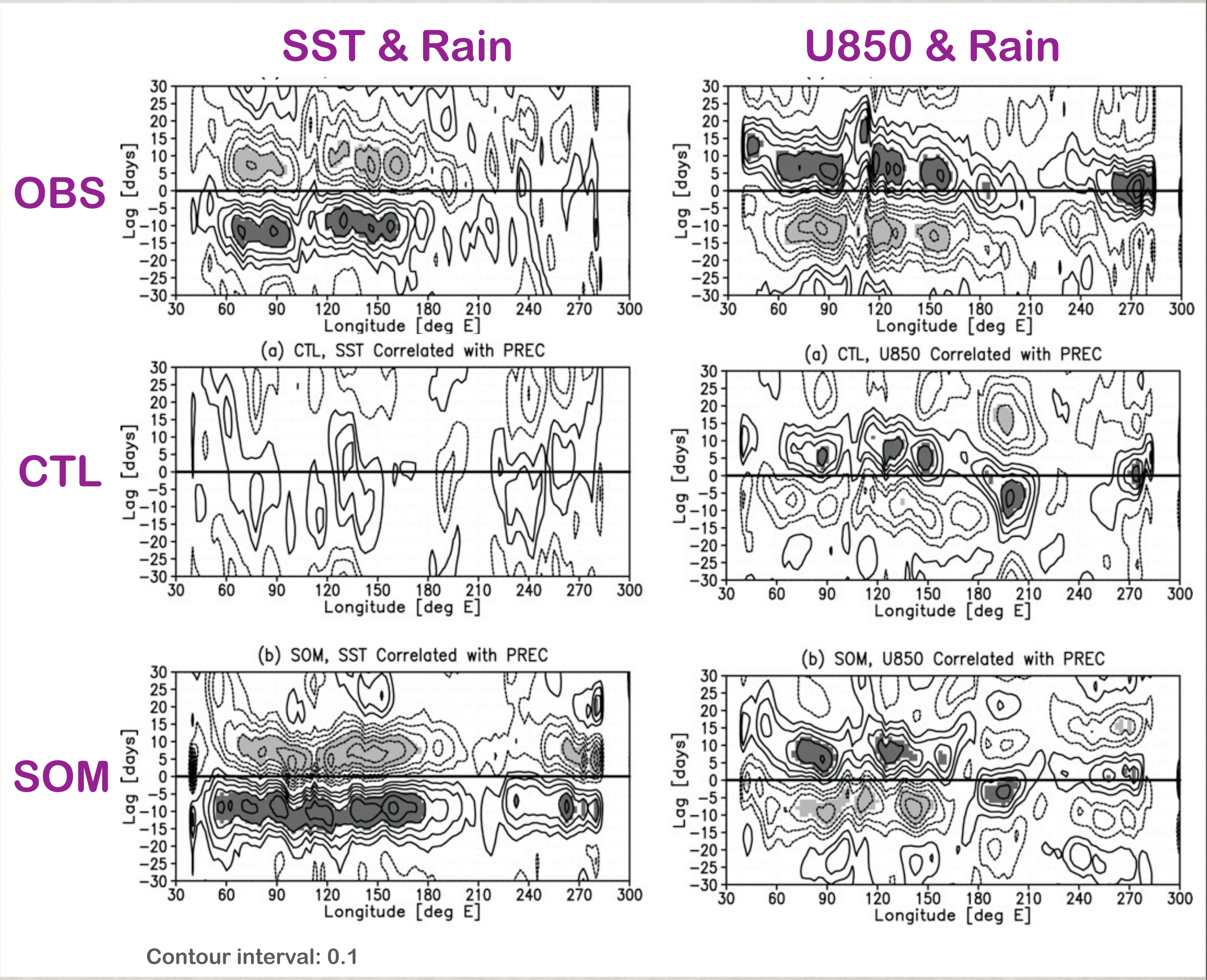


Contour interval: 0.1

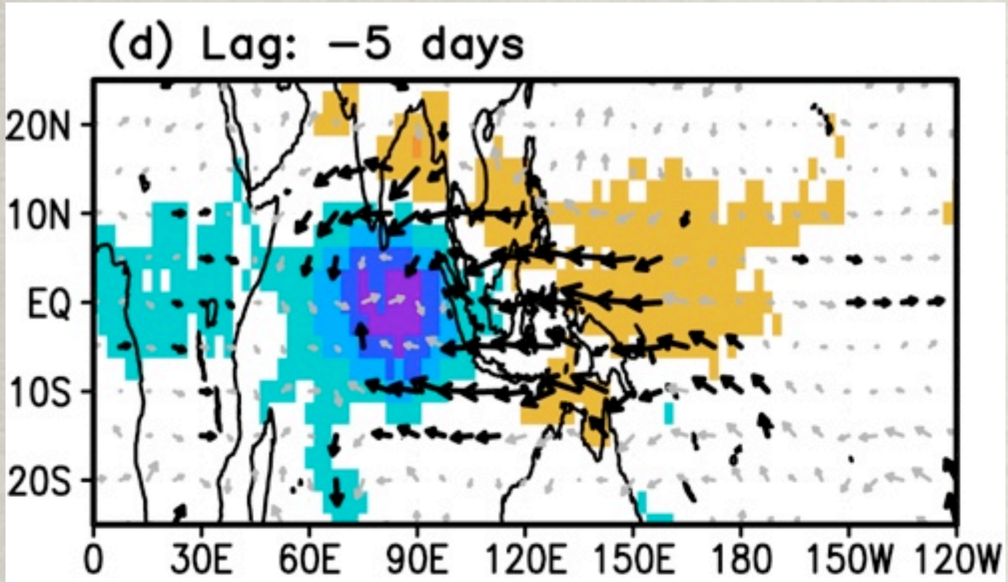
- 20-100-day filtered signals
- SOM: Greater MJO signal coherence
  - MJO convection remains organized over a larger space-time domain
- Couplet of leading easterlies-trailing westerlies
  - improved relationship between convection and dynamics

Selected Results: Lag Correlation 2

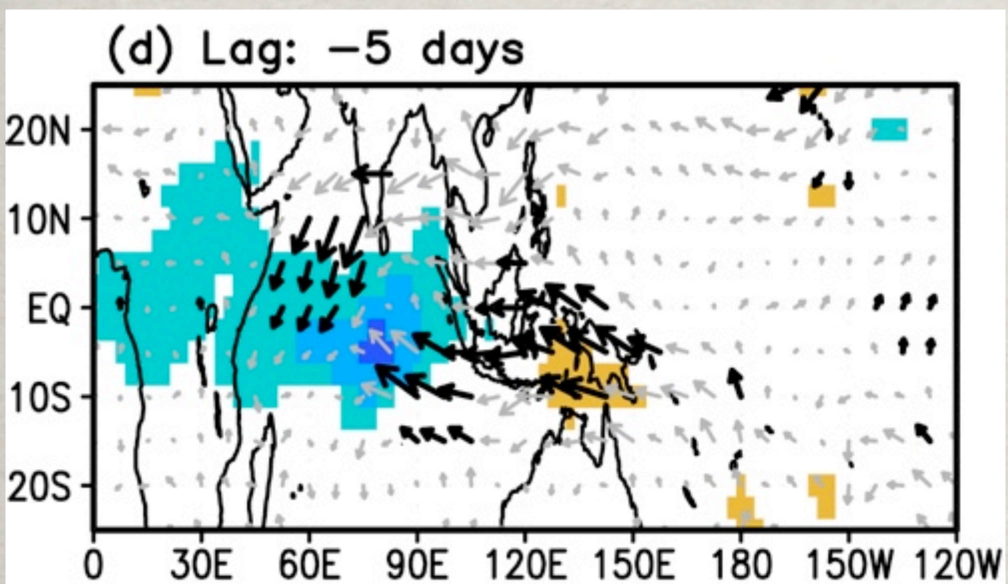
- 20-100-day filtered signals
- Substantially more realistic SST structure in SOM
- Improved coupling of low-level zonal winds over a larger spatial domain in SOM



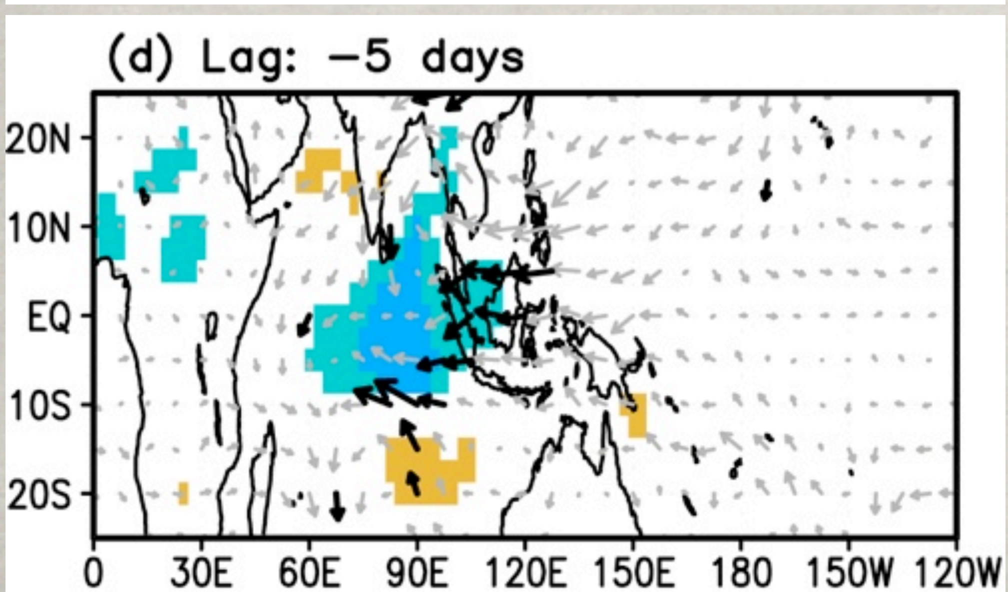
Selected Results: Lag Regression



OBS



SOM

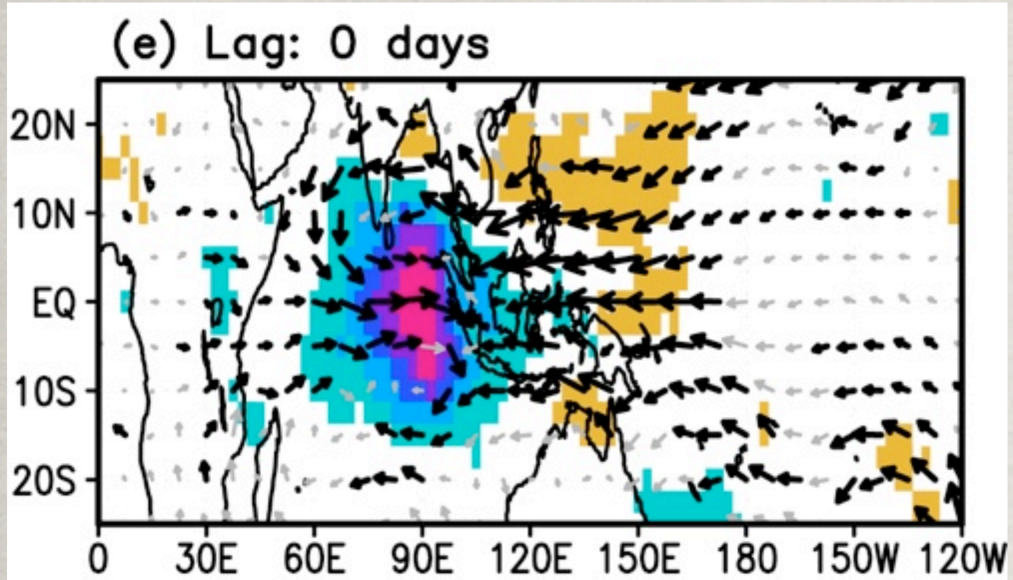


CTL

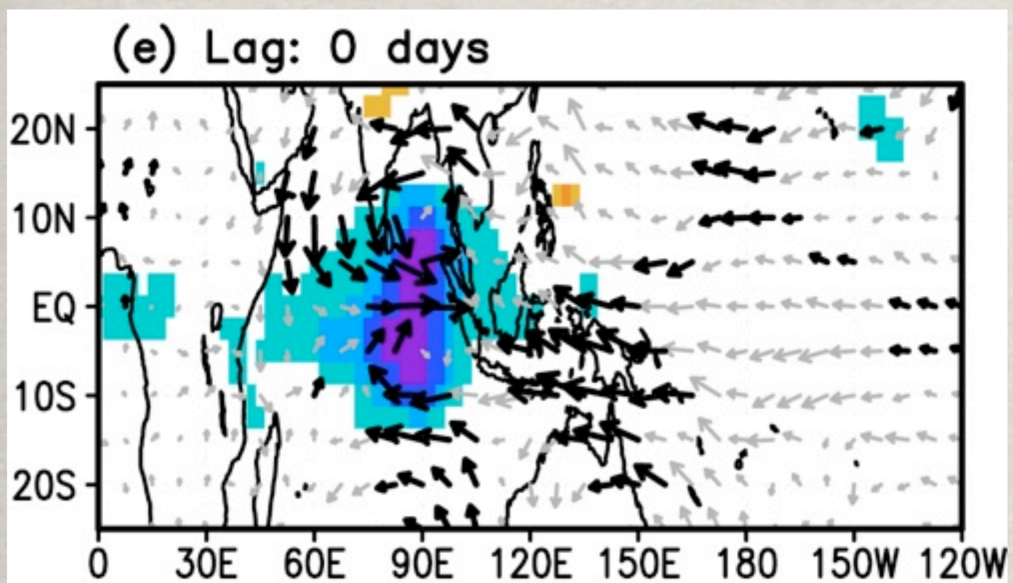
LAG DAY –5

- More robust convection that has propagated into the 90°E focus region in SOM
- Weaker convection appears to develop in situ at 90°E in CTL

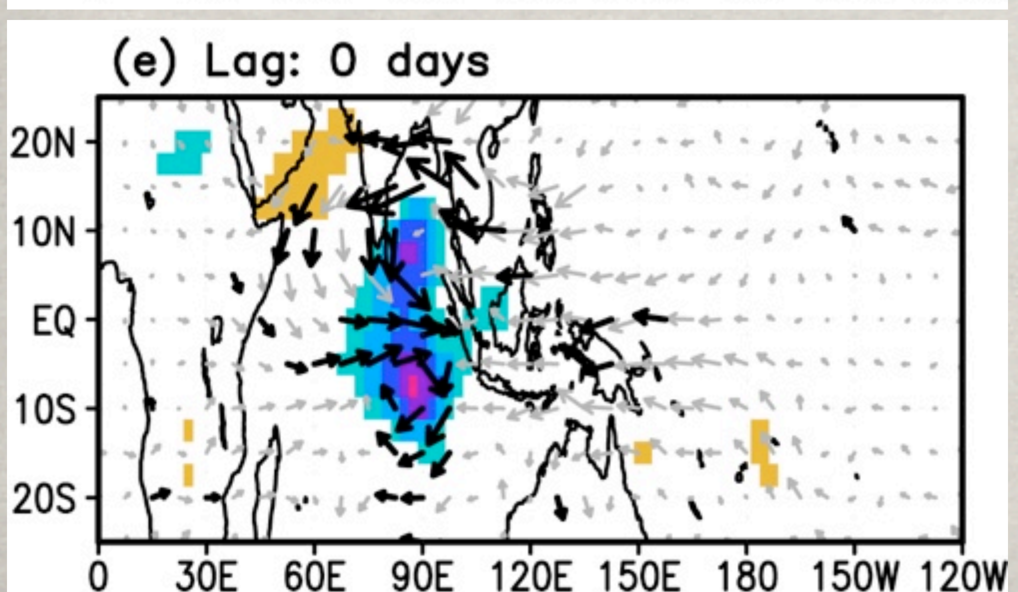
Selected Results: Lag Regression



OBS



SOM

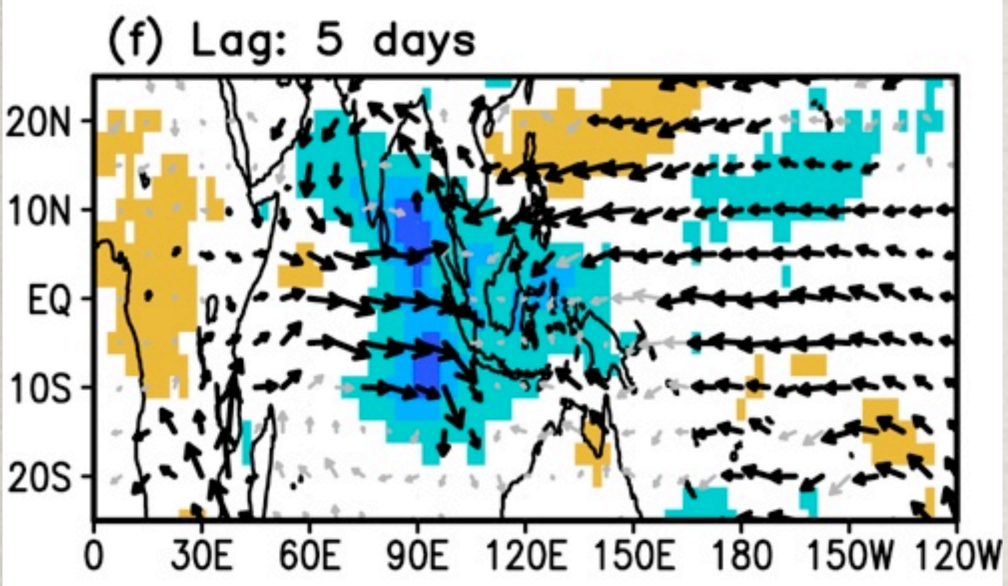


CTL

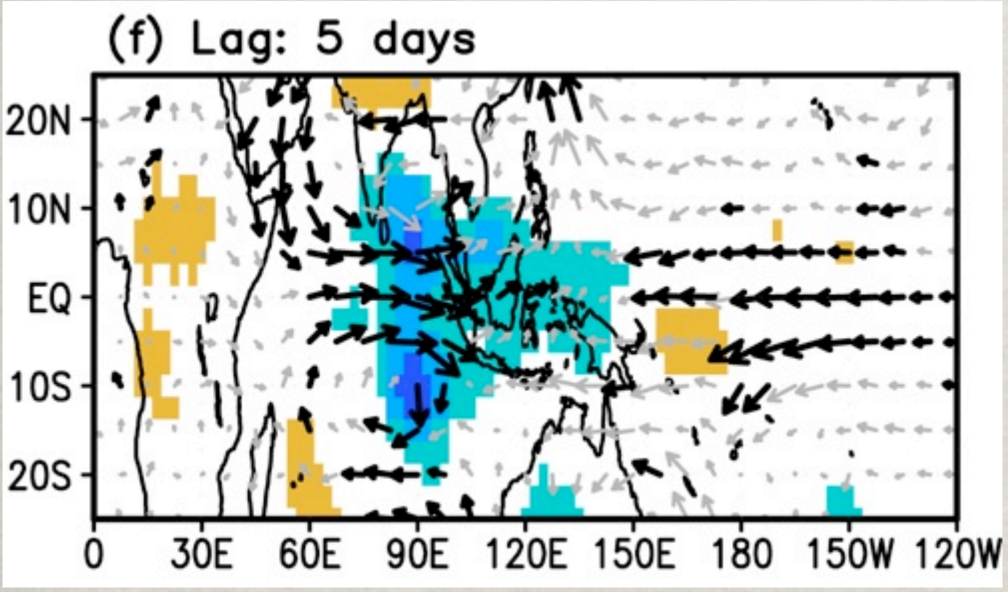
LAG DAY 0

- Considerably broader longitudinal extent of convection in SOM
- Noticeable weakening of convection along Equator in CTL

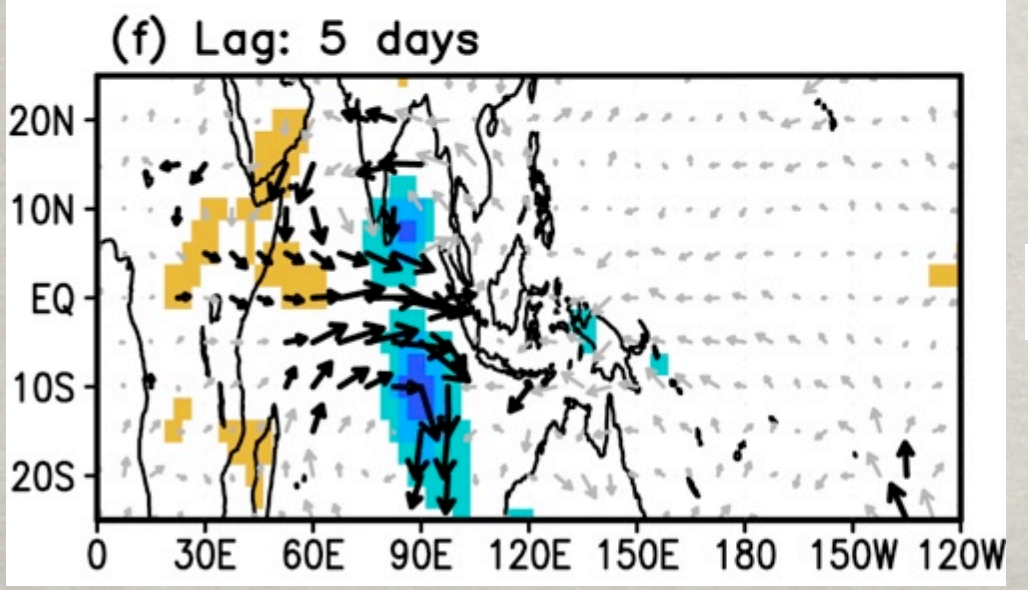
Selected Results: Lag Regression



OBS



SOM

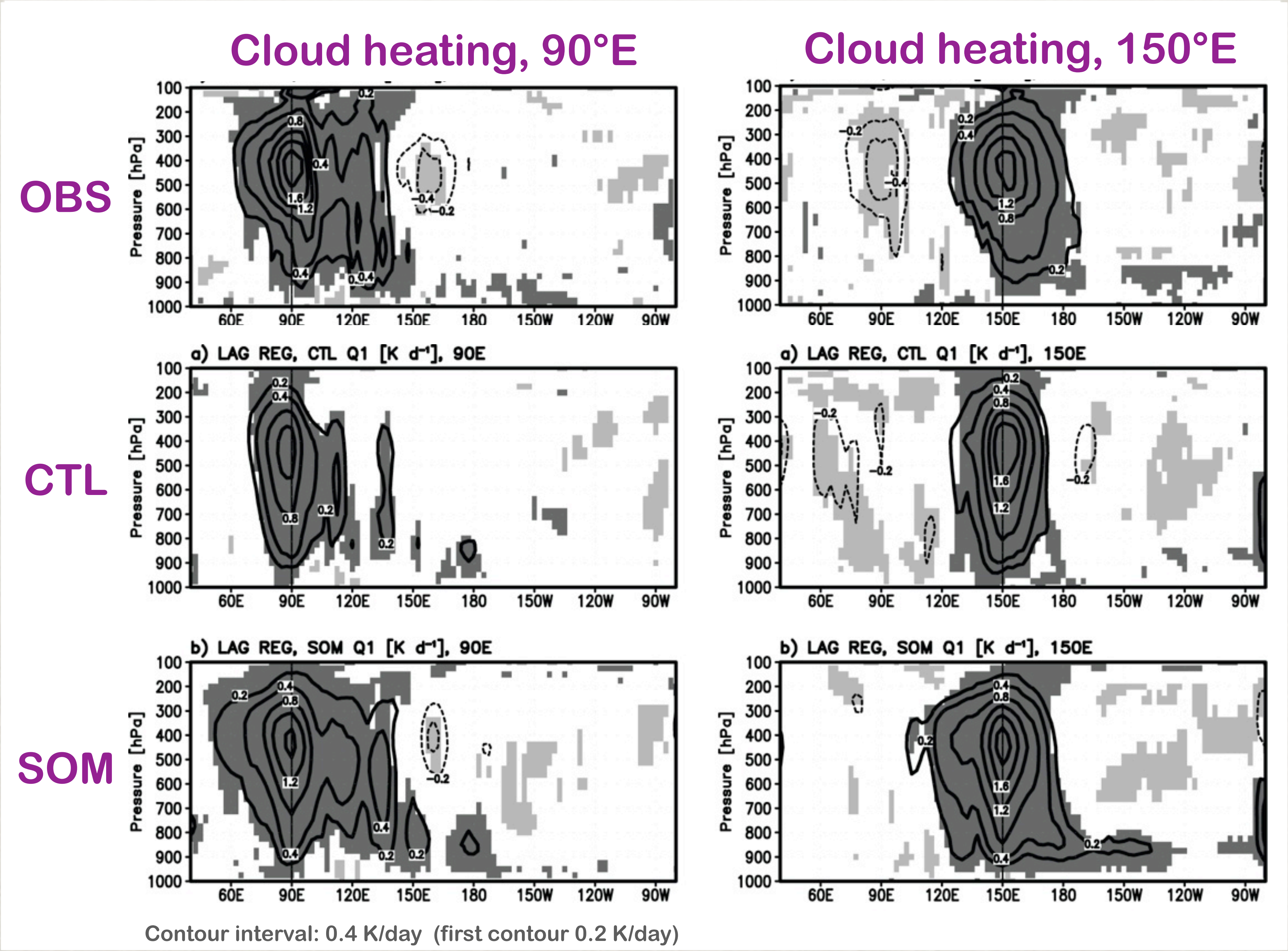


CTL

LAG DAY +5

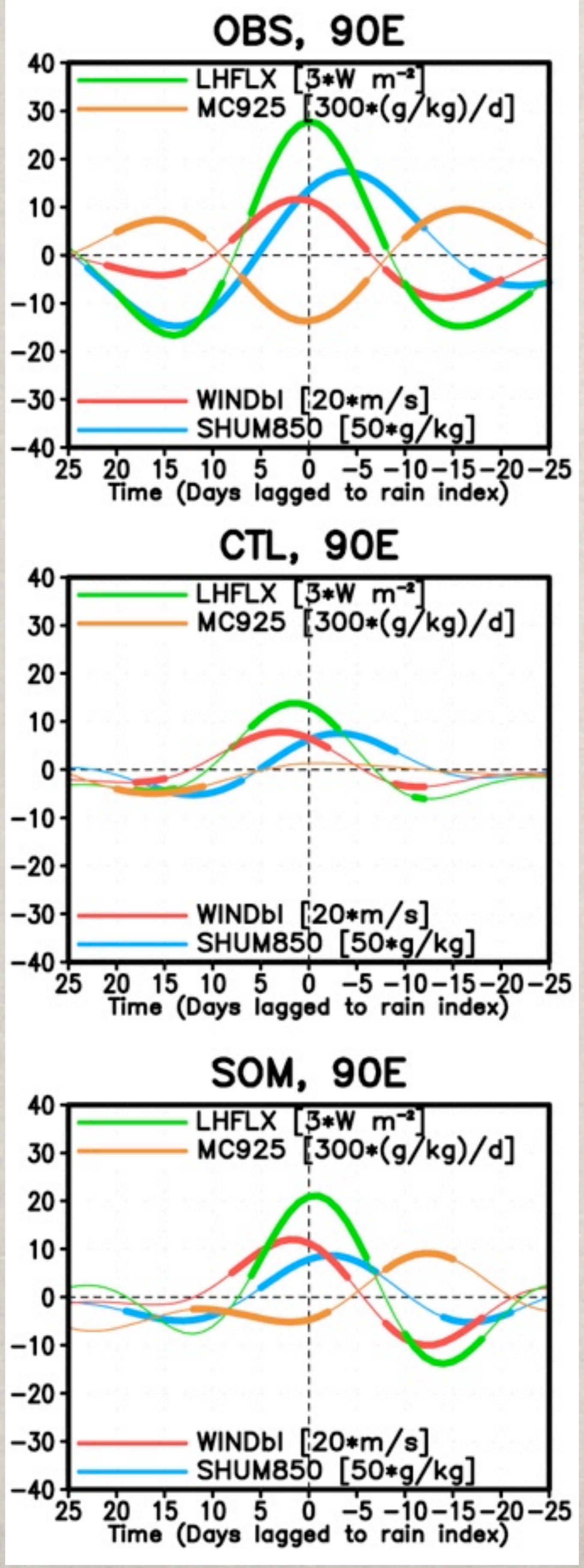
- Significantly improved longitudinal extent of convection and low-level winds in SOM
- No significant convective or dynamic signal in West Pacific in CTL

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: Mechanisms



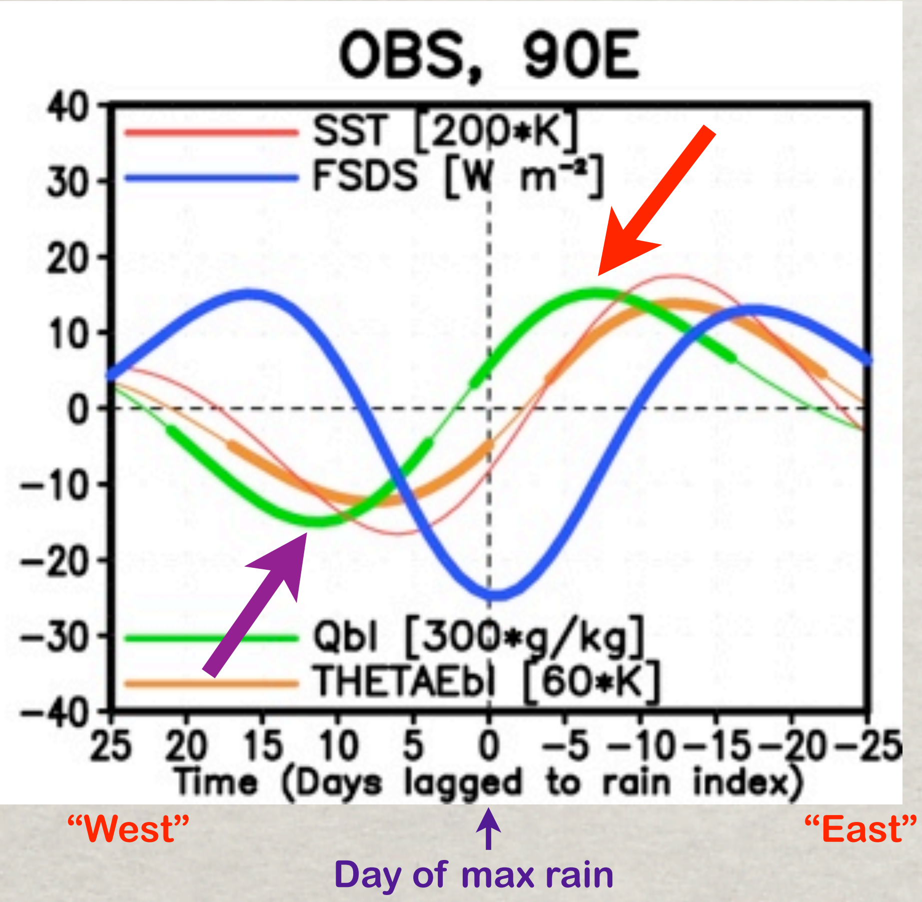
- Timeseries of spatially averaged regression values
  - Index: standardized rainfall at 90°E
  - Spatial average: 10°x10° box, centered on 90°E and Equator
  - Unified y-axis (for comparison)

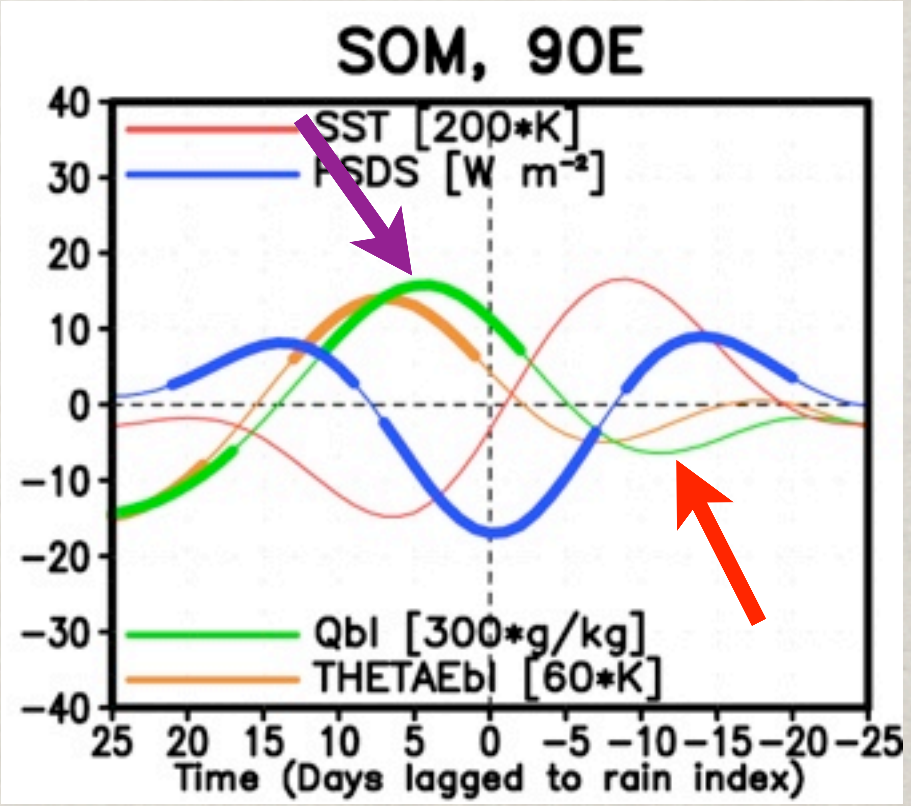
- CTL: Before Day –10, no significant relationships between most low-level variables

- 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: Model Biases

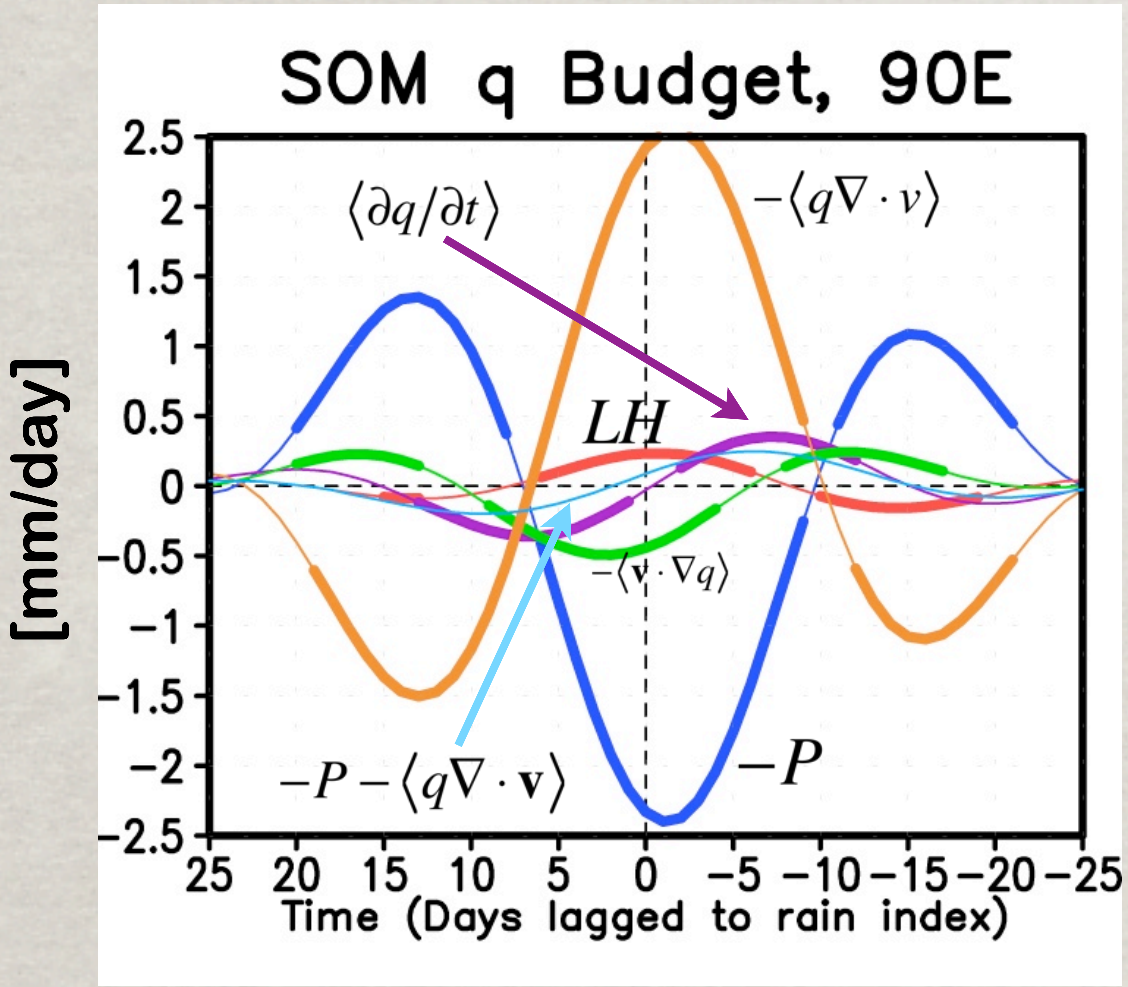
- Out-of-phase relationship of boundary layer moisture between SPCAM and observations



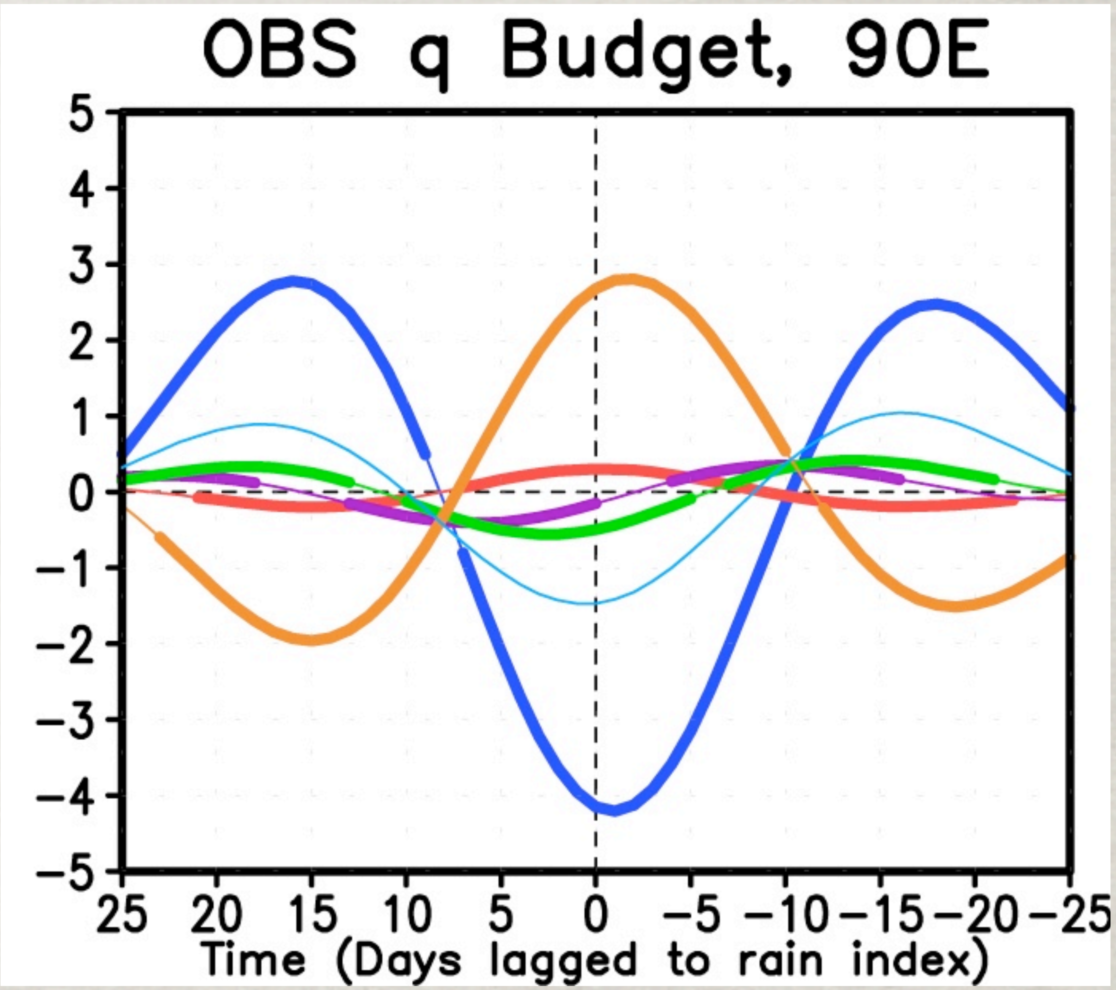


q Budget, 90°E

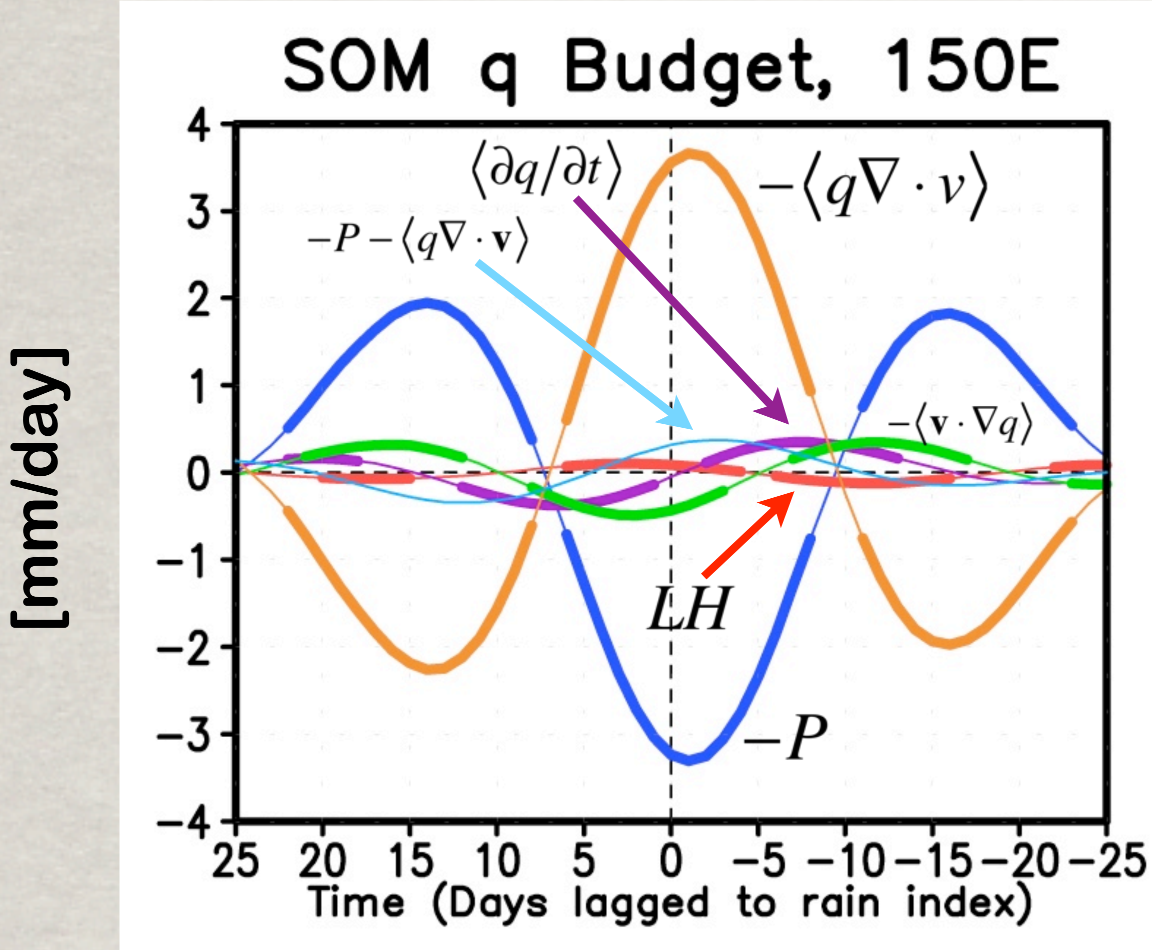
Coupled SPCAM

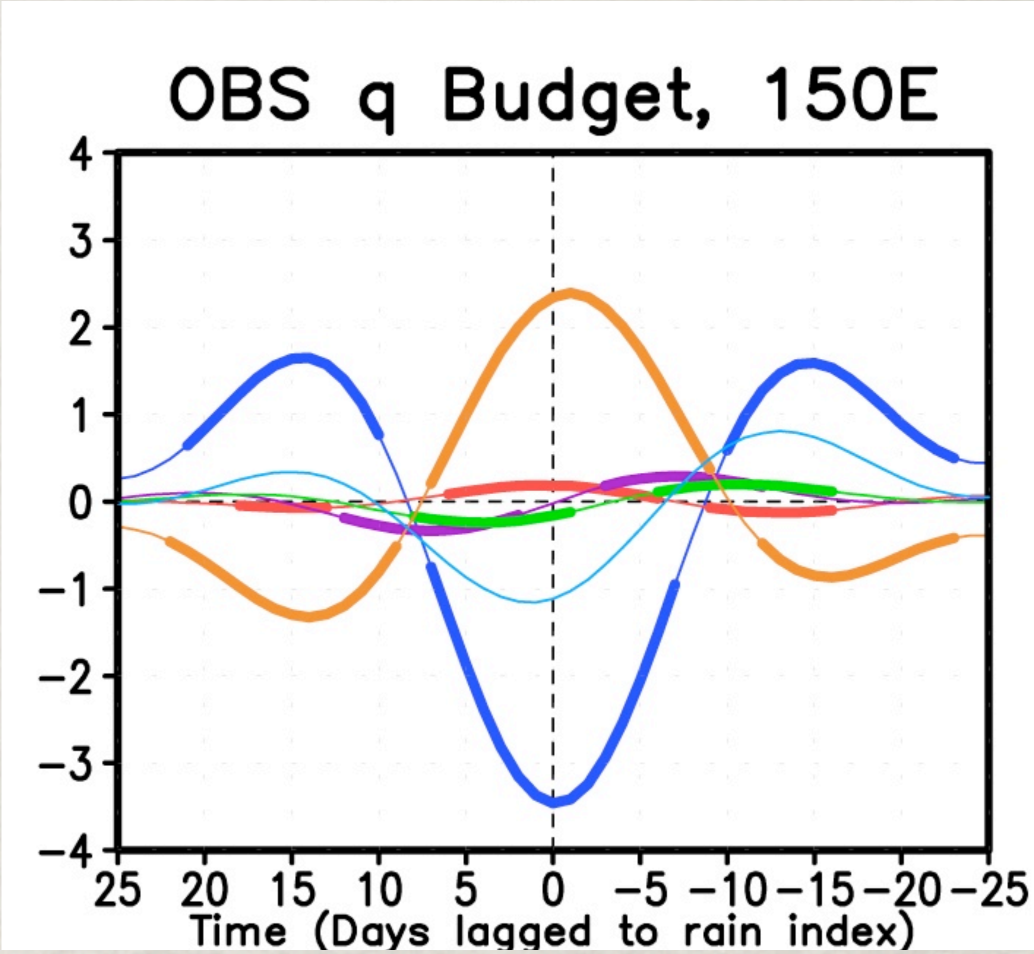


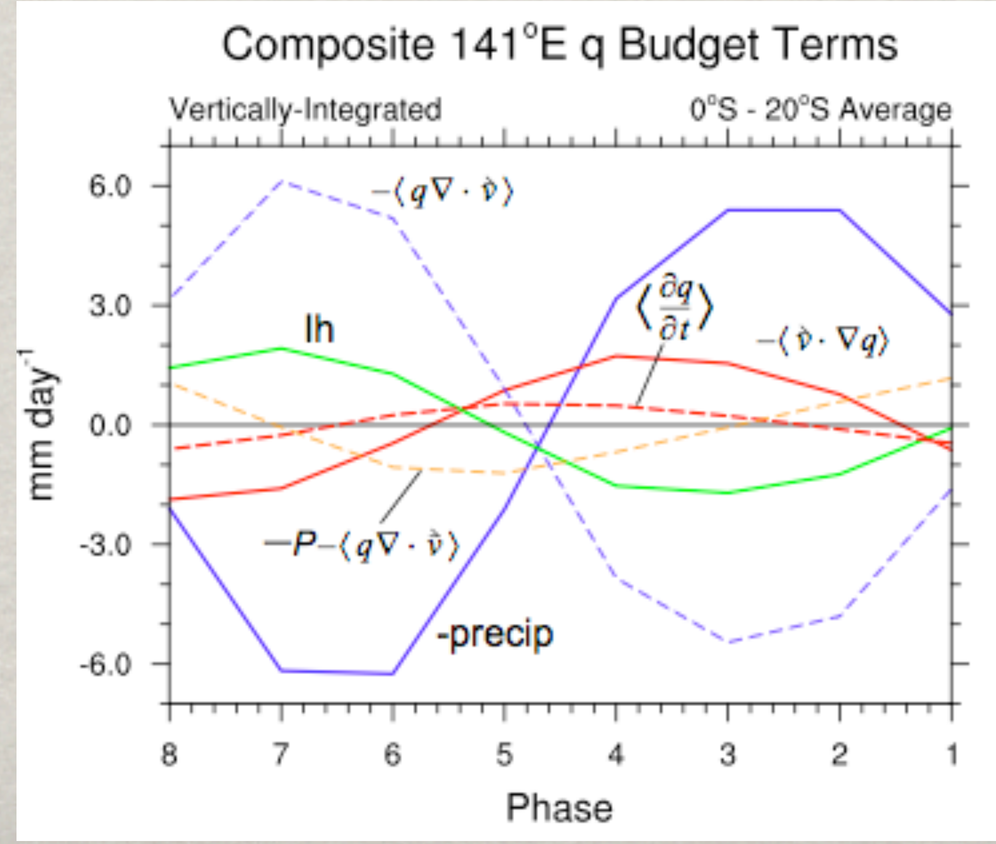
Reanalysis



q Budget, 150°E





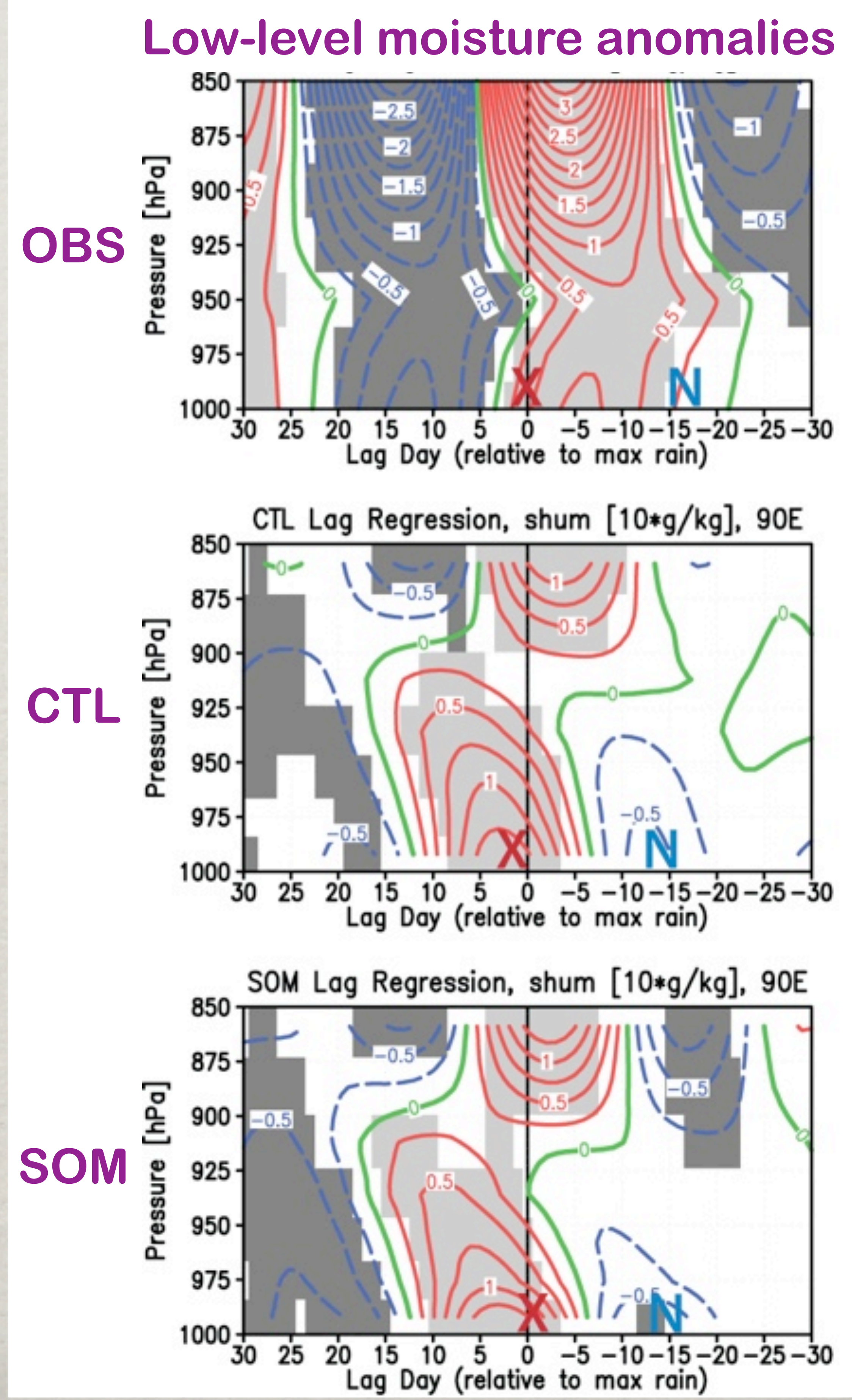


Maloney et al. 2009, JAMES

Discussion: Model Biases

- Notes on the low-level moisture bias:
  - Not related to air-sea coupling
  - Errors are largest in the lower boundary layer
  - Not related to large-scale advection
  - SPCAM boundary layer moisture too sensitive to surface evaporation
  - Processes (on CRM scale or smaller) that regulate boundary layer moisture are too weak…

- Hypothesis: Underrepresentation of shallow cumuli in the SPCAM leads to unrealistically weak vertical moisture fluxes and excessive accumulation of water vapor within the boundary layer



Conclusions

- Analysis of 19 years of data from an 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
- Compared to the uncoupled SPCAM, the MJO in the coupled SPCAM is more realistic
  - improved spectral and physical MJO structures
  - improved signal coherence and eastward propagation → better phasing between low-level variables, including moisture convergence
- Model deficiencies need to be addressed
  - Overly intense MJO in West Pacific → mean state errors, lack of CMT
  - Boundary layer moist bias → underrepresented shallow cumuli

Items to Consider...

- Longer simulation of the coupled SPCAM (> 5 years), more MJO events
- Investigate the quantitative impact of air-sea coupling by re-running the SPCAM forced by the resulting SSTs from the coupled simulation
- Extend the influence of the slab-ocean model to higher latitudes and examine:
  - changes to the “Great Red Spot”
  - impacts on marine stratus clouds
- CRM resolution, CRM parameterizations, shallow cumuli