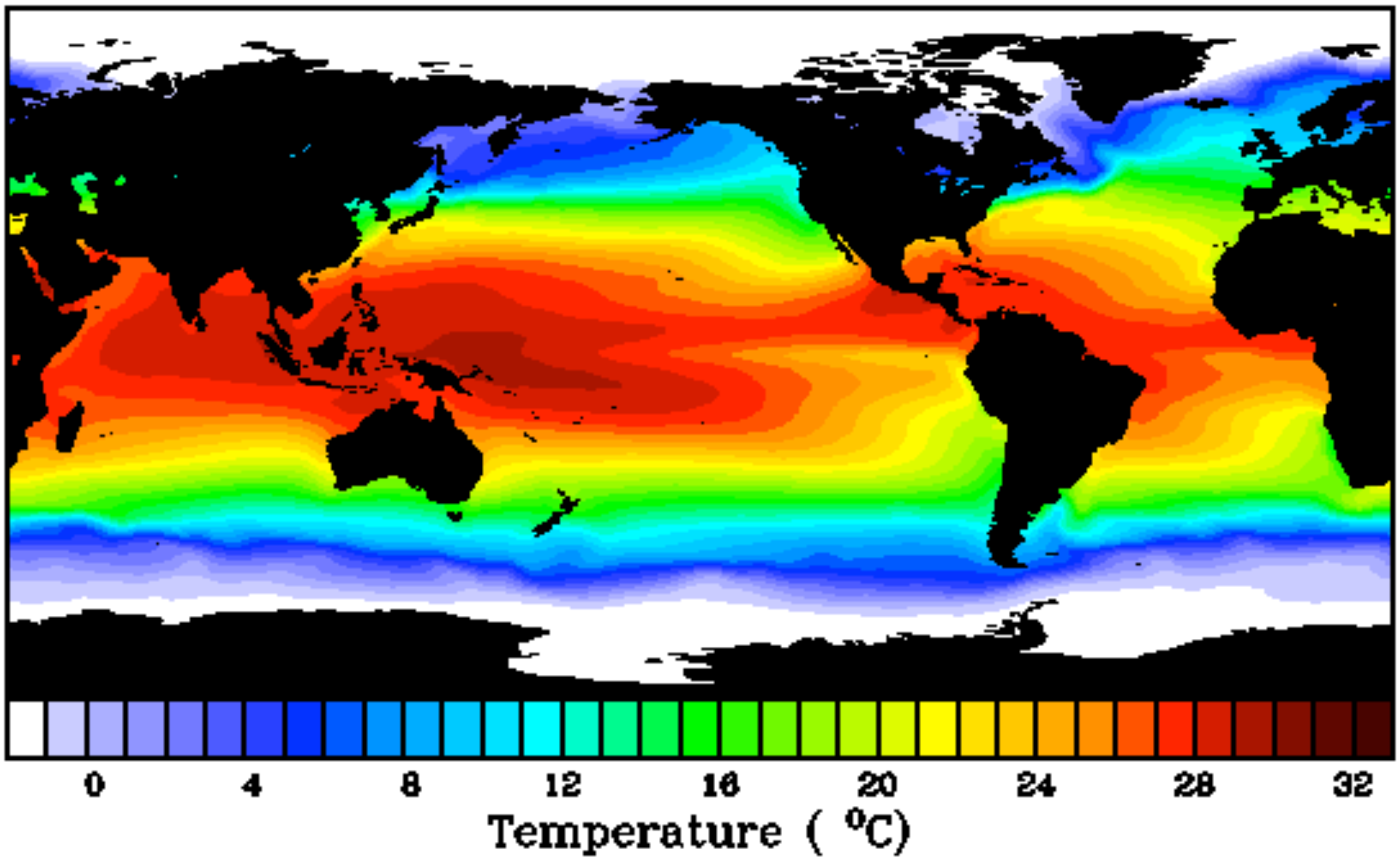
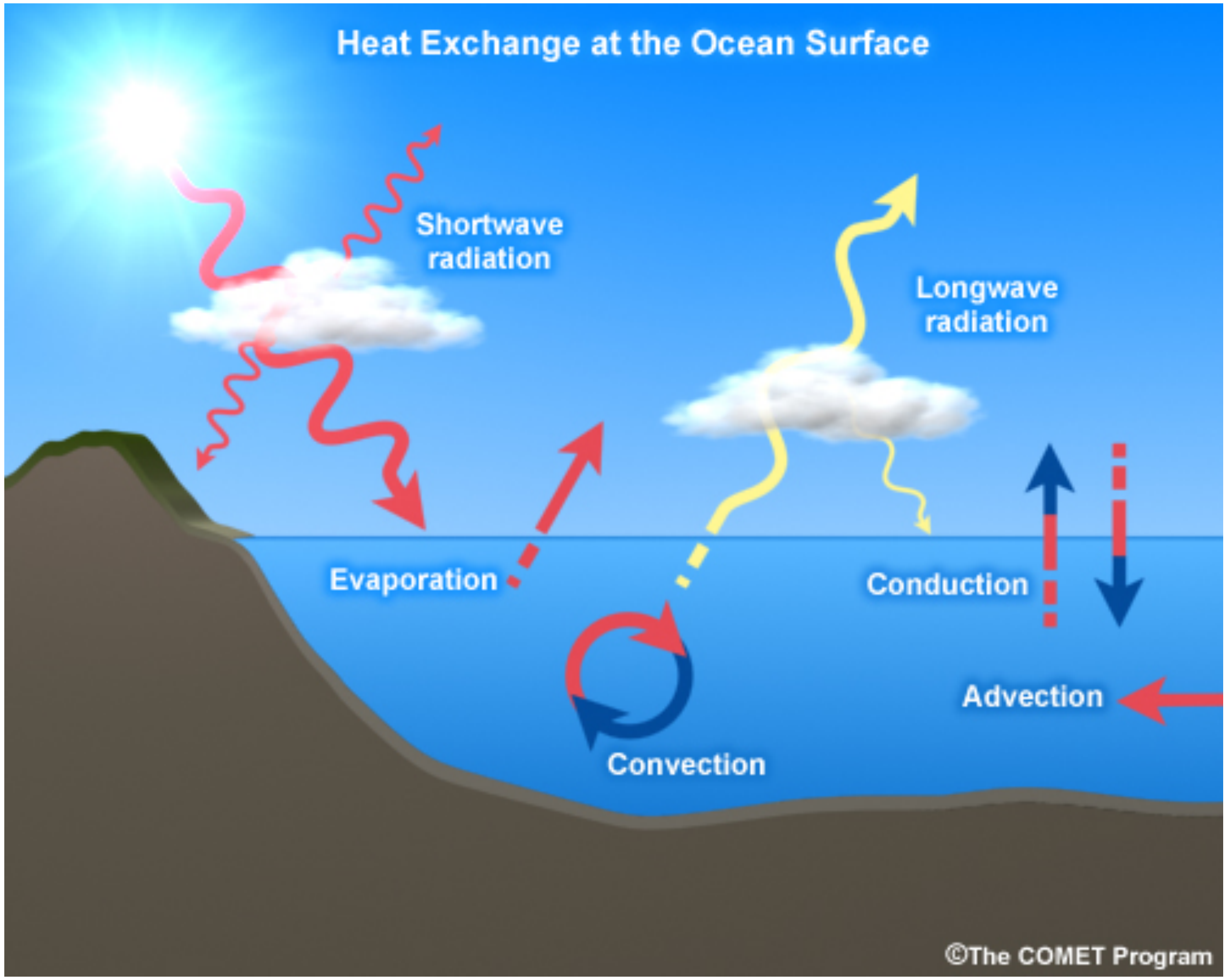
How does ocean coupling improve simulations of the Intraseasonal Oscillation?

Charlotte DeMott
Cristiana Stan
Mark Branson
David Randall

ANNUAL MEAN
GLOBAL SEA SURFACE TEMPERATURES





Heat Exchange at the Ocean Surface
Shortwave radiation
Longwave radiation
Evaporation
Conduction
Advection
Convection
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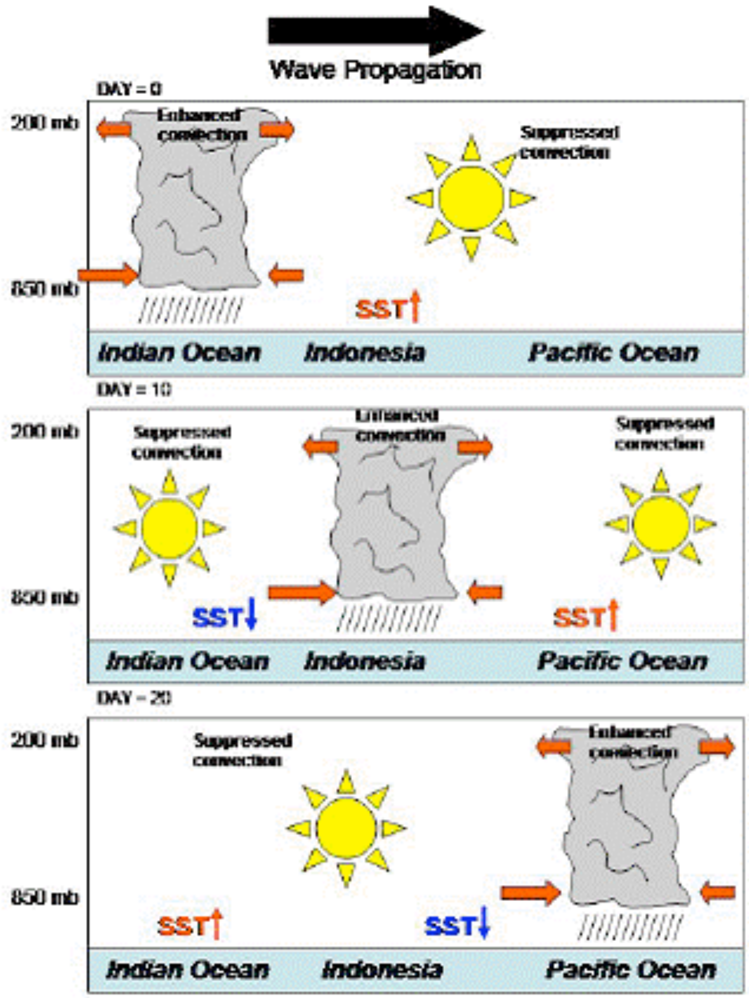
air-sea interactions within the MJO



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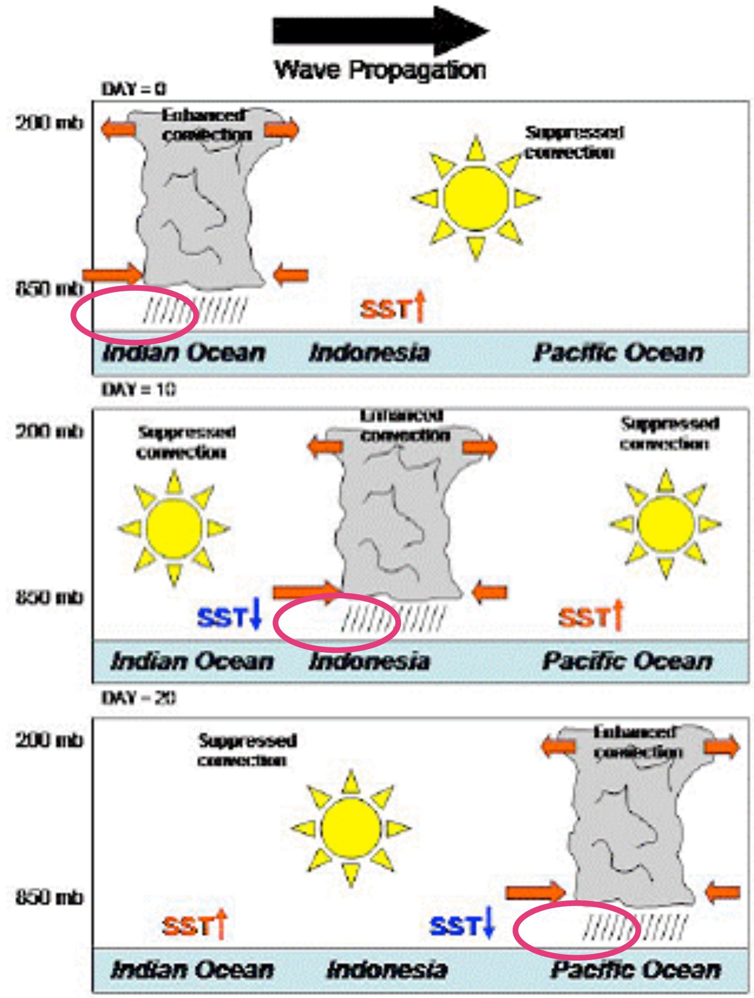
max sfc fluxes



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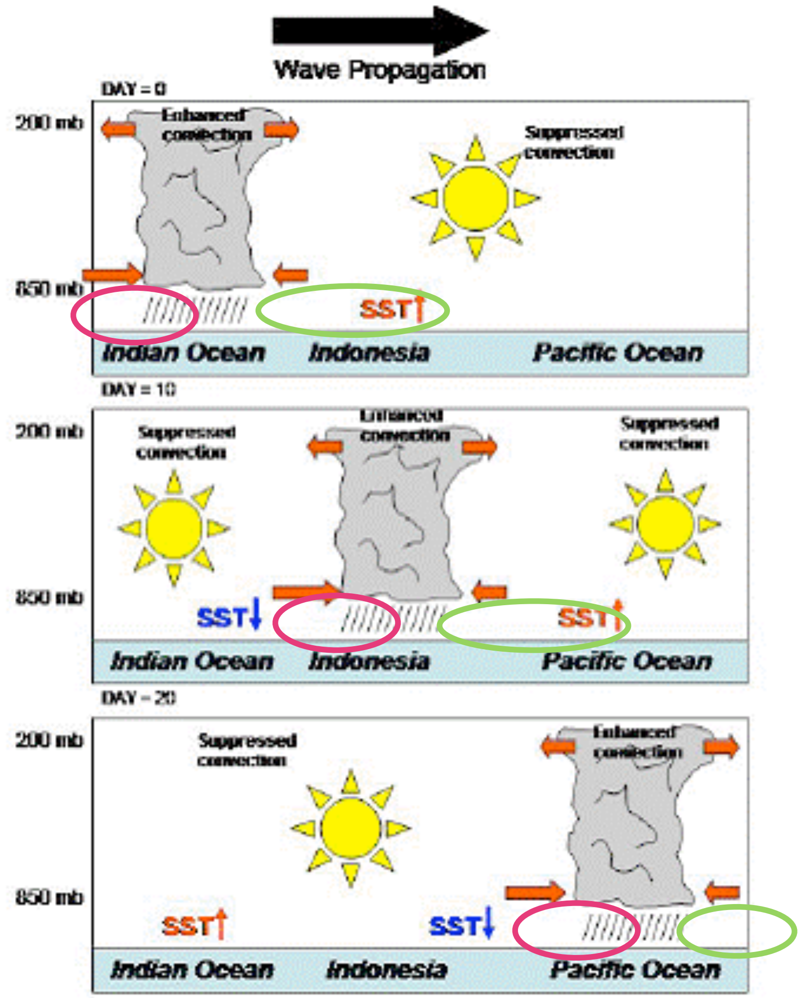
destabilization, convergence



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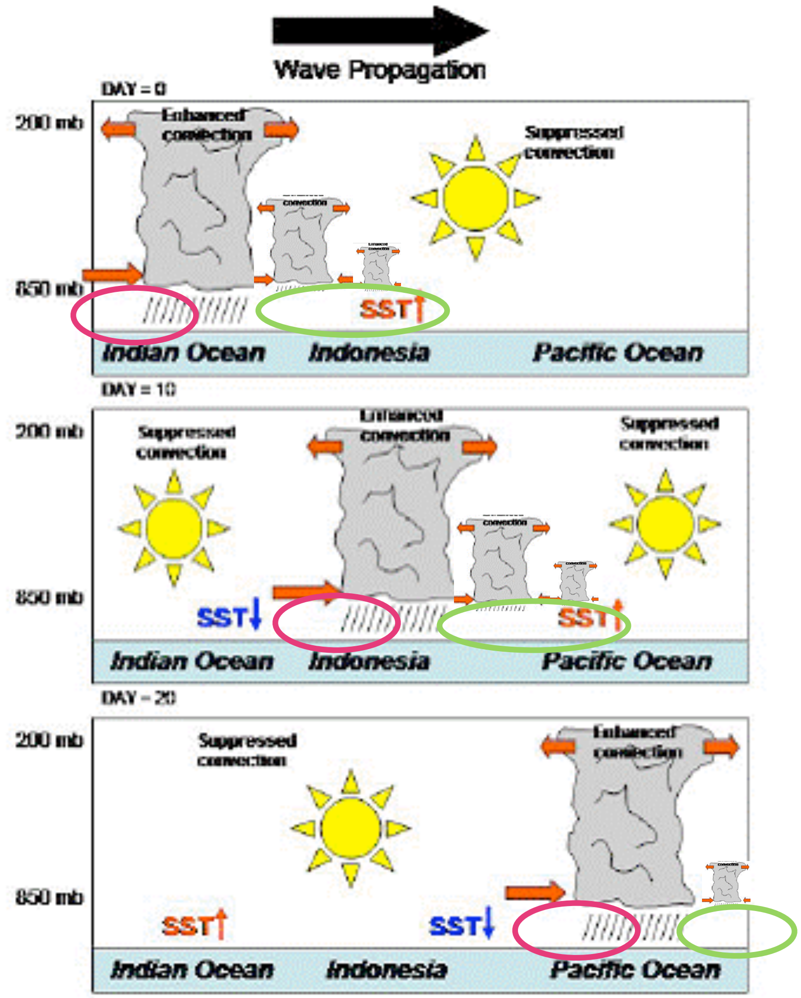


A blast from the past...

January 2009 Team Meeting Presentations

Tuesday January 6

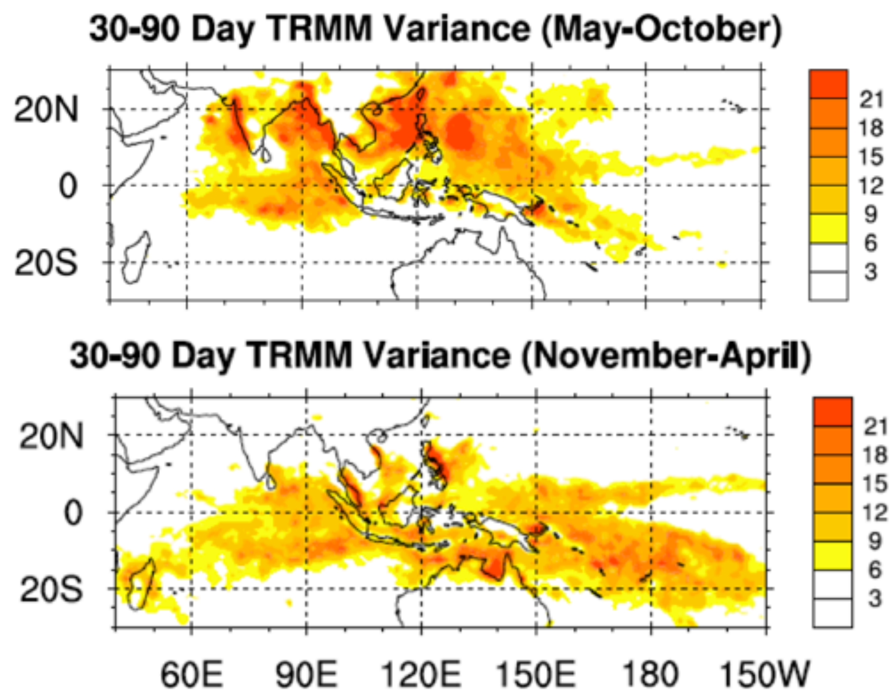
David Randall, Jay Fein, Cindy Carrick	Opening remarks/Agenda/Logistics, (3MB)
David Randall	Updates (see file, above)
Charlotte DeMott	Implied Ocean Heat Transports in the MMF, (9MB)
James Kinter	Testing the MMF in a coupled climate simulation, (9MB)
Chris Bretherton	Boundary-Layer Cloud Feedbacks on Climate - An MMF Perspective, (9MB)
Howard Drossman	Undergraduate Earth System Science Education, (2MB)
Michele Betsill	Climate Change Policy and Politics: A Status Report, (1MB)
Breakout Session I	• MJO - Maloney, Waliser ◦ MJO Theme, Mitch Moncrieff & Marat Khairoutdinov (7MB) ◦ US CLIVAR MJO Working Group: Efforts to Establish and Improve Subseasonal Predictions, Duane Waliser (4MB) ◦ Update on MJO modeling activities with CAM3/RAS, Eric Maloney (3MB) ◦ Variation of Energy Transfer to the Atmosphere associated with the MJO, Eric Tromeur (6MB) ◦ Dynamics of tropical intraseasonal variability: the role of fluxes, Adam Sobel (3MB) ◦ Progress in the development of a zonal channel version of the vector vorticity model, Hiroaki Miura (3MB) • KT to NWP and Climate Centers - Collins
Connie Uliasz	Information and its Relationship to Power, (< 1MB)

Wednesday January 7

Andy Majda	Non-linear models for convective momentum transport in the MJO and new algorithms for superparameterization models on mesoscales, (6MB)

Variance of rainfall on intraseasonal timescales shows structure on both global and regional scales

Intraseasonal rain variance

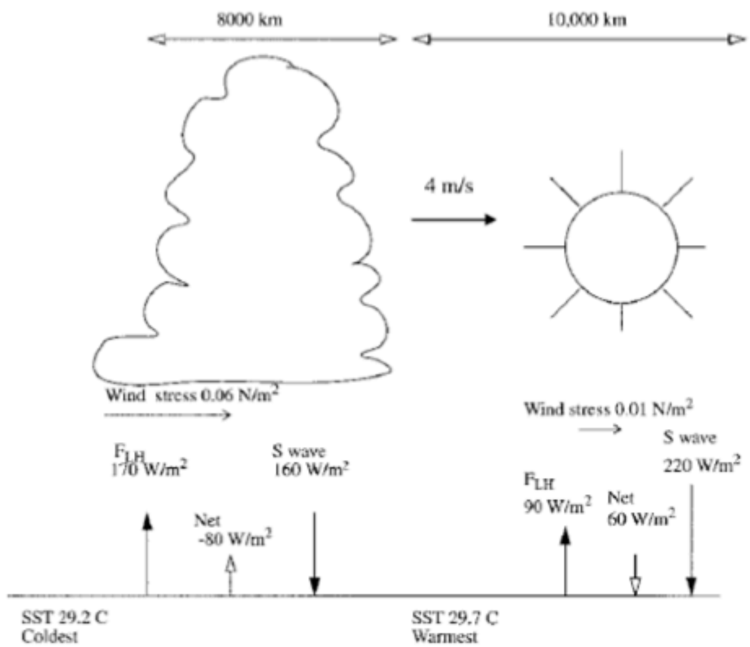


Northern Summer

Southern Summer

Sobel, Maloney, Bellon, and Frierson 2008: *Nature Geosci.*, **1**, 653-657.

Over land, there can be no significant net flux variations on intraseasonal time scales - so if net flux were important to ISO, the observed variance maps should look as they do!



ocean

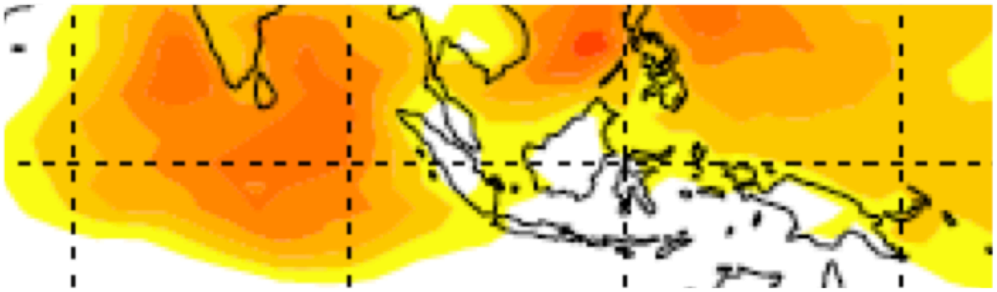
Net = 0 W/m^2

land

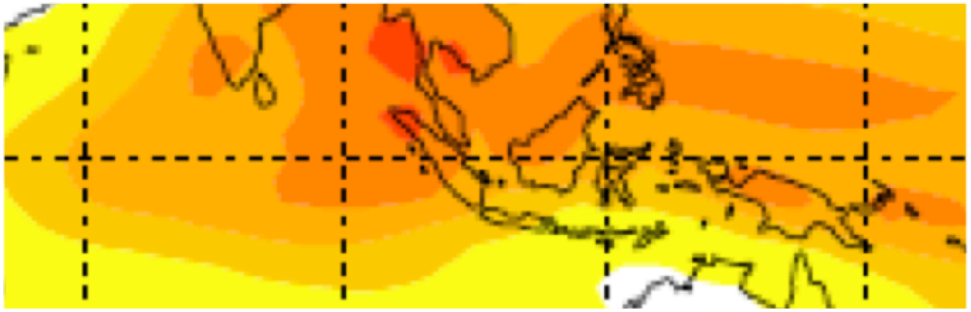
Shinoda et al. 1998

Wet land is like a mixed layer of zero depth (swamp). Thus if MJO is dependent on surface energy fluxes (turbulent, radiative, or both) it should weaken over land… as observed.

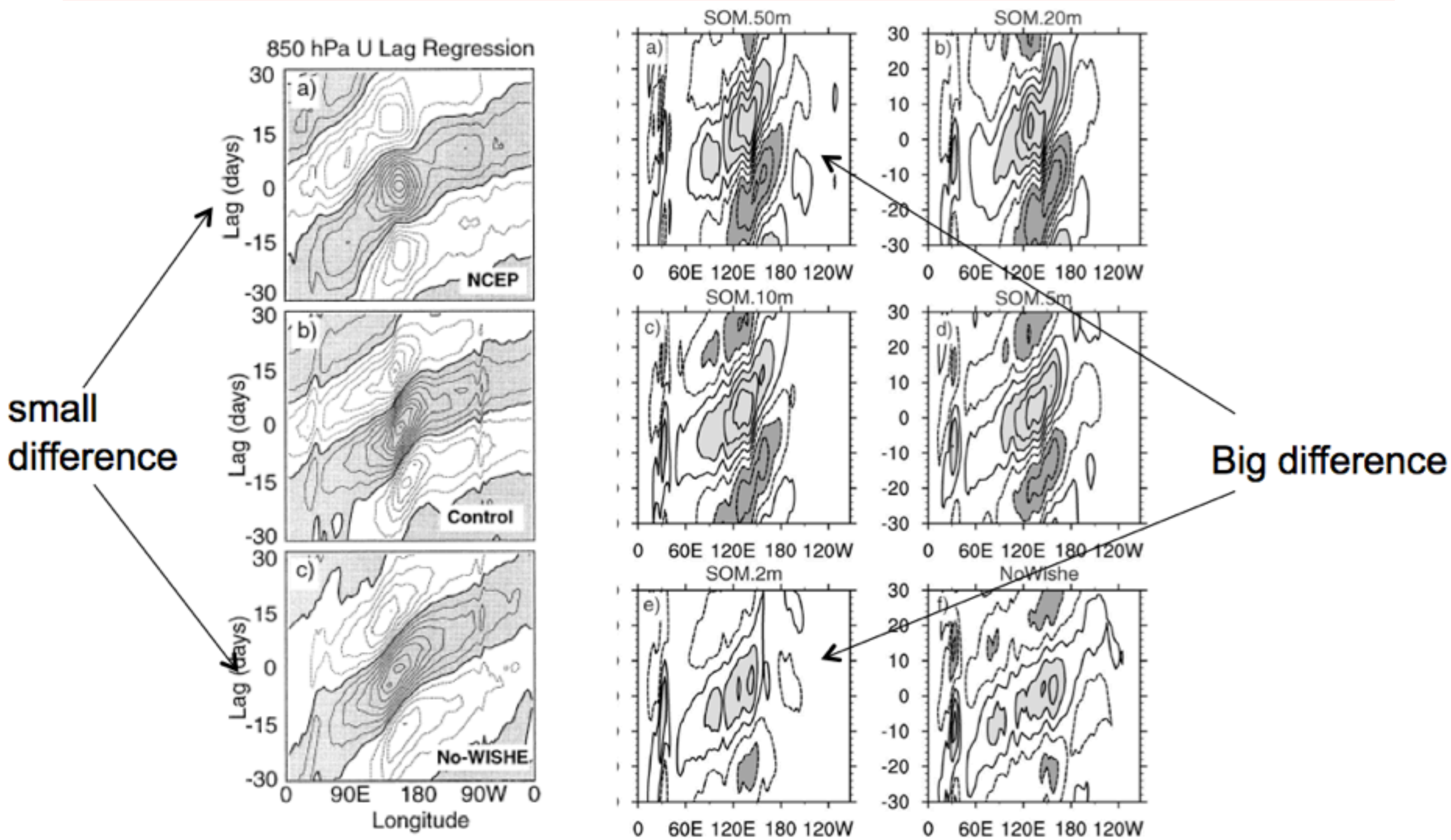
Intraseasonal OLR variance (may-oct)



Climatological mean OLR (may-oct)



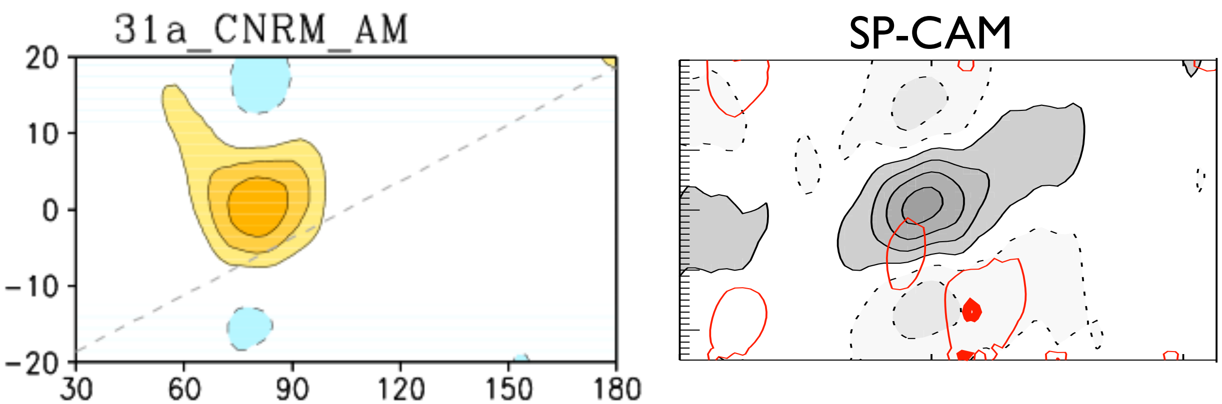
The GCM-simulated dependence on surface turbulent flux feedback is very dependent on convective scheme.



Precip (Maloney 2002)

Precip (Maloney & Sobel 2004)

illustration: effects of coupling in two different models



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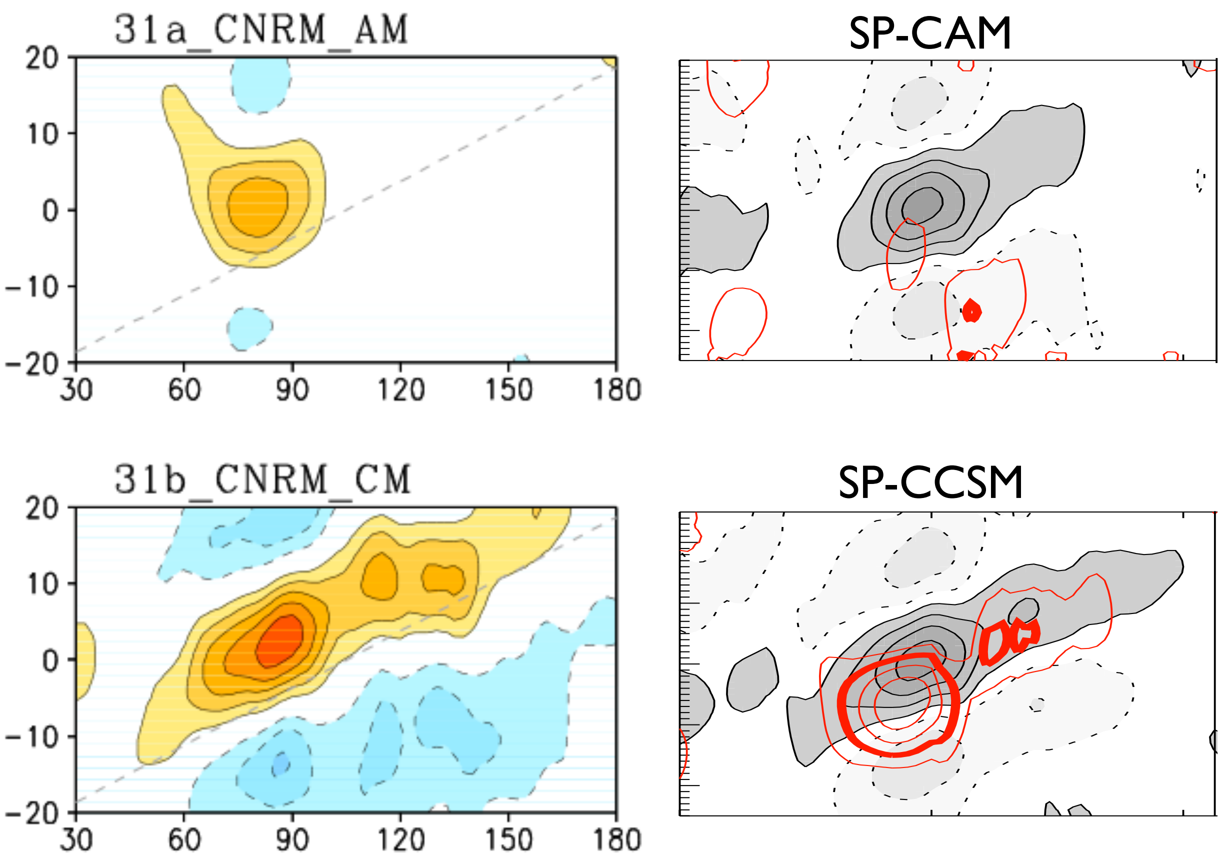

what is the consensus from the literature?

The search for common findings in the literature...

Coupled vs. AMIP or OBS					
			MJO (boreal winter)		
			both		Improves
referenced in paper			BSISO		cautionary note
Author	**Year**	**Journal**	**Title**	**Conclusions**	**Take Home**
Kemball-Cook, Wang, Fu	2002			written up in next section	
Fu, Wang, Li	2002	MWR	Impacts of air-sea coupling on the simulation of mean Asian summer monsoon in the ECHAM4 model	ECHAM4: Coupling results in better JJAS rainfall climatology in IO & WPac. Both local and remote effects are important.	
Sperber, Gualdi, Legutke	2005	Climate Dyn	The Madden-Julian oscillation in ECHAM4 coupled and uncoupled general circulation models	ECHAM4: AMIP and coupled w/ 3 different ocean models (2 flux-adjusted, 1 not). Eprop is sensitive to choice of ocean model w/ better Eprop in the FA models. Also points to the importance of the mean state.	
Zhang, Dong, Gualdi, Hendon, Maloney, Marshall, Sperber, Wang	2006	Climate Dyn	Simulations of the Madden-Julian oscillation in four pairs of coupled and uncoupled global models	Selected 4 models that produce a reasonable eastward-propagating intraseasonal signal (ECHAM4, CAM2R, BAM3, GFS03). Only CAM2R (NCAR/OSU) uses A-S closure, the others are mass flux schemes. Air-sea coupling stengthens simulated Eprop, but improvement in the precip-low-level wind relation varies with model. MJO biases appear to be related to mean state biases.	4 MODELS: coupling improves E-prop. Mean state difference dominate
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Wang and Seo	2009	Terr. Atm. and Ocn Sci	The Mdden-Julian Oscillation in NCEP coupled model simulation	NCEP GFS and CFS: Too fast Eward prop from IO to WPac is slowed down in CFS. Also improves the structure of the MJO. However, CFS does produce mean low-level westerlies over MC in boreal winter.	
Lloyd and Vecchi	2010	J. Climate	Submonthly Indian Ocean cooling events and their interaction wiht large-scale conditions	Observational and modeling study using GFDLCM2.1 and GFDLCM2.4. Strongest cooling events cannot be explained by air-sea enthalpy fluxes alone (they represent about 50% of observed cooling), they also involve mixing associated with unusually shallow thermocline in the eastern IO. These strong cooling events are more likely associated with La Nina than El Nino.	ocean mixed layer depth is important for strongest cooling events
Klingaman, Woolnough, Weller	2011	J. Climate	The impact of finer-resolution air-sea coupling on the intraseasonal oscillation of the Indian monsoon	Uses HadKPP (KPP is a limited-depth ocean model). Modest improvements to NP achieved when either veritcal resolution OR coupling frequency increased, but tended to yield a standing oscillation. Realistic NP only achieved when both increased. Did NOT improve the eastward propagation. These results are probably very highly model dependent.	ISO is sensitive to ocean vertical resolution, coupling frequency.
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(previous findings from modeling studies)

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- Many studies have demonstrated improved ISV when coupling is introduced.
- Several modeling studies suggest that coupling is more important in the Indian Ocean than the West Pacific Ocean.
- In the absence of coupling, high frequency SSTs can improve ISV.

What kinds of improvements?

it depends on the study...

Compared to an AGCM simulation, coupling can:

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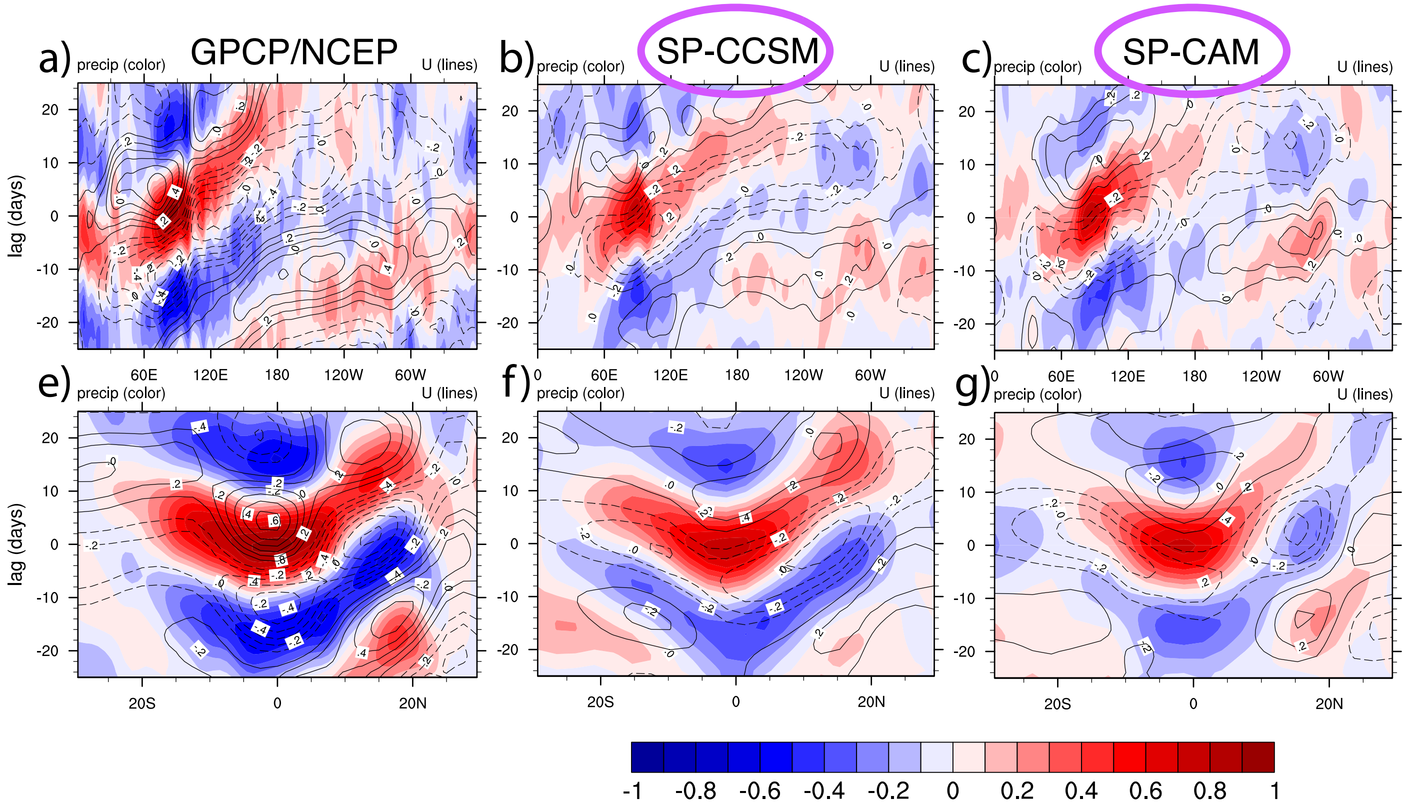
- produce an eastward-propagating ISO when the AGCM could not.
- extend eastward propagation beyond the Maritime Continent.

Questions

- In what manner do SST anomalies affect the simulated ISO?
  - latent heat fluxes--moistening
  - sensible heat fluxes--lower tropospheric stability
- How does the choice of model physics influence coupled and uncoupled behavior?

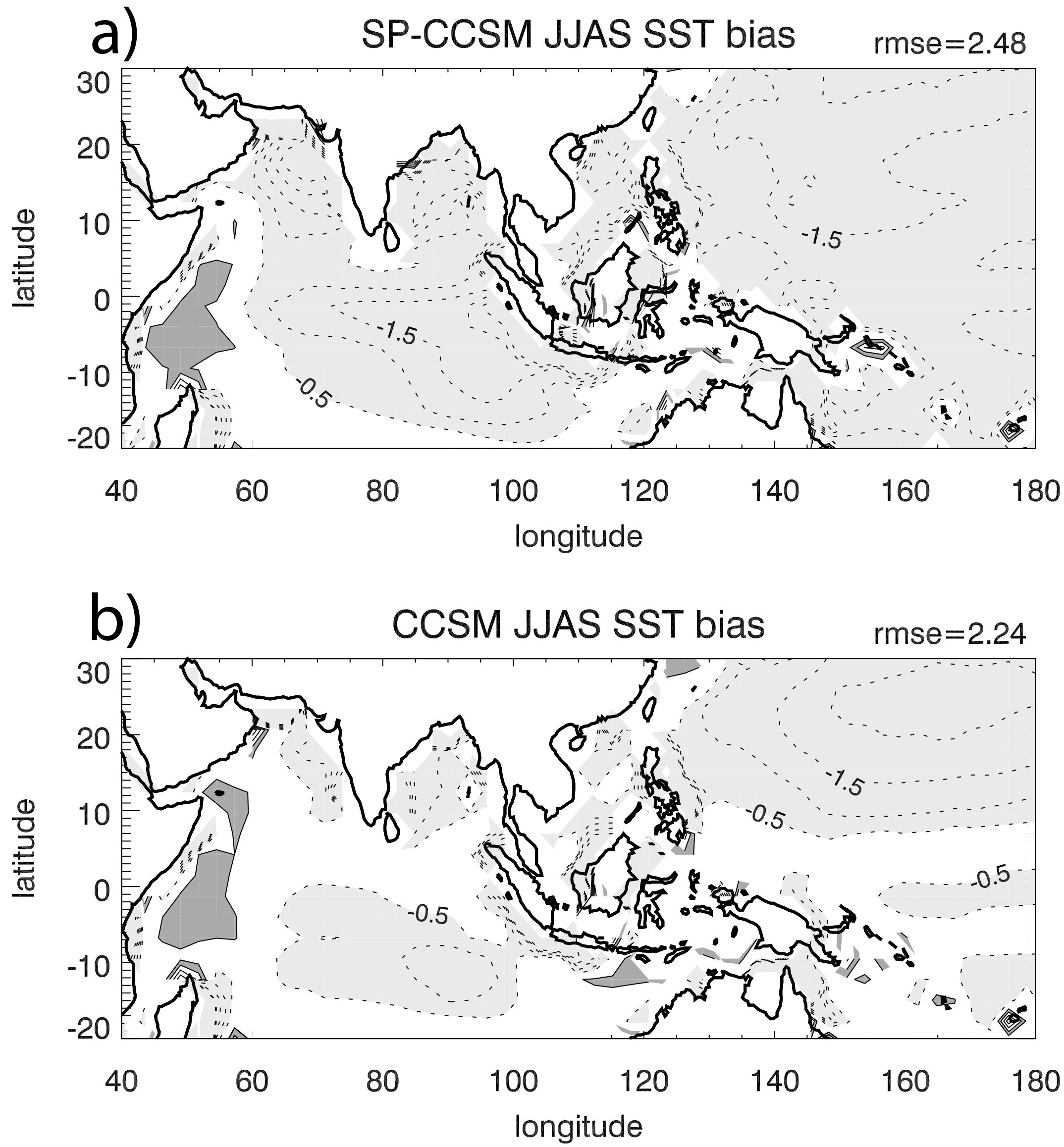
These questions are addressed with a suite of model simulations

A Typical Experimental Setup



coupled vs. uncoupled simulations with the same model are analyzed in terms of their ISO simulation

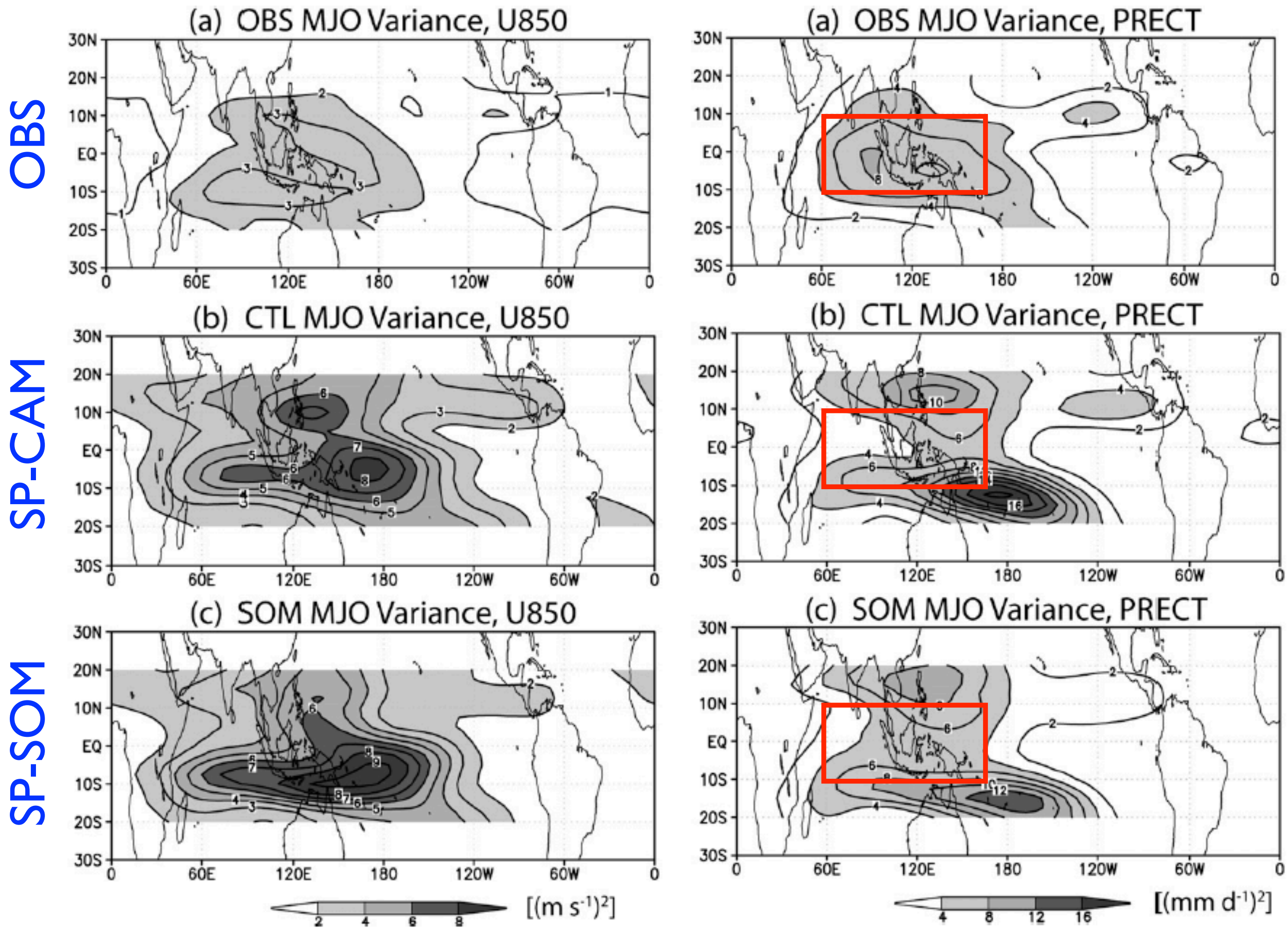
Caveat to the Typical Experimental Setup



Coupled models often result in cold SST biases, leading to **different mean climate states** than their uncoupled counterparts.

Does improved ISV arise from coupling, or from mean state changes?

The MJO with SP with a slab ocean model

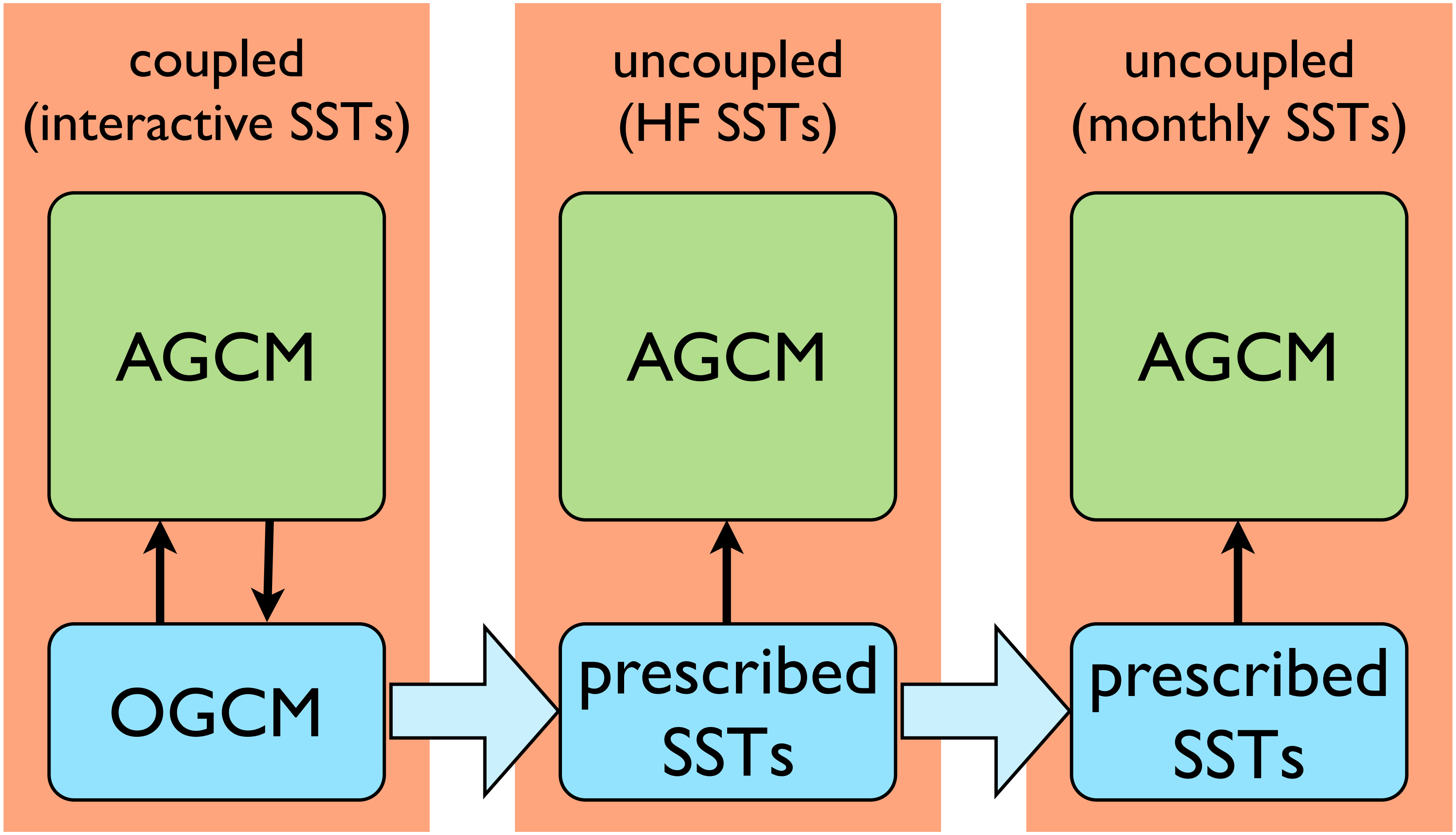


extra-tropical variance is greater than equatorial variance: excessive ER wave activity

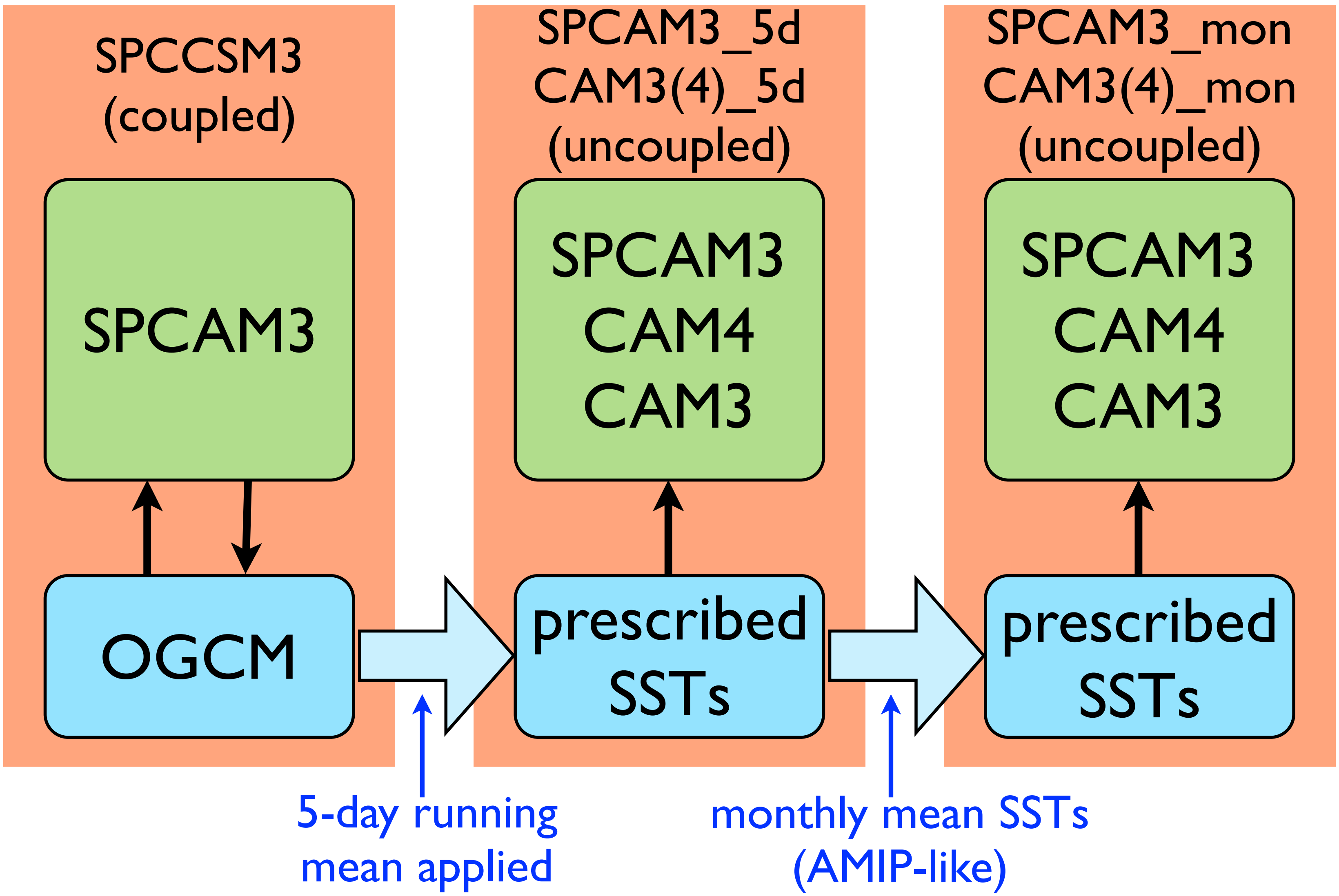
coupling mitigates this somewhat

Benedict and Randall 2011

Another Experimental Setup



Our Experimental Setup



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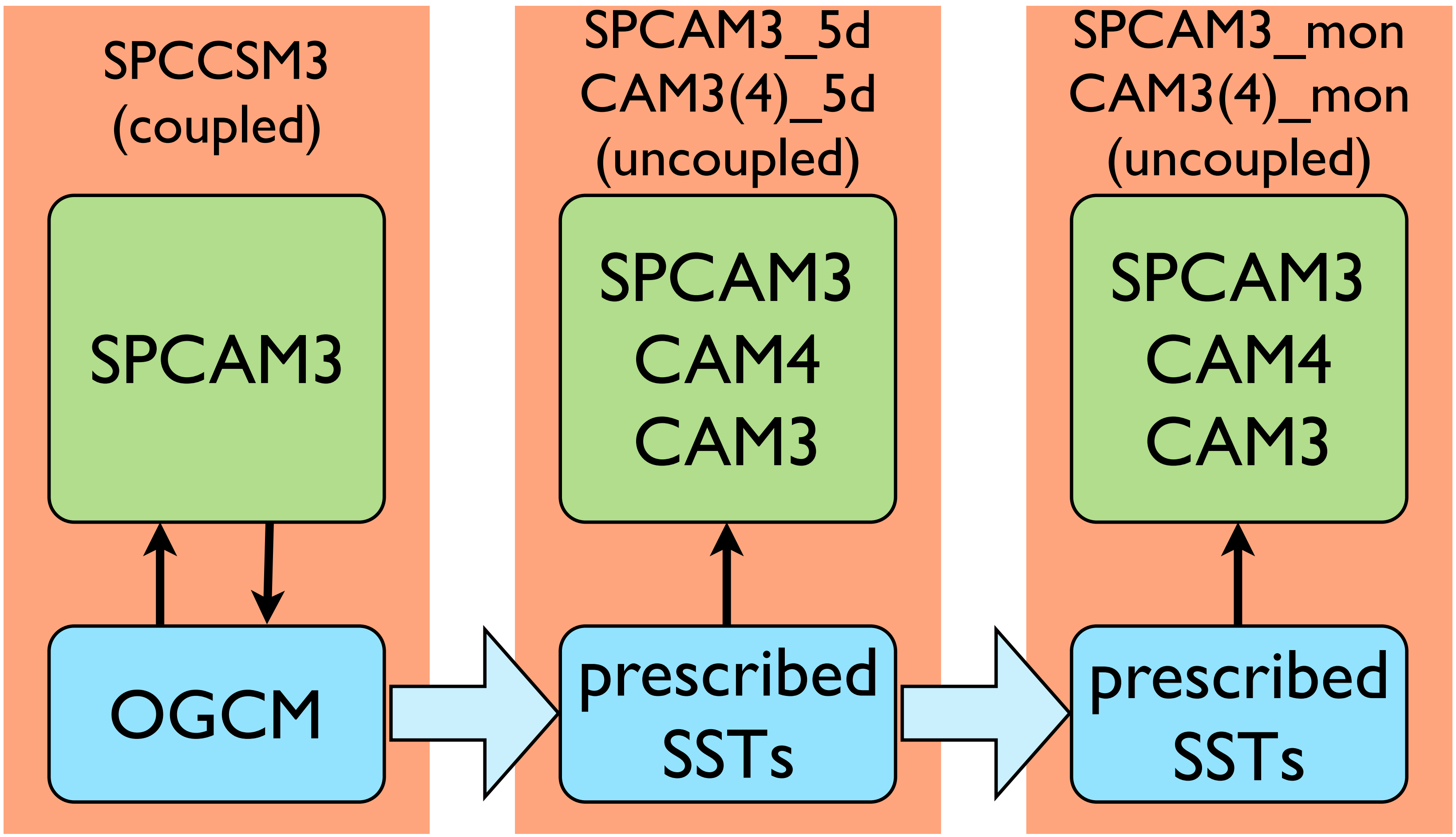
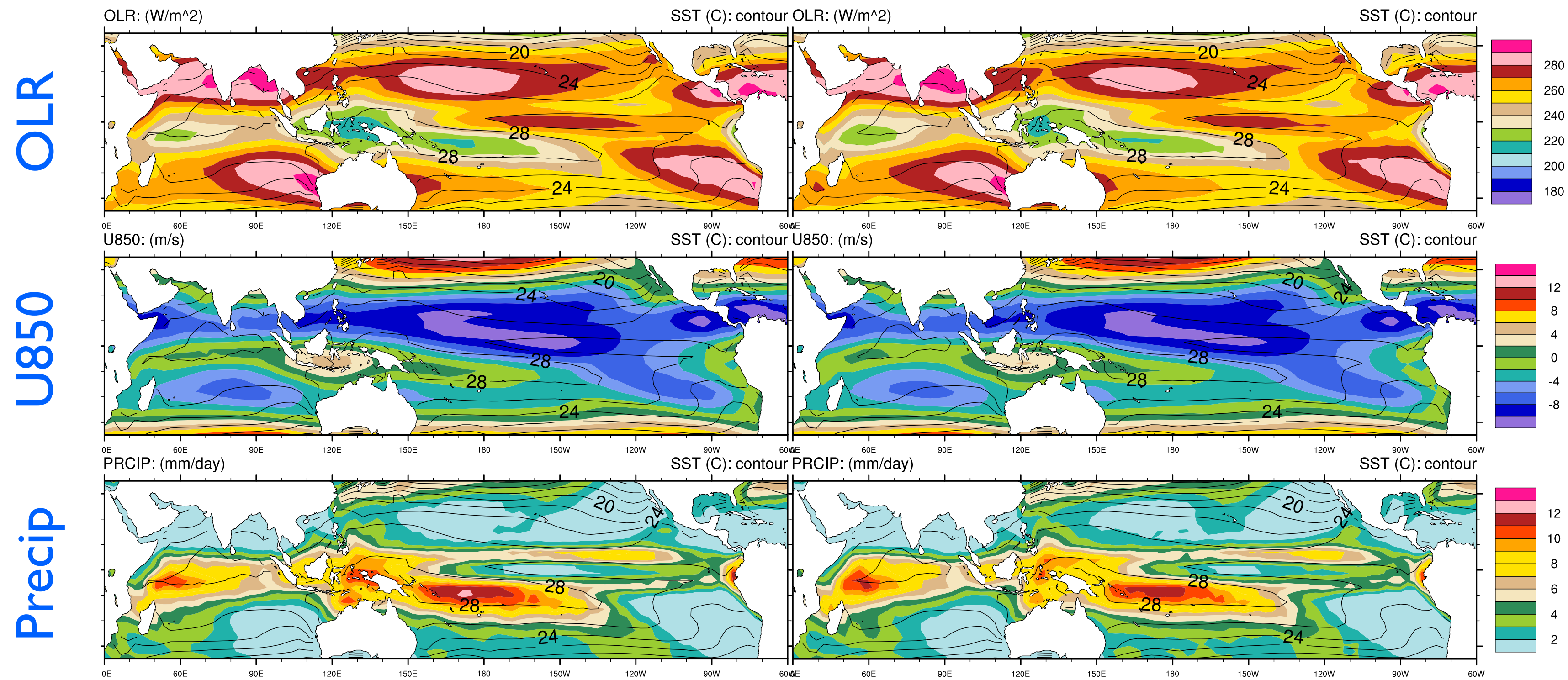


Models Mean State

Nov-Apr:4-23

SP-CCSM **SP-CAM5d**



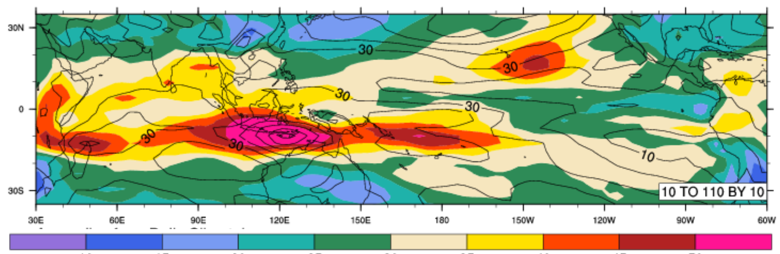
Models Variance

Nov-Apr:4-23

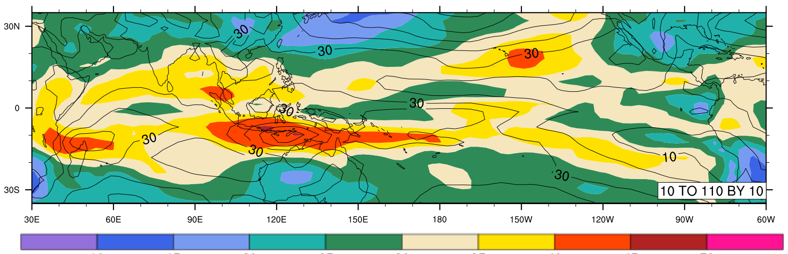
SP-CCSM | **SP-CAM5d**

OLR

OLR



OLR



U850

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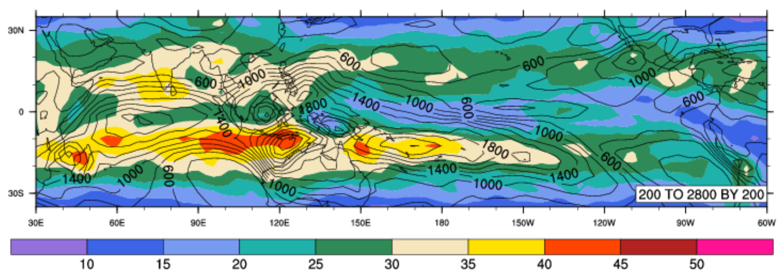
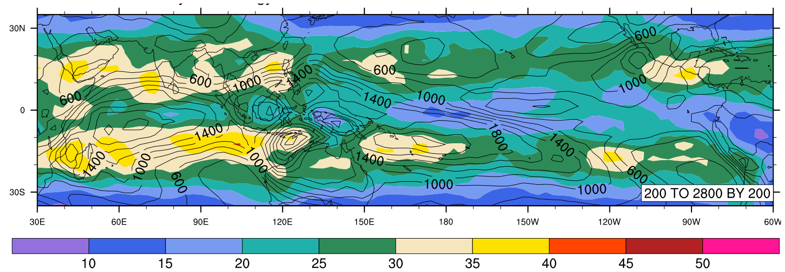
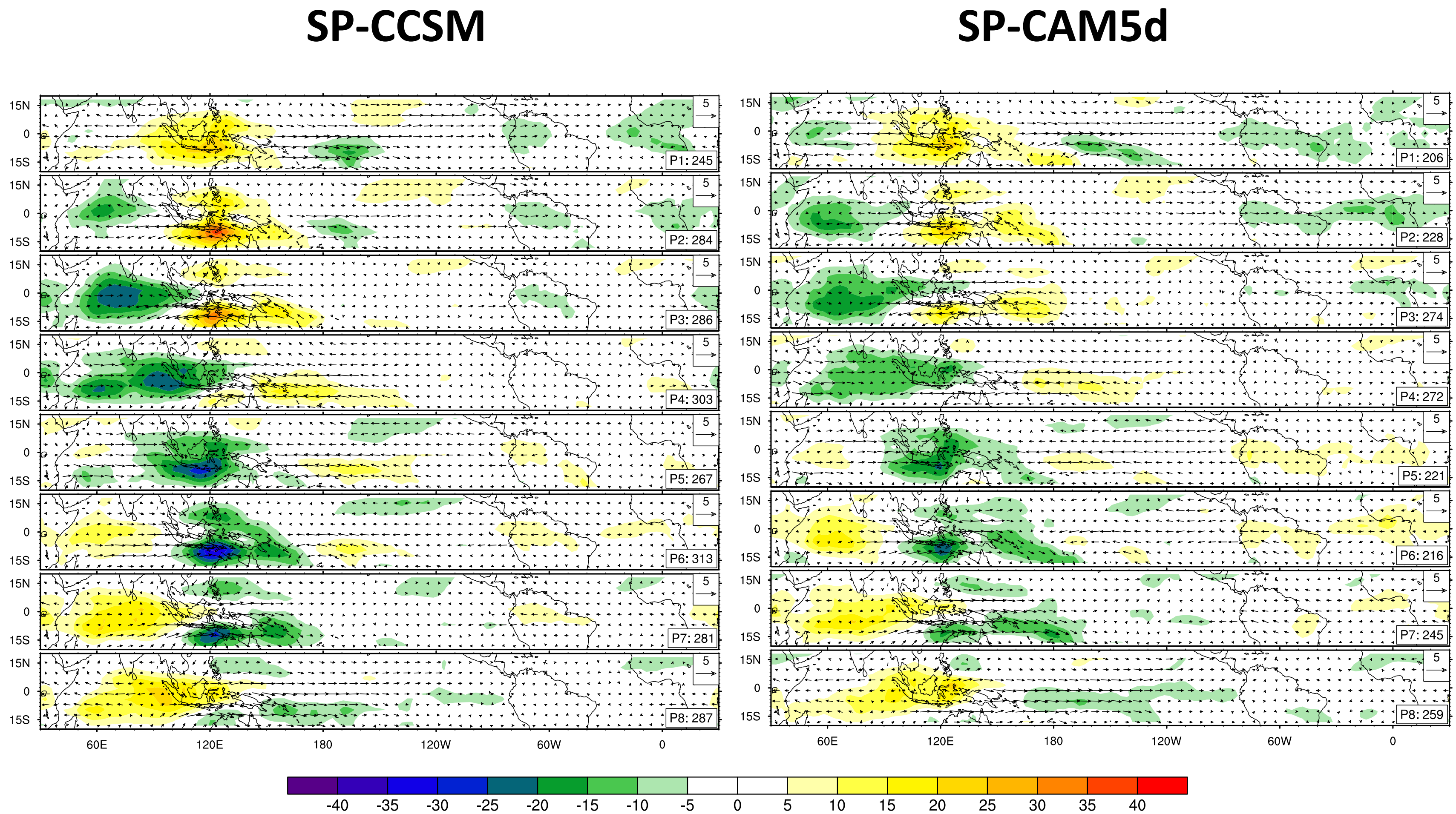


U850



MJO Life-Cycle

Nov-Apr:4-23



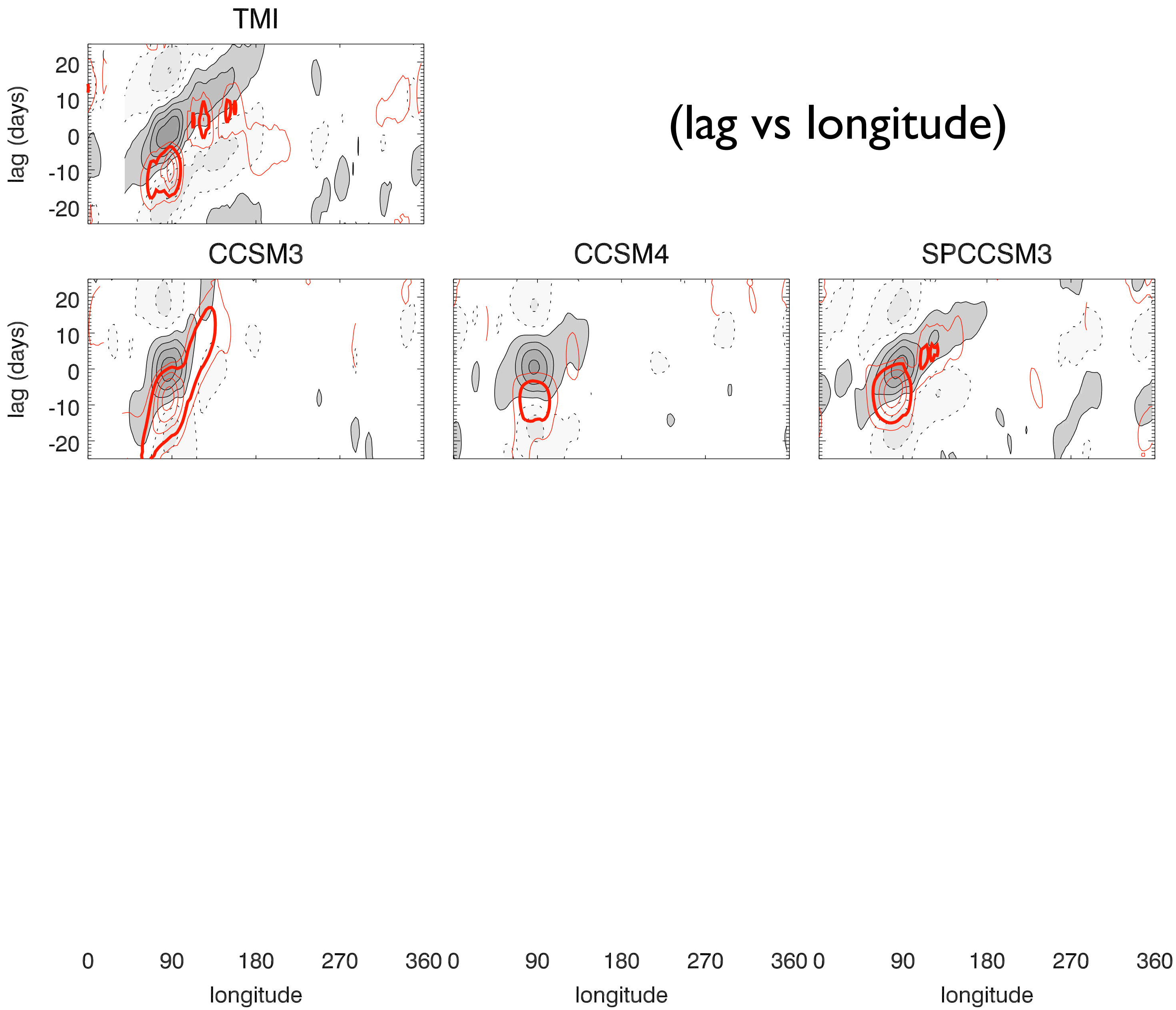
compared to SPCCSM3, SPCAM3_5d has:

- same mean state
- different variability
- weaker MJO amplitude

mean states in CAM3_x, CAM4_x
also resemble SPCAM3_5d

Rainfall and SST anomaly lag-correlation (all seasons)

(lag vs longitude)



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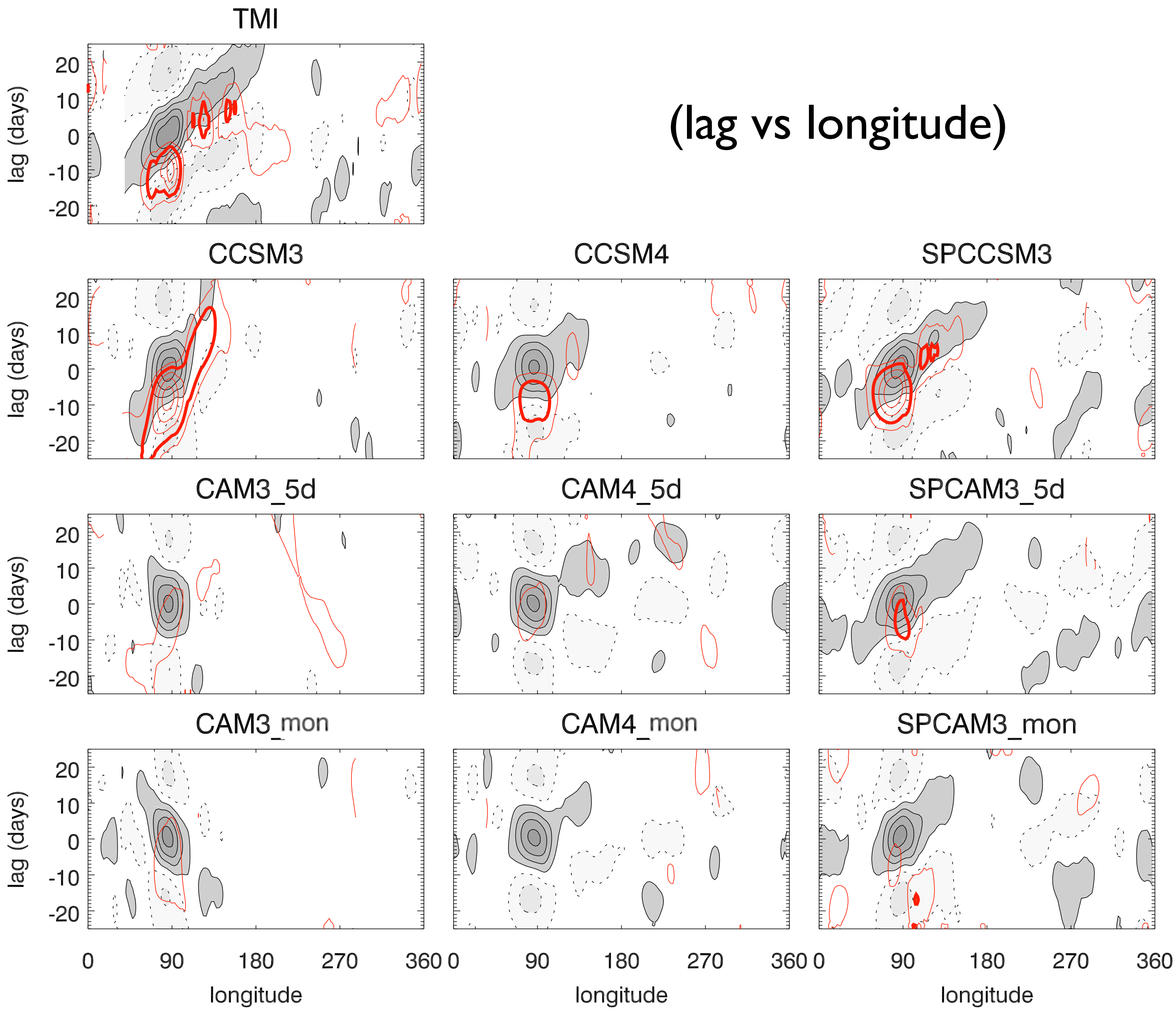
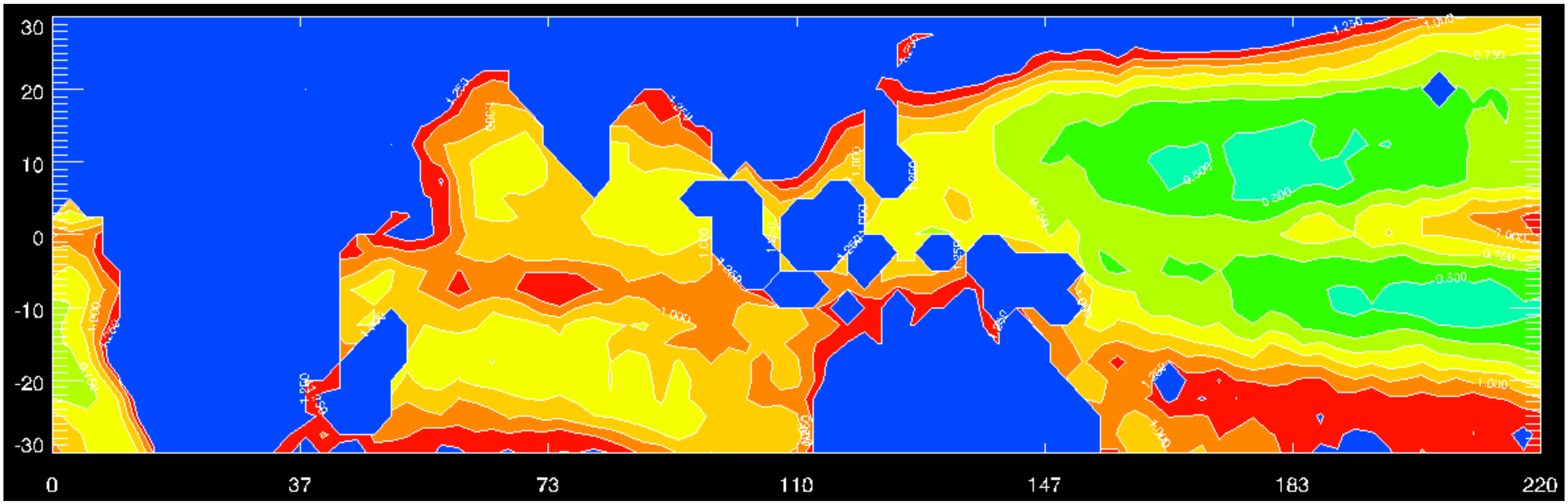


how sensitive are the surface fluxes to SST anomalies?

typical SST anomaly range @ ISO timescales (K)



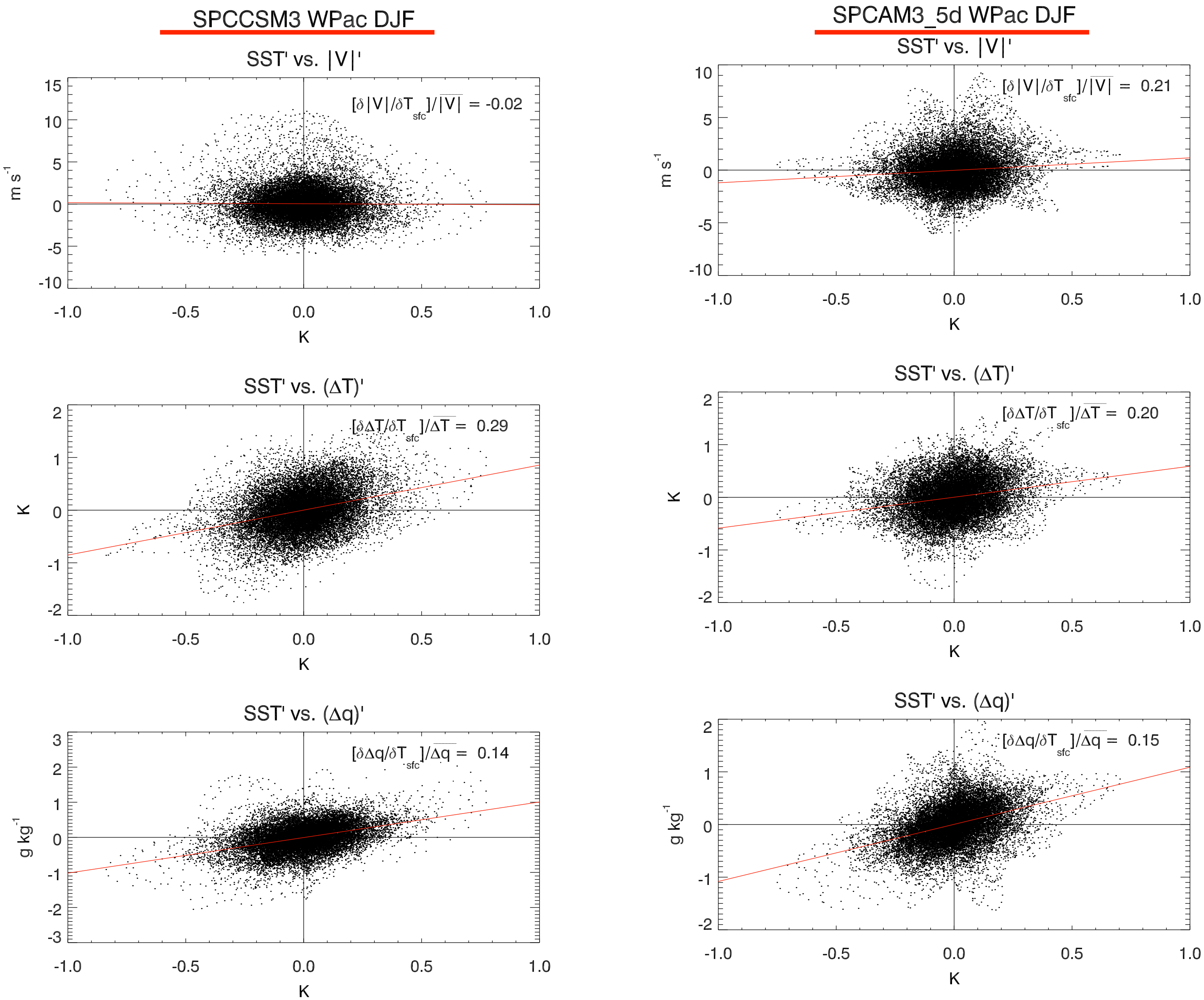
greater variability in Indian Ocean

linearized latent heat flux terms

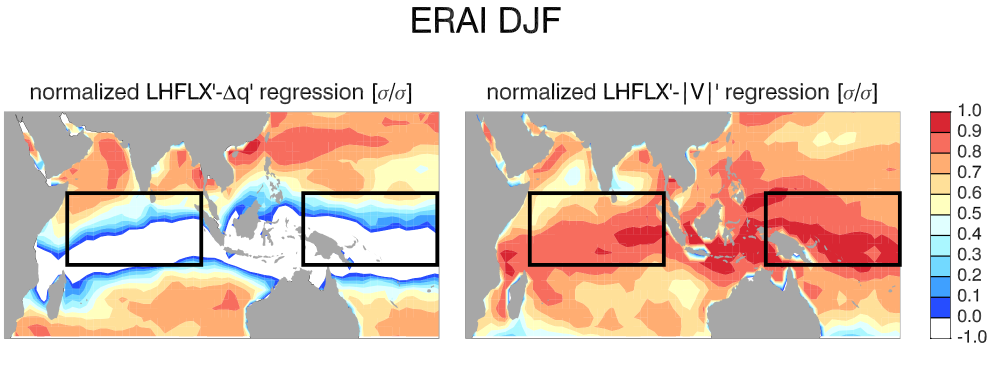
$$\mathrm{LH}' = \rho L C_H(\overline{\Delta q}|V|' + \Delta q'\overline{|V|})$$

which term dominates LH'?

sensitivity of anomaly terms to SST perturbations



What controls LHFLX?



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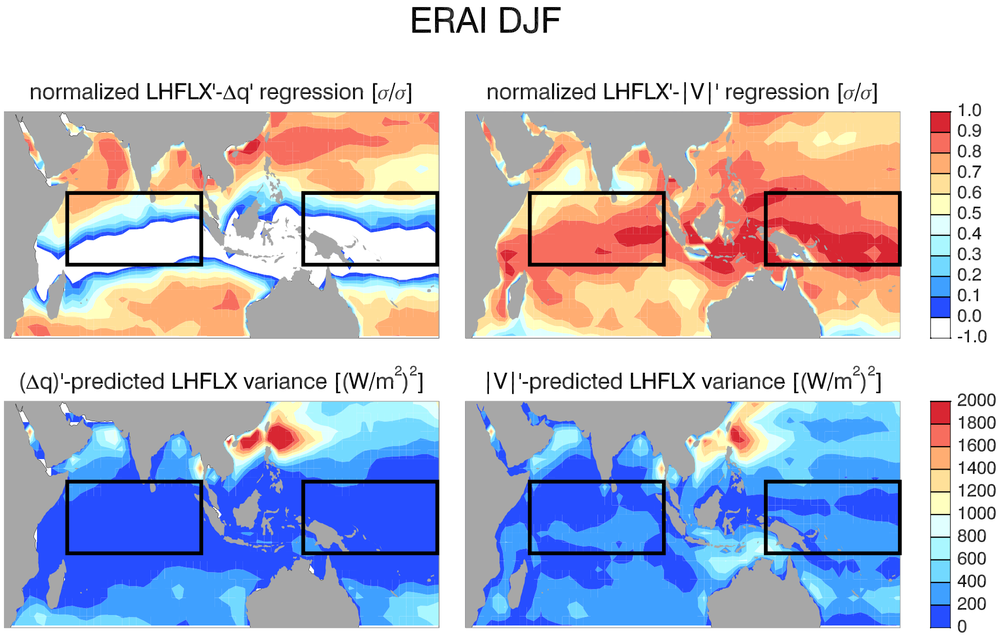

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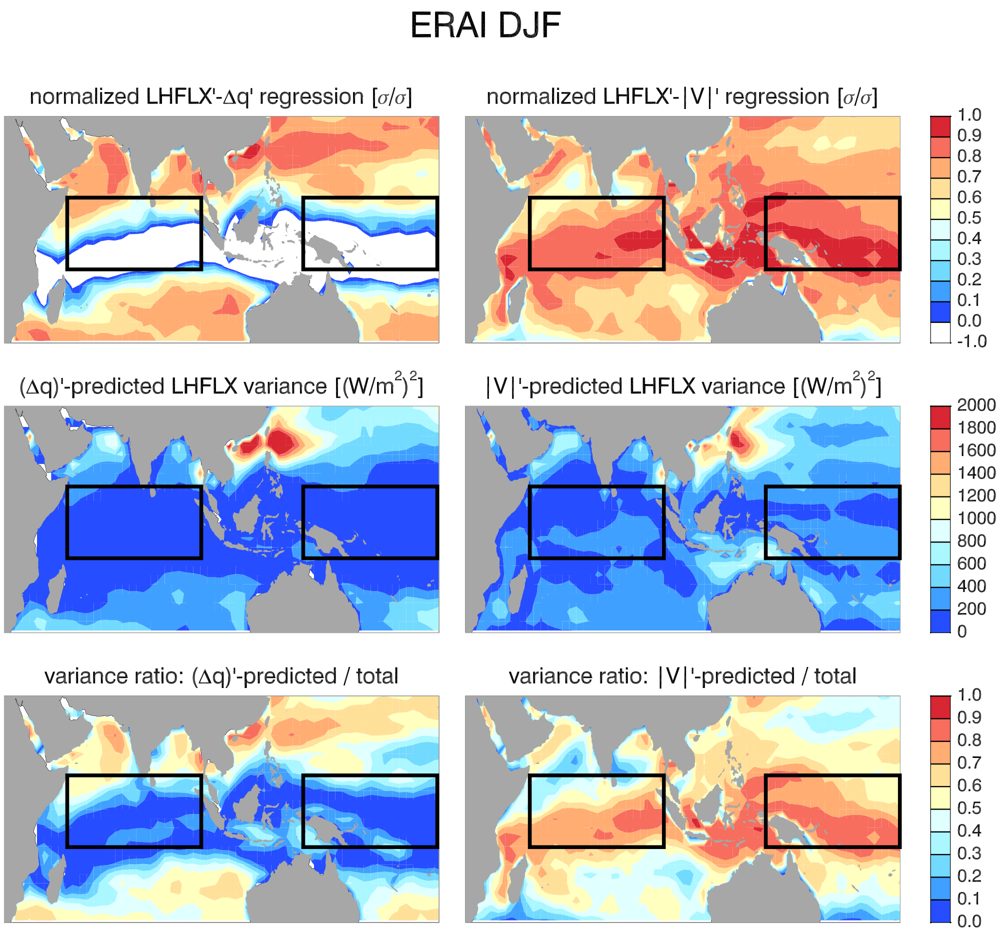

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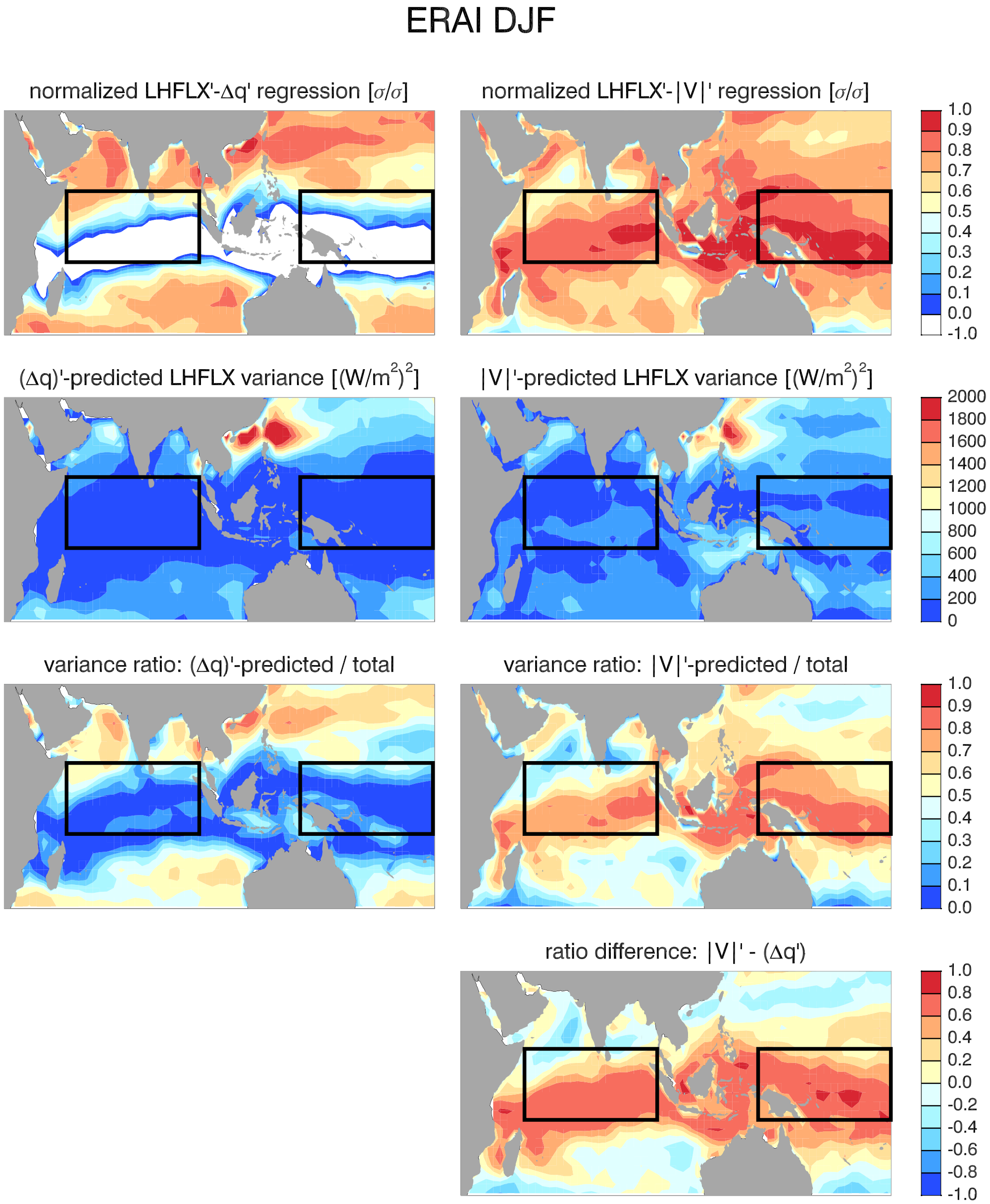

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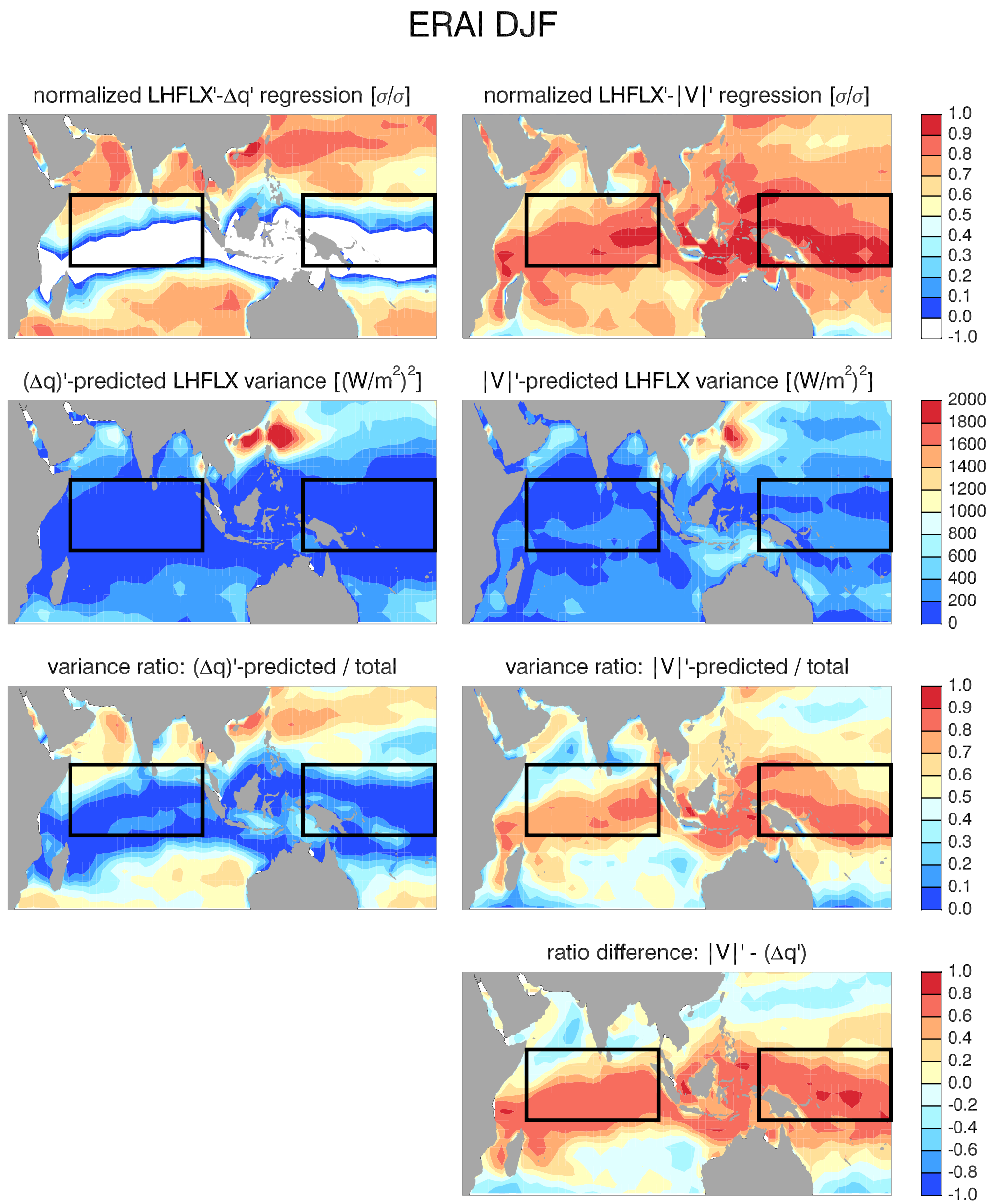

- Equatorial LH fluxes are small
- Equatorial LH fluxes are mostly determined by wind speed
- Subtropical LH fluxes are large
- Subtropical LH fluxes are sensitive to both wind speed and vertical moisture gradient

linearized latent heat flux terms

$$\mathrm{LH}' = \rho L C_H(\overline{\Delta q}|V|' + \Delta q'\overline{|V|})$$

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how sensitive are anomalies to SST?

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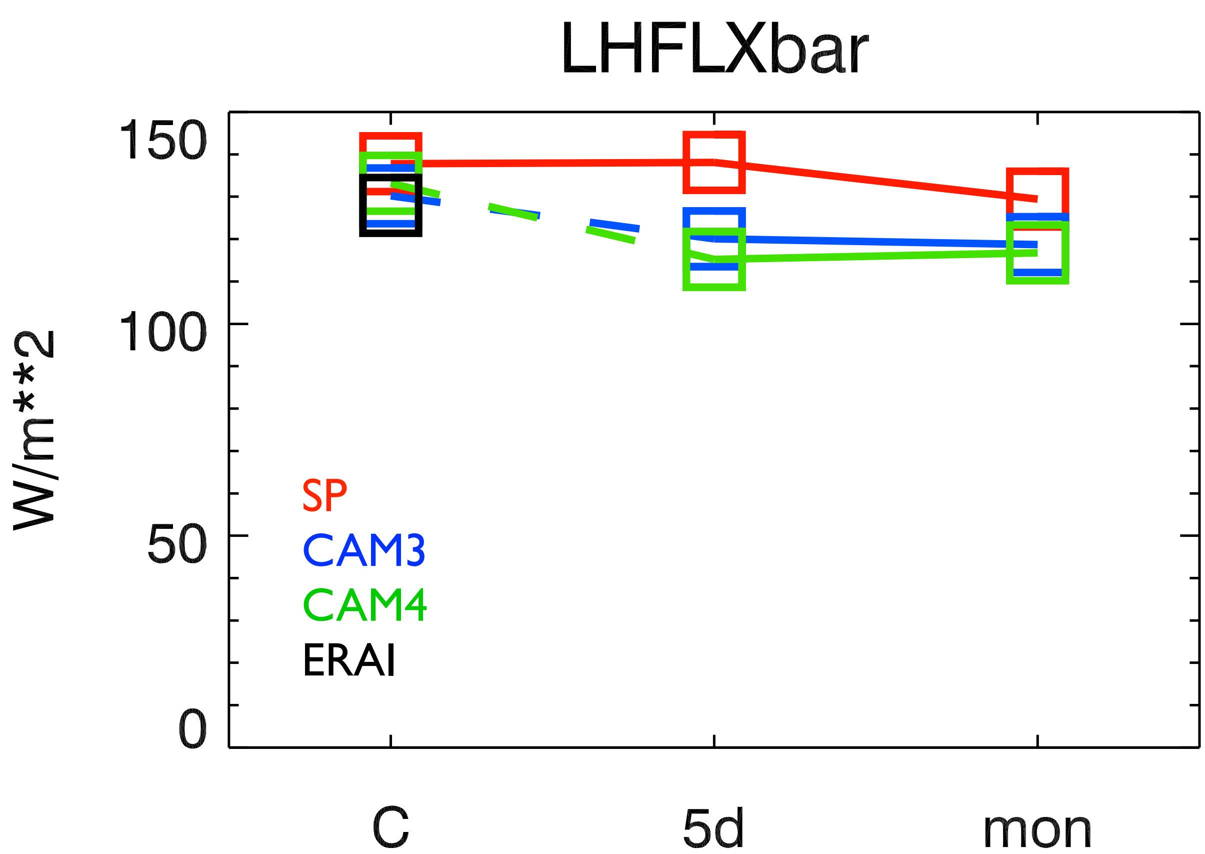
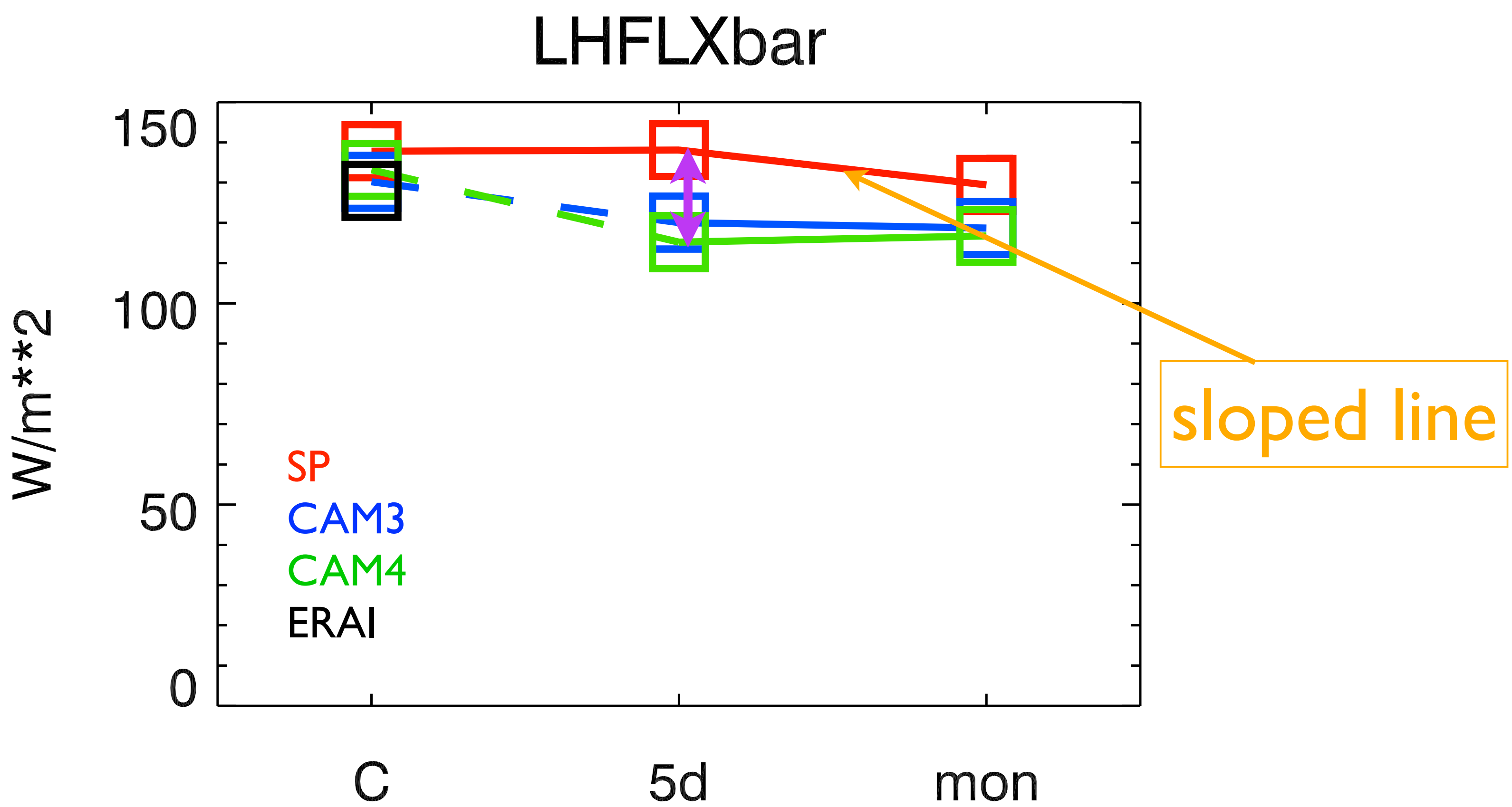
how sensitive are anomalies to SST?

how sensitive are mean quantities to ocean treatment?

How sensitive are LHFLX terms to SST treatment?



How sensitive are LHFLX terms to SST treatment?

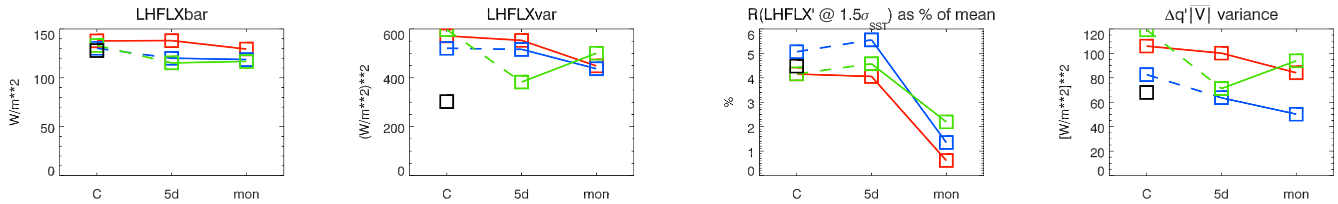


- vertical differences arise from model physics
- solid line slopes indicate sensitivity to ocean treatment (coupling or no coupling; presence or absence of high-frequency variability)

How sensitive are LHFLX terms to SST, model physics?

IO DJF

SP
CAM3
CAM4
ERAI



Ocean-only data points.
Variance and regressions are based on 20-70 day filtered data.

How sensitive are LHFLX terms to SST, model physics?

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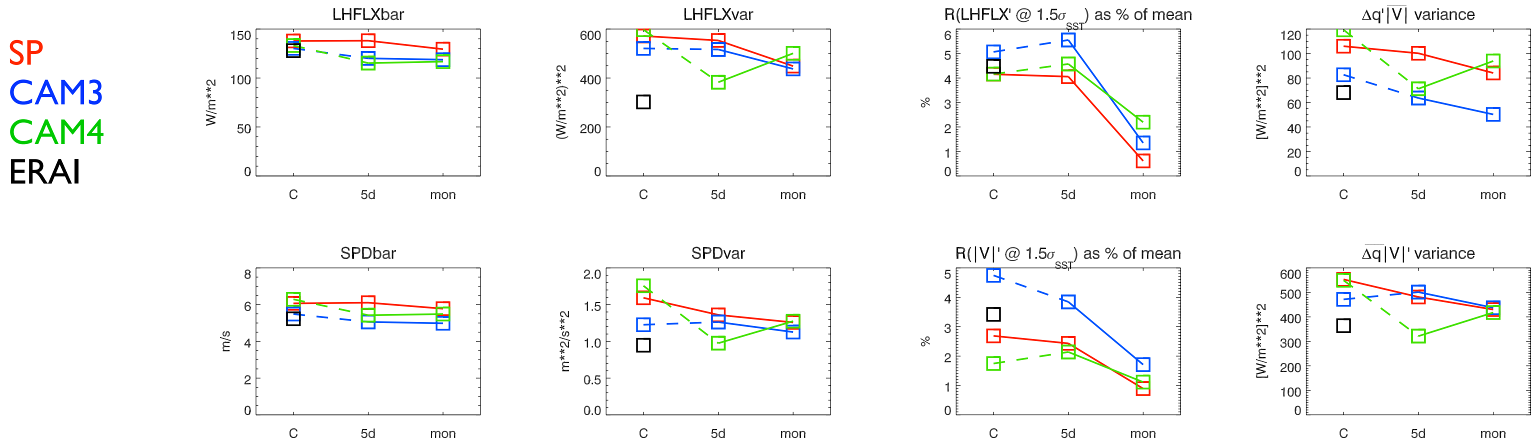

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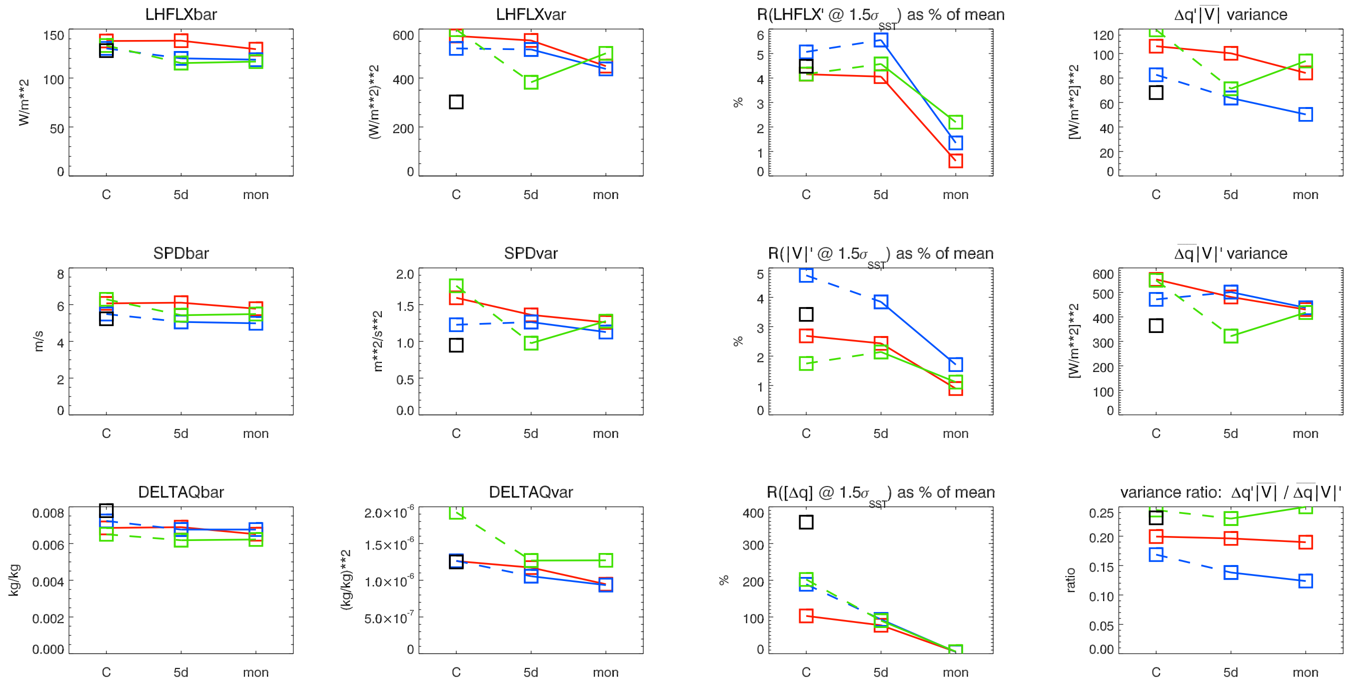

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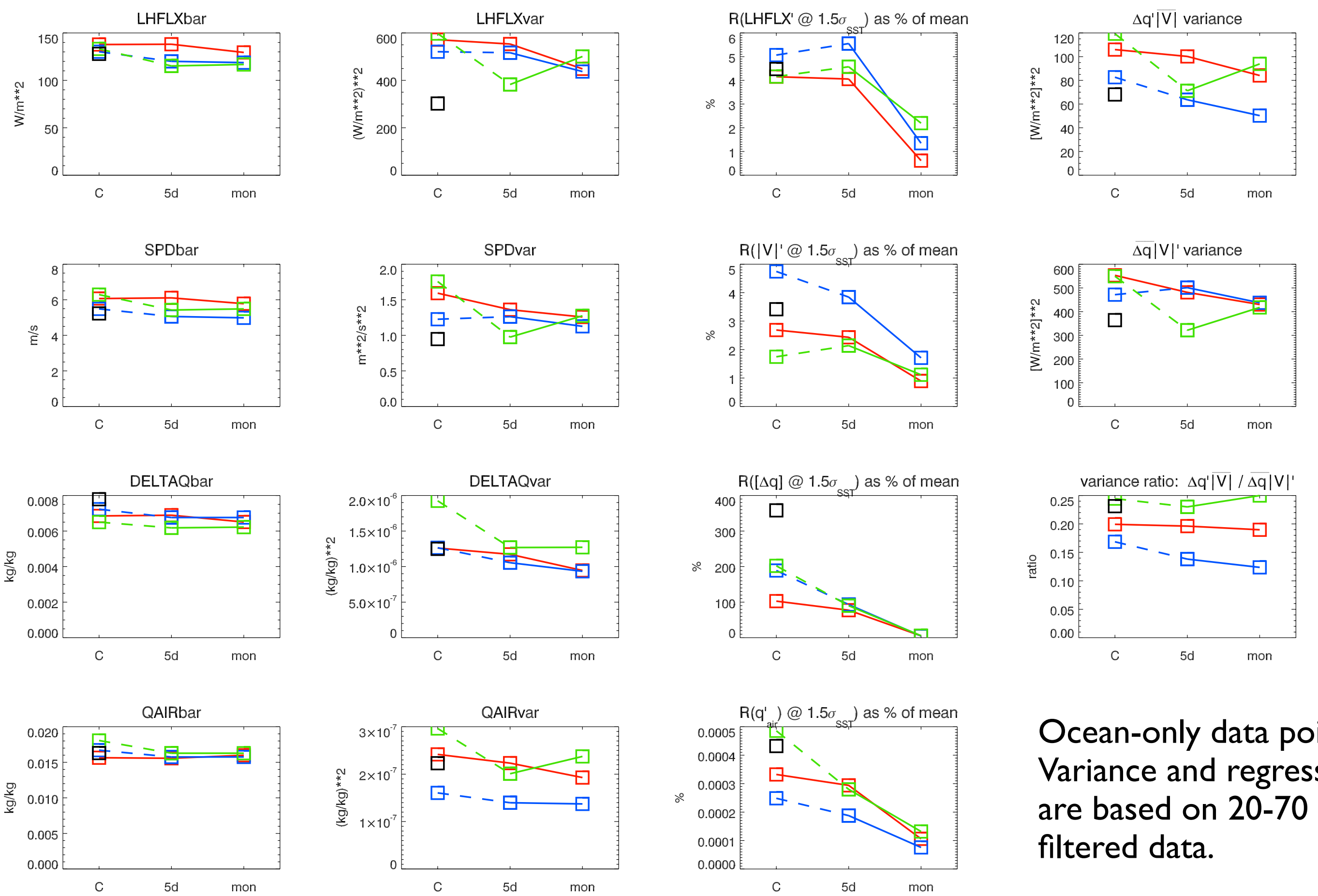

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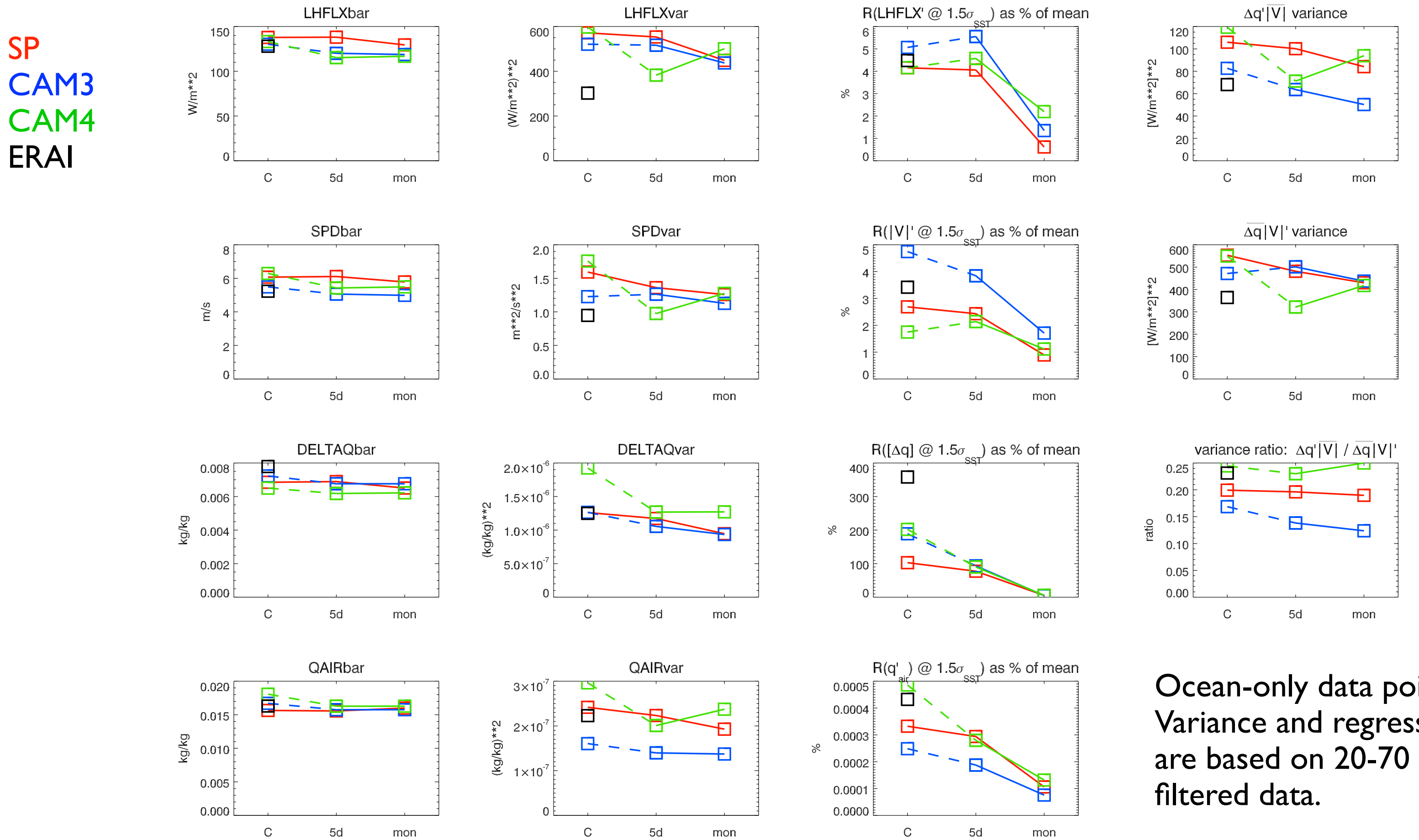


Ocean-only data points. Variance and regressions are based on 20-70 day filtered data.

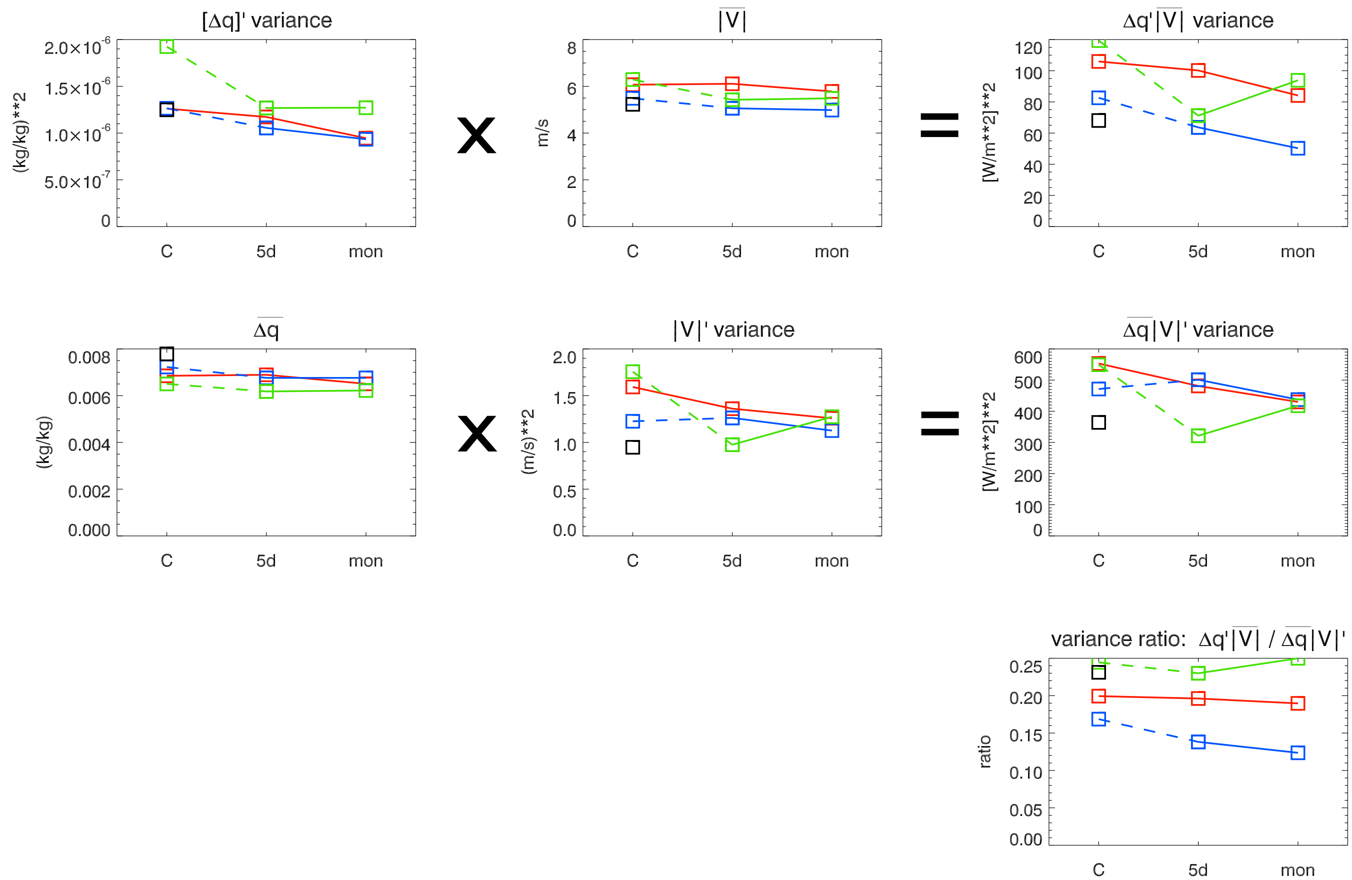
- Seasonal means are sensitive to model physics, but not to ocean treatment.
- Variance about the mean is sensitive to both model physics and ocean treatment.
- Local effect: vertical moisture gradient variability is highly sensitive to SST anomalies.
- Remote effect: sensitivity of wind speed variability to ocean treatment.
- LHFLX terms that are most sensitive SST anomalies account for only 10~15% of total LHFLX variability.

How sensitive are LHFLX terms to local, remote SST effects?

IO DJF

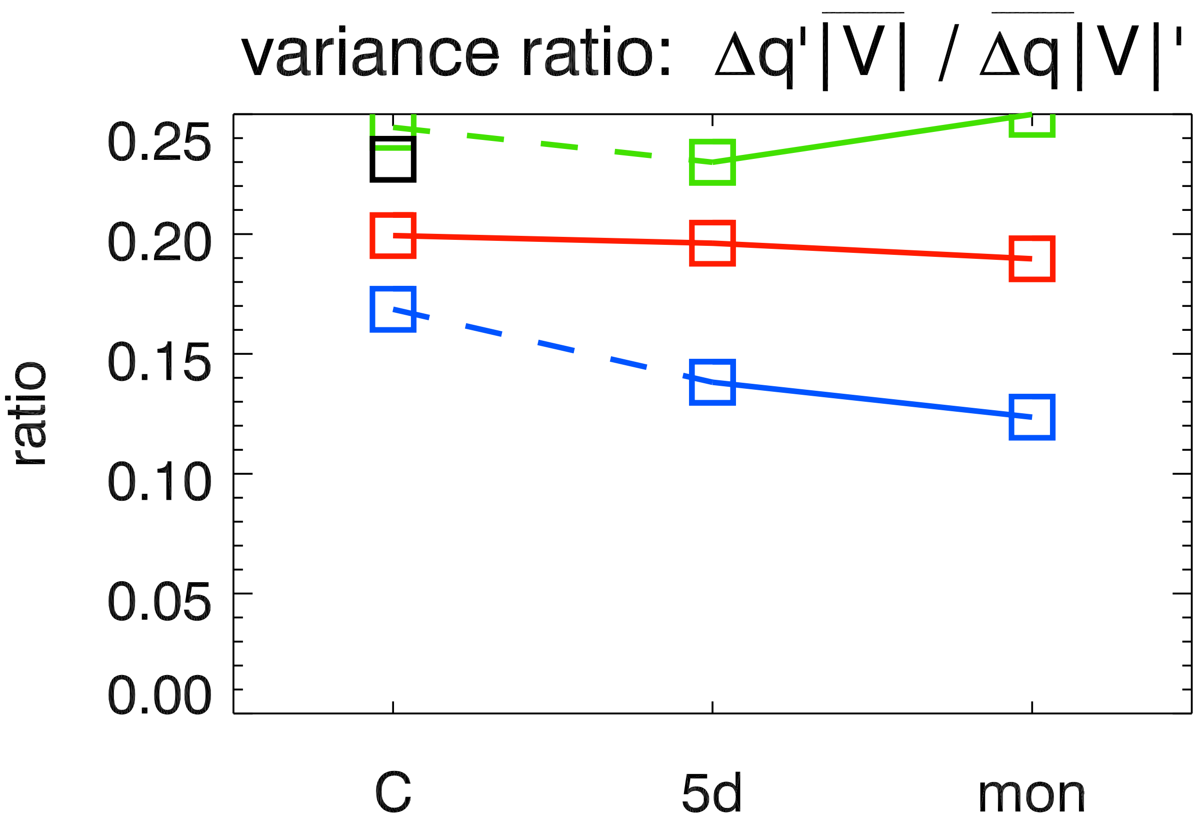
$$\Delta q' \overline{|V|}$$

$$\overline{\Delta q} |V|'$$

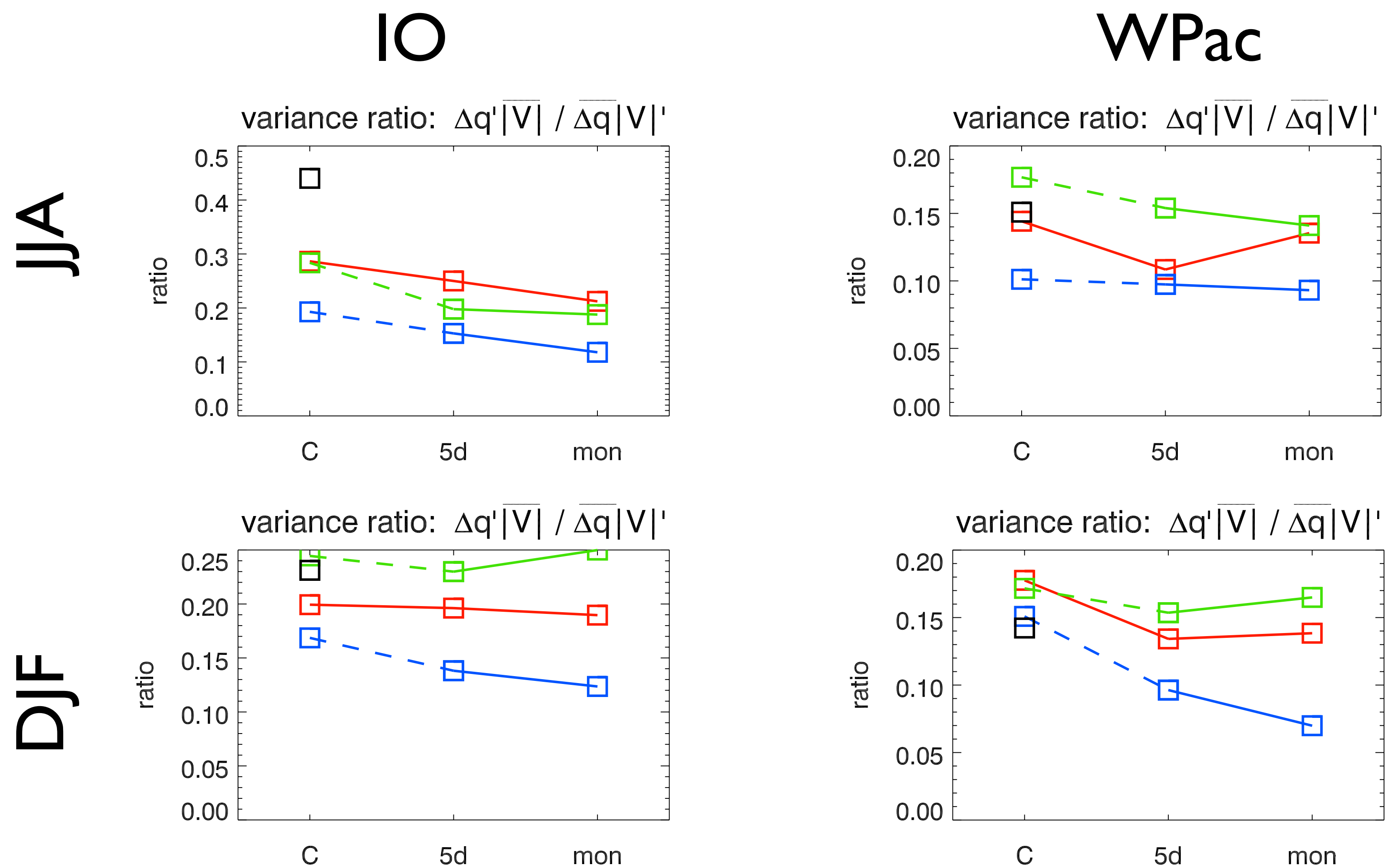


- Vertical moisture gradient is sensitive to the local SST anomaly.
- Processes that control wind speed variance are probably complex and non-local.

local vs remote SST effects is sensitive to model physics



Does SST sensitivity vary with region and season?



- SST effects are larger in the Indian Ocean than the West Pacific Ocean.
- Indian Ocean SST effects are greater during boreal summer than in boreal winter.

Conclusions I

- Model physics (cumulus parameterization) appears to be more important than coupling or realistic SST variability for simulating the ISO.
- Latent heat fluxes vary with model physics and ocean treatment, and are dominated by wind speed variability.
- Sensitivity of wind speed variability to ocean treatment is probably complex and non-local.

Conclusions II

- Many question remain in trying to understand the role of air-sea interaction in models and the real world.

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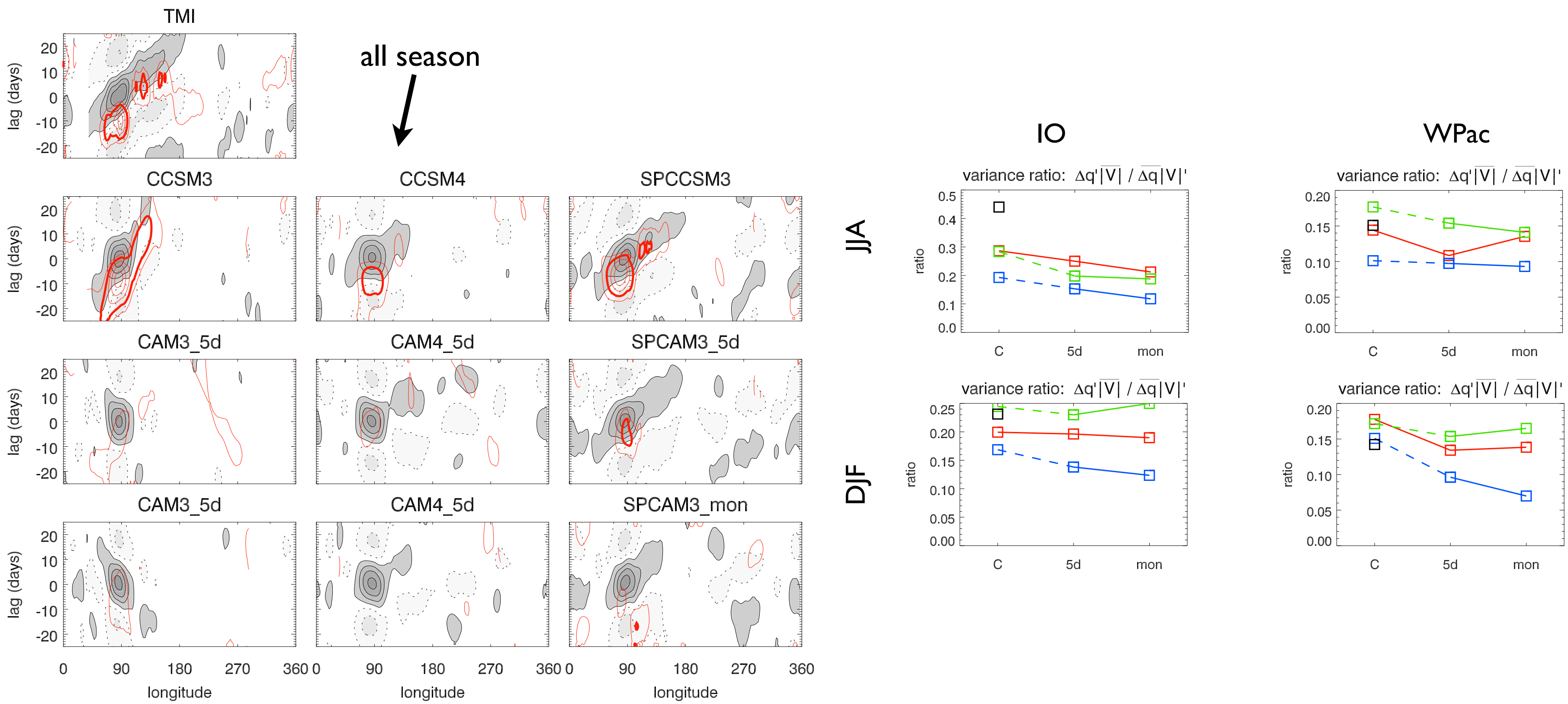
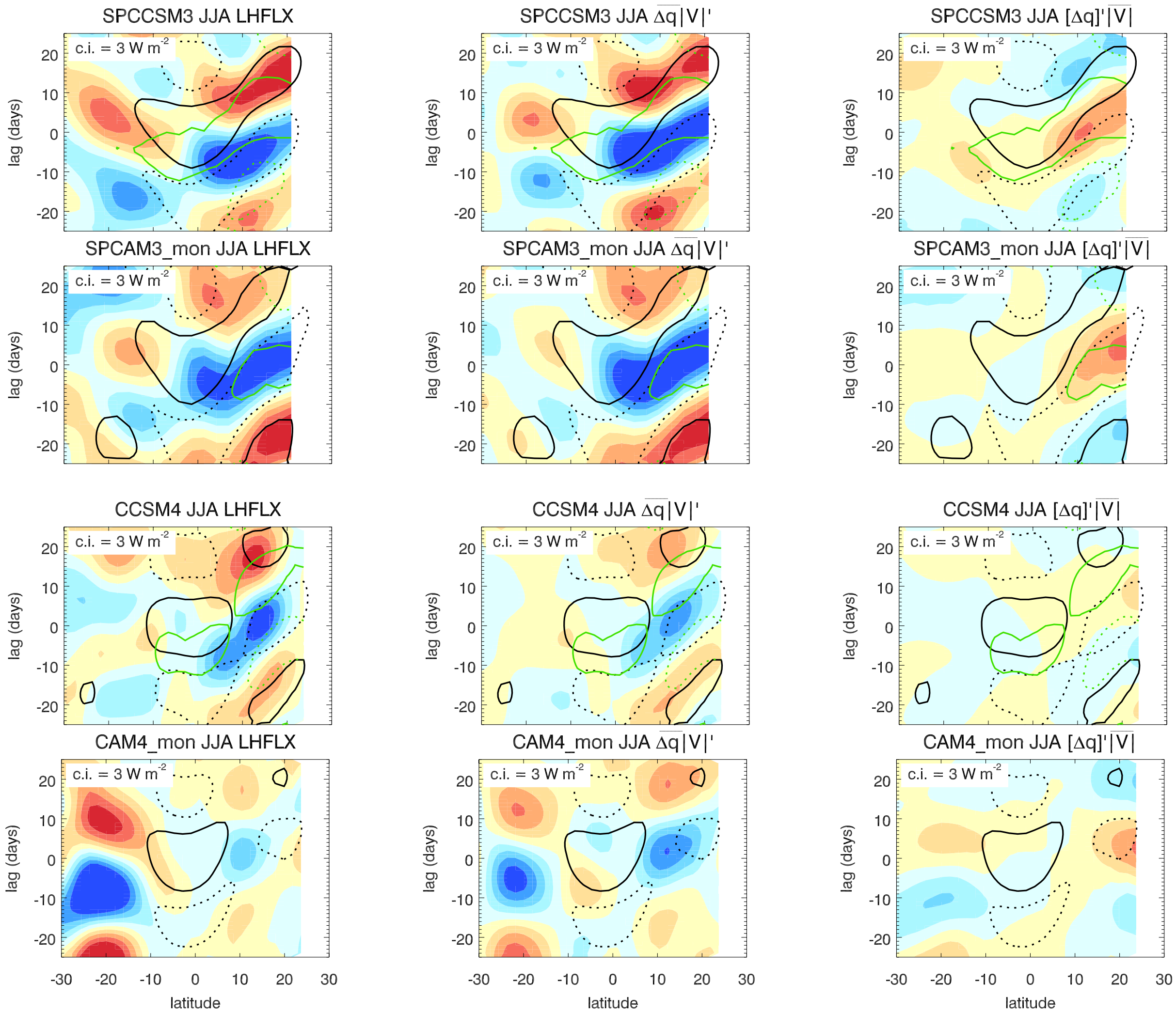
Extra Slides

Can we understand ISV in terms of SST sensitivity?



- Does CAM3 struggle because delta-q effects are small? It has the smallest delta-q of all models.
- CAM4-SP differences cannot be explained by SST effects. Possibly:
  - tropical-subtropical interactions? we have not examined this here.
  - Inherent atmospheric control of ISV?
- Could diminished ISV in SP models simply be a result of decreased LHFLX and moisture convergence?

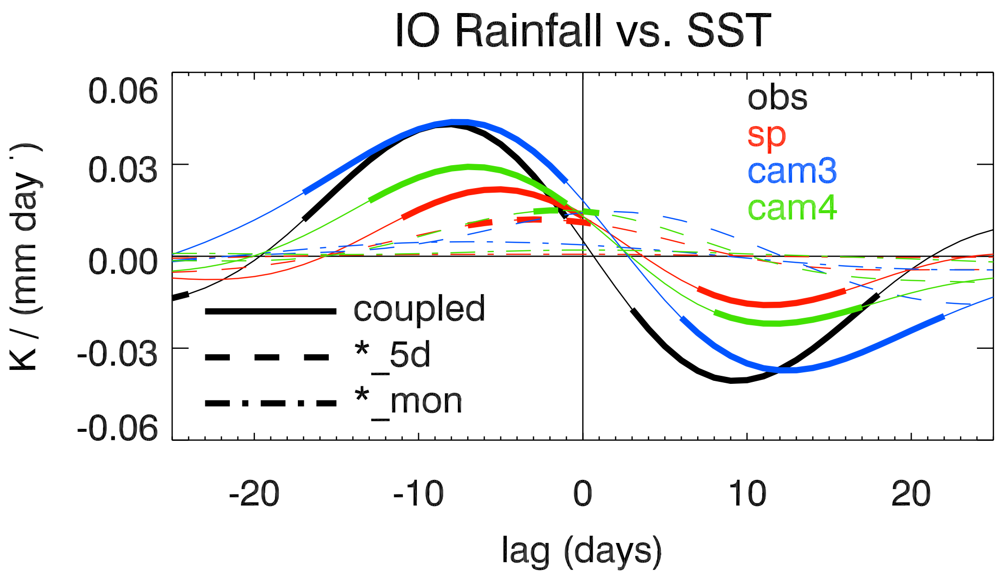
Latent Heat Flux Terms (poleward, JJA)



Correlations
black: r = 0.2 (rainfall')
green: r = 0.2 (SST')

Regressions
Surface fluxes are regressed onto Indian Ocean rainfall and scaled by 1.5 standard deviations of the base point time series.

Rainfall and SST anomaly lag-regression (all seasons)



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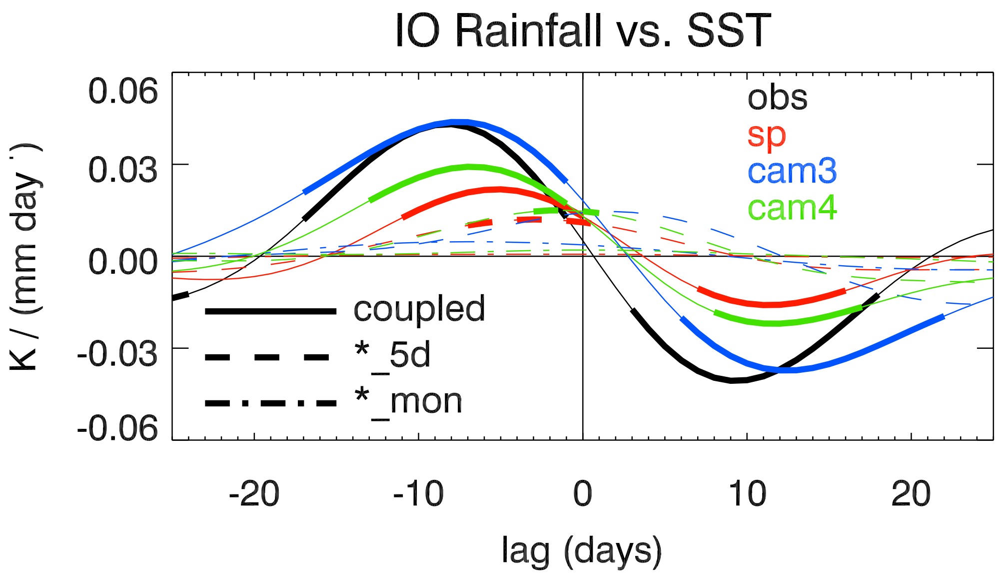

- In OBS and coupled runs, warm SSTs prior to precipitation are the result of reduced cloudiness and surface fluxes (atm driving SSTs).

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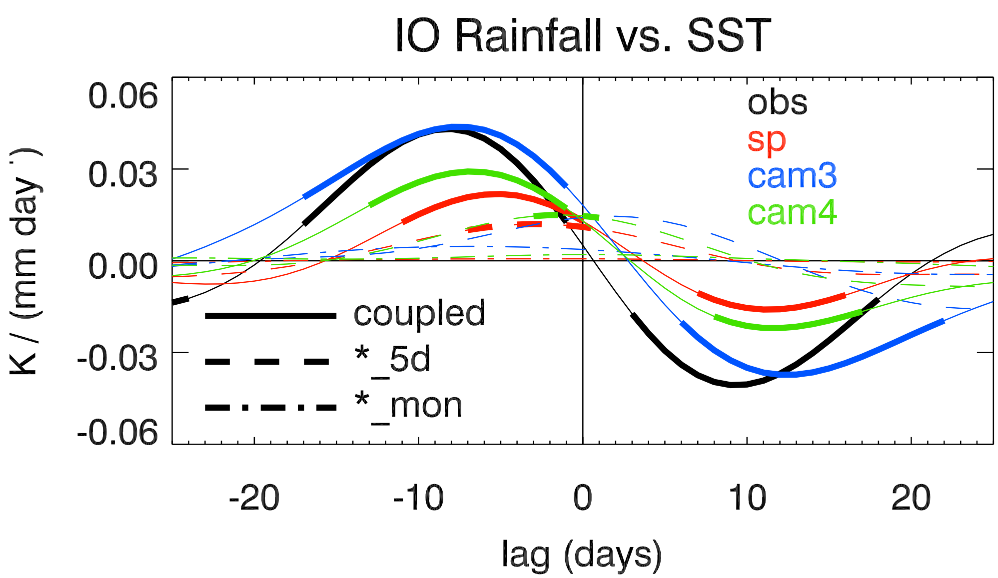

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- How can we assess the role of SST anomalies on the atmosphere?

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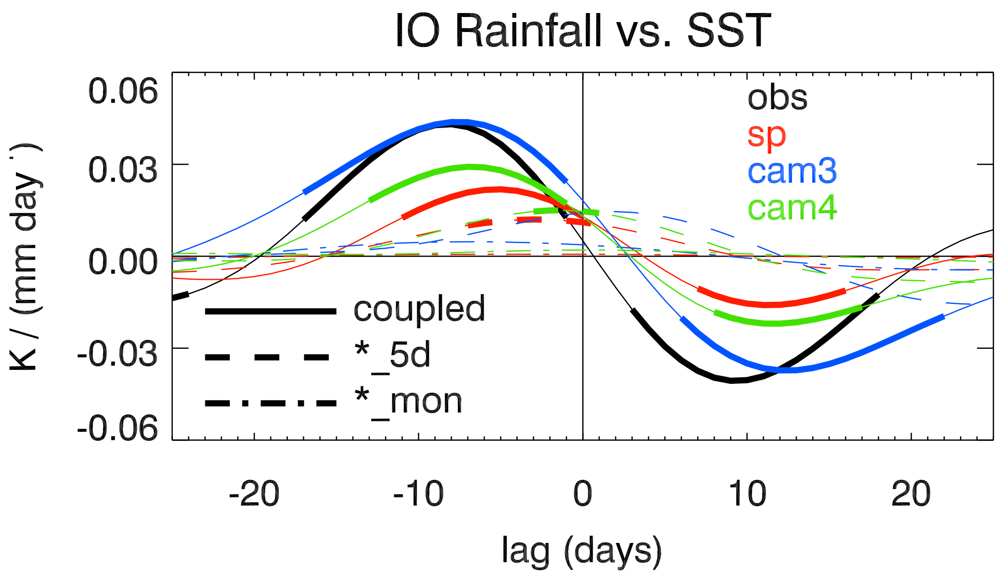

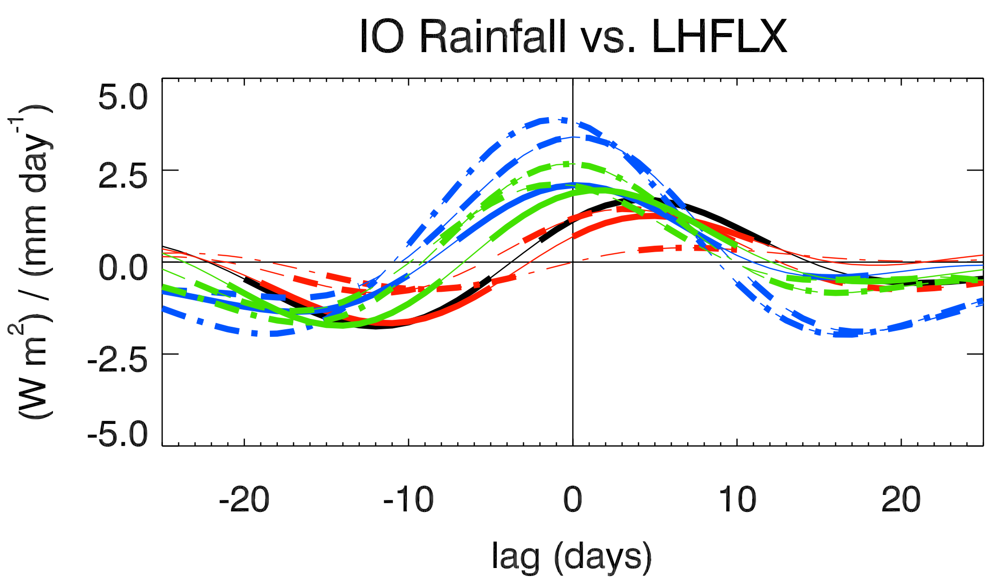

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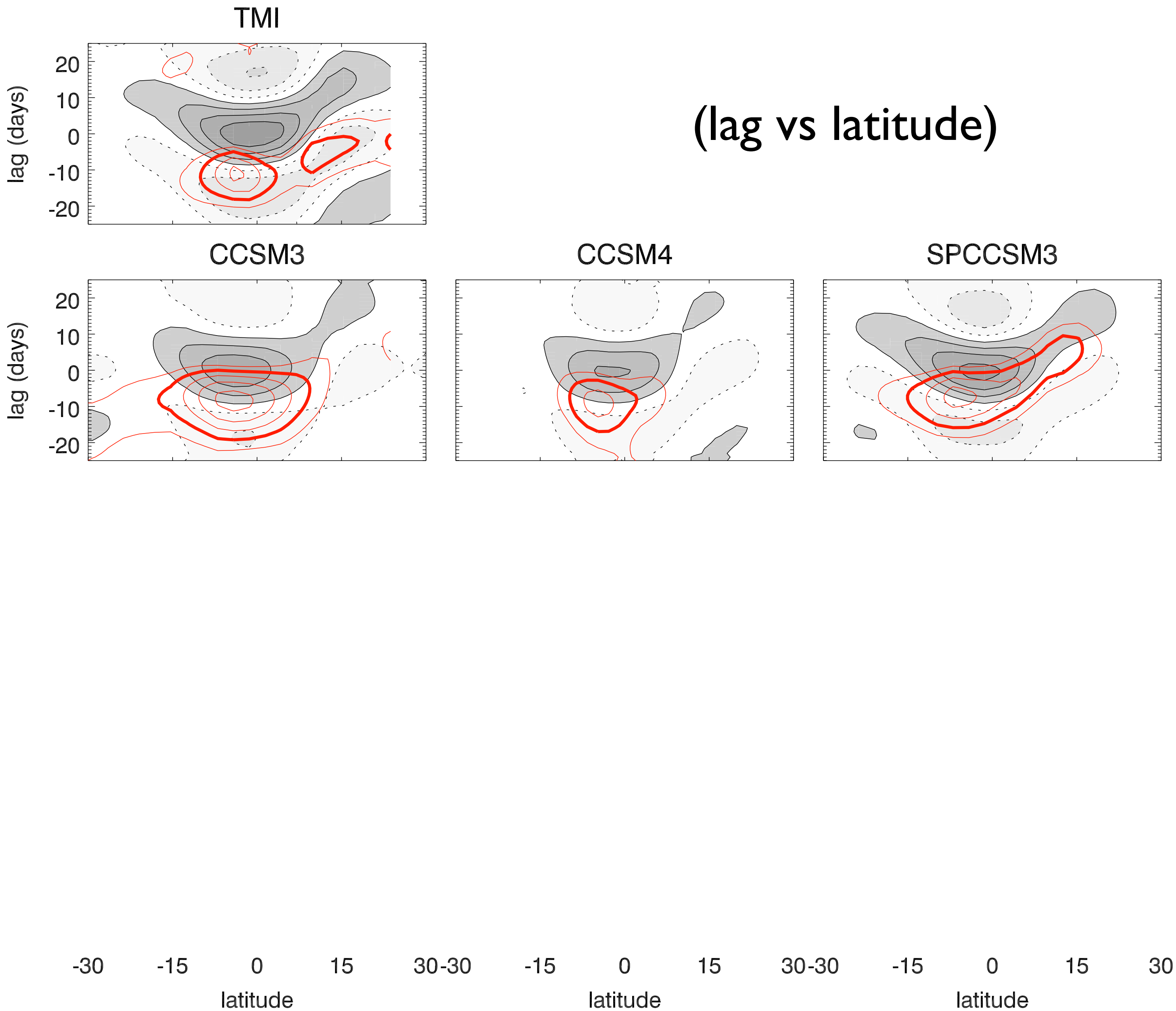
Rainfall and SST anomaly lag-correlation (all seasons)

(lag vs latitude)



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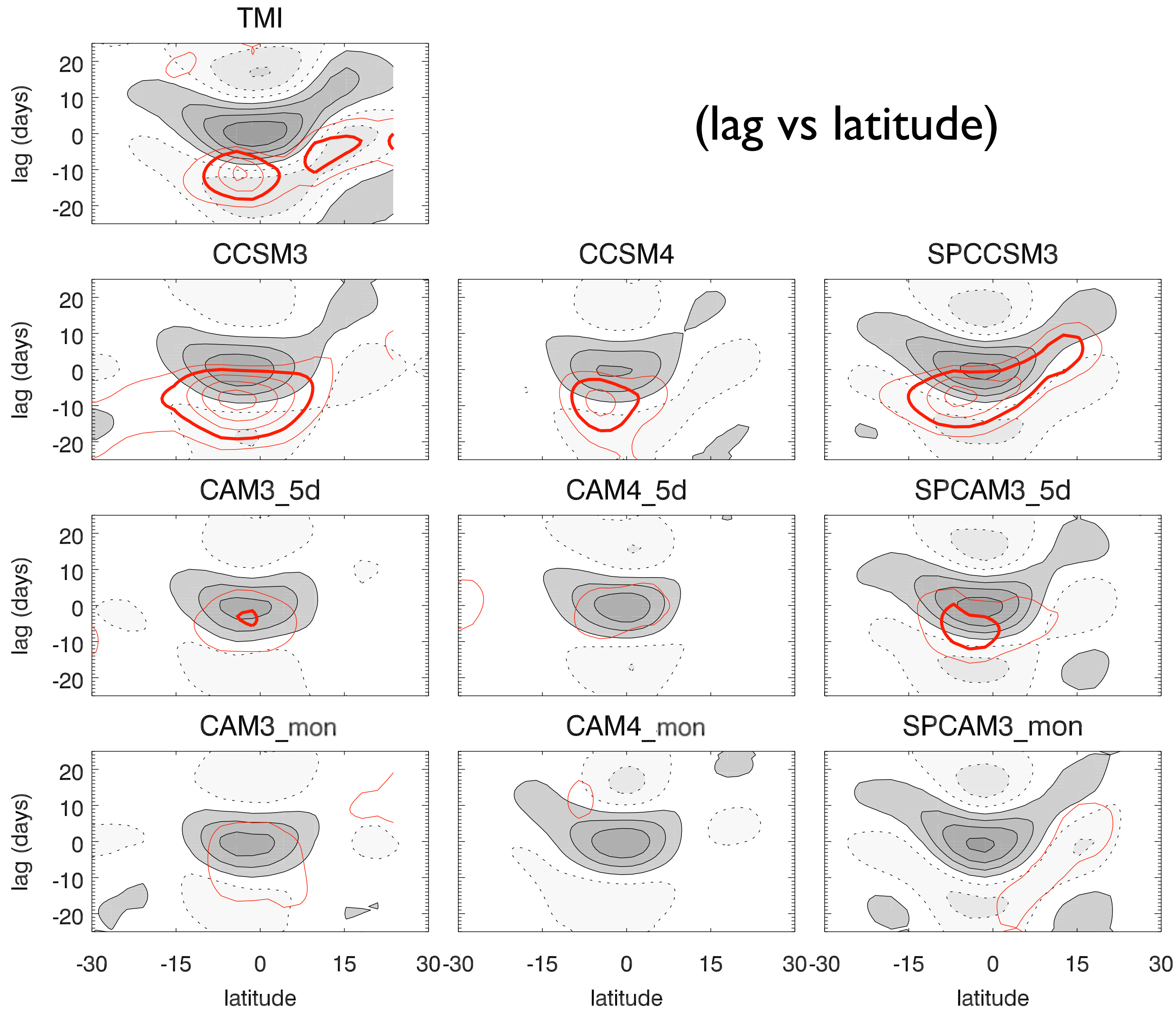
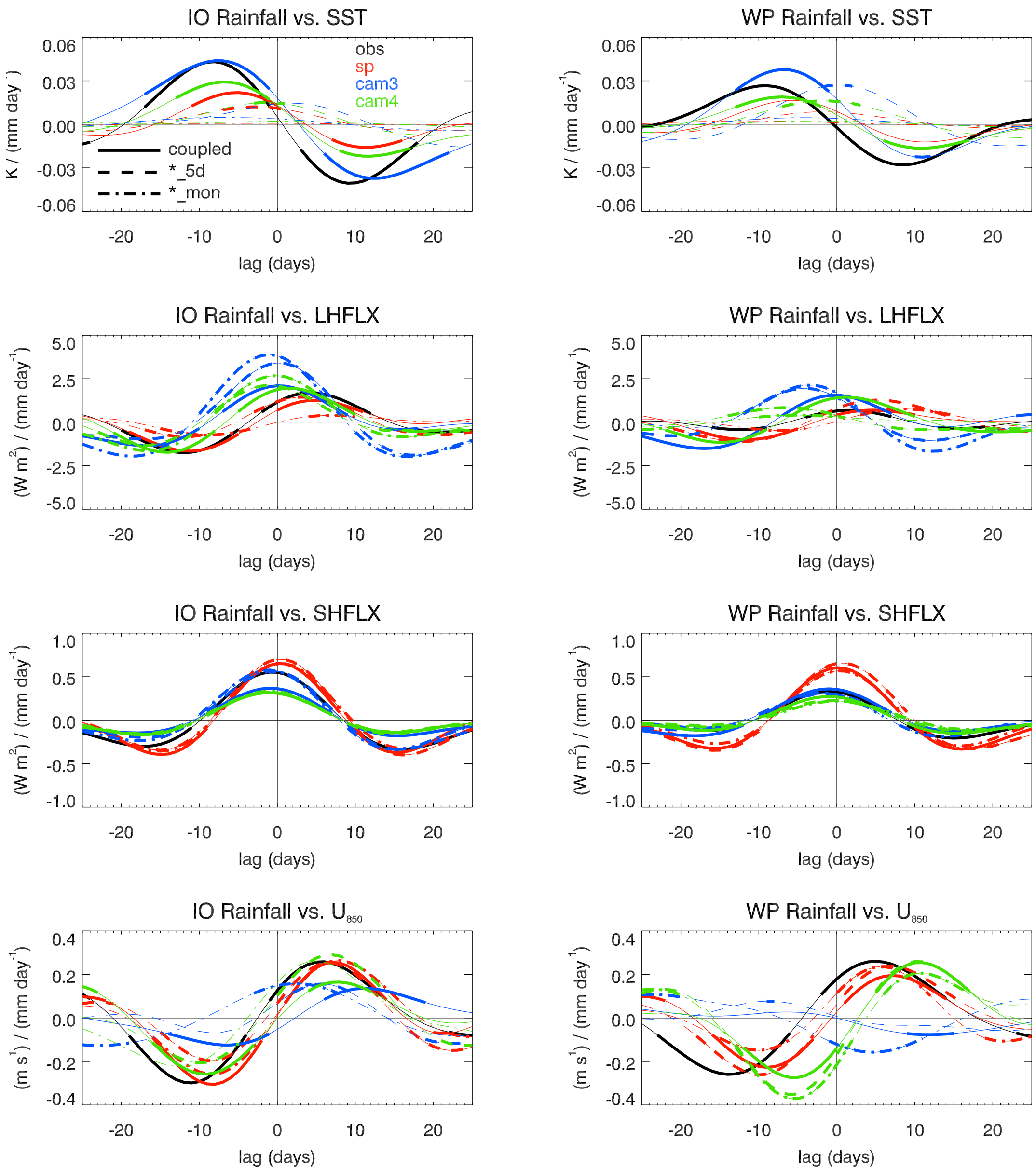


Rainfall vs other anomalies



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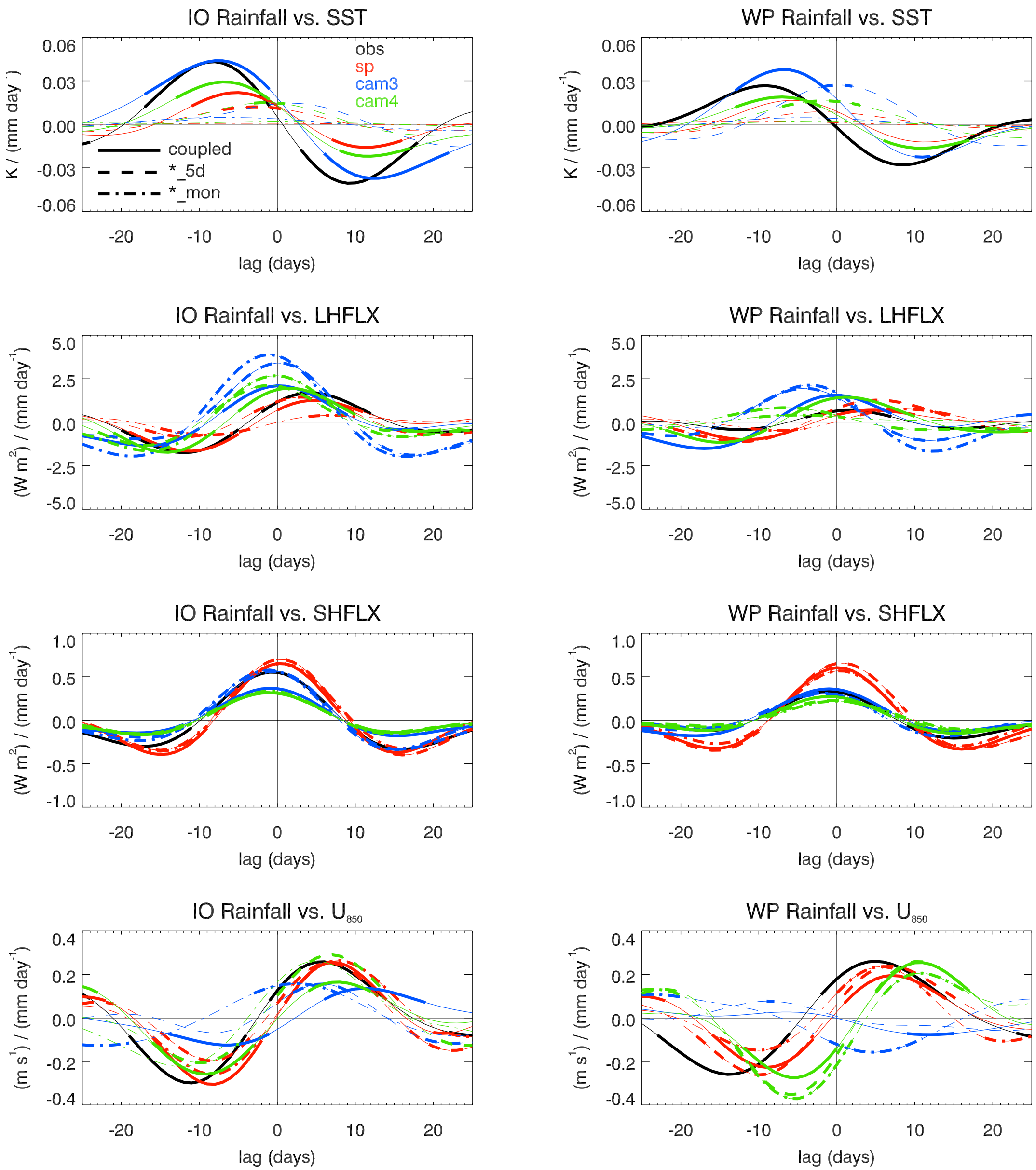

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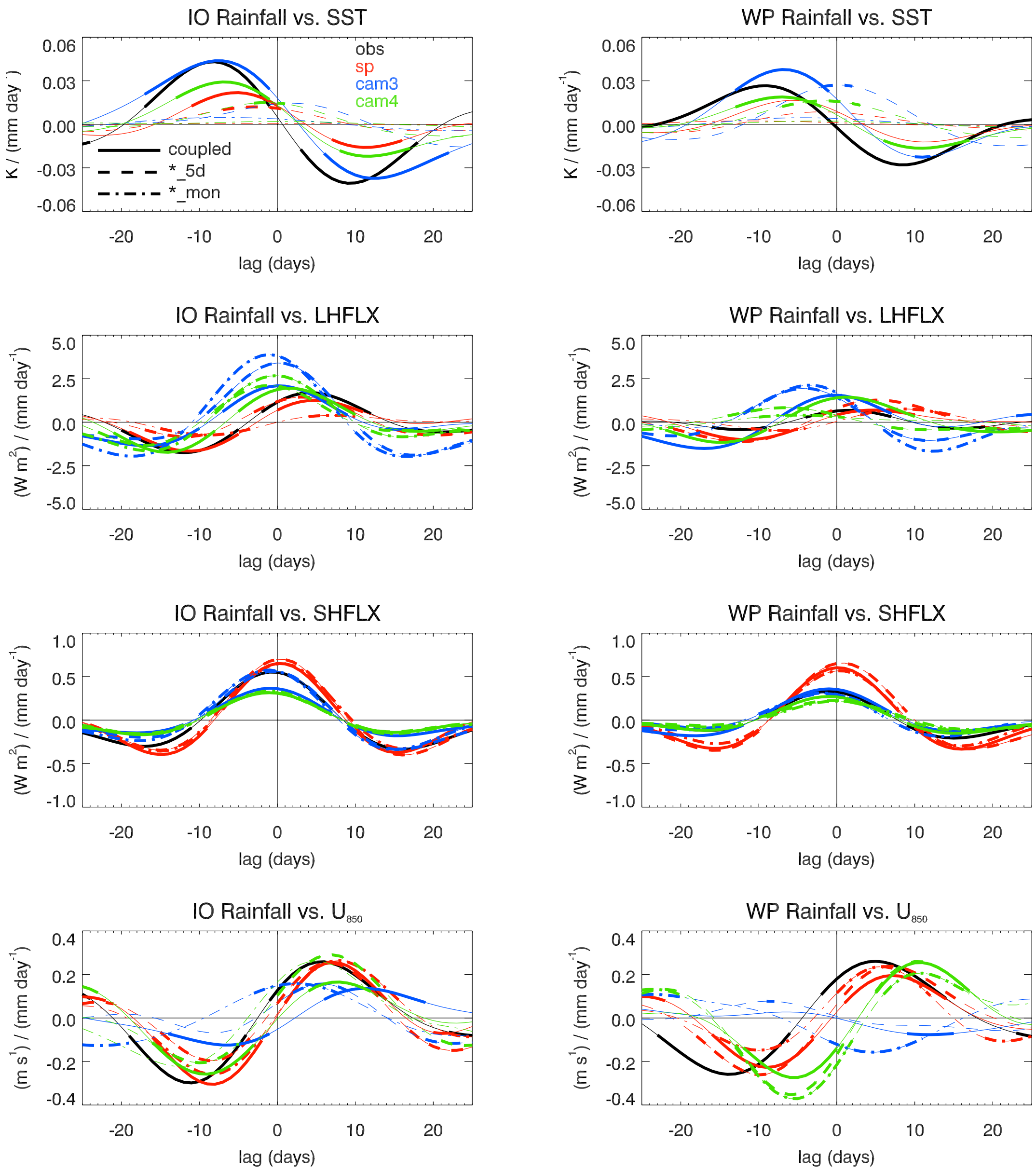


- In OBS and coupled runs, warm SSTs prior to precipitation are the result of reduced cloudiness and surface fluxes (atm driving SSTs).
- How might the atmosphere respond to the phasing of flux anomalies?

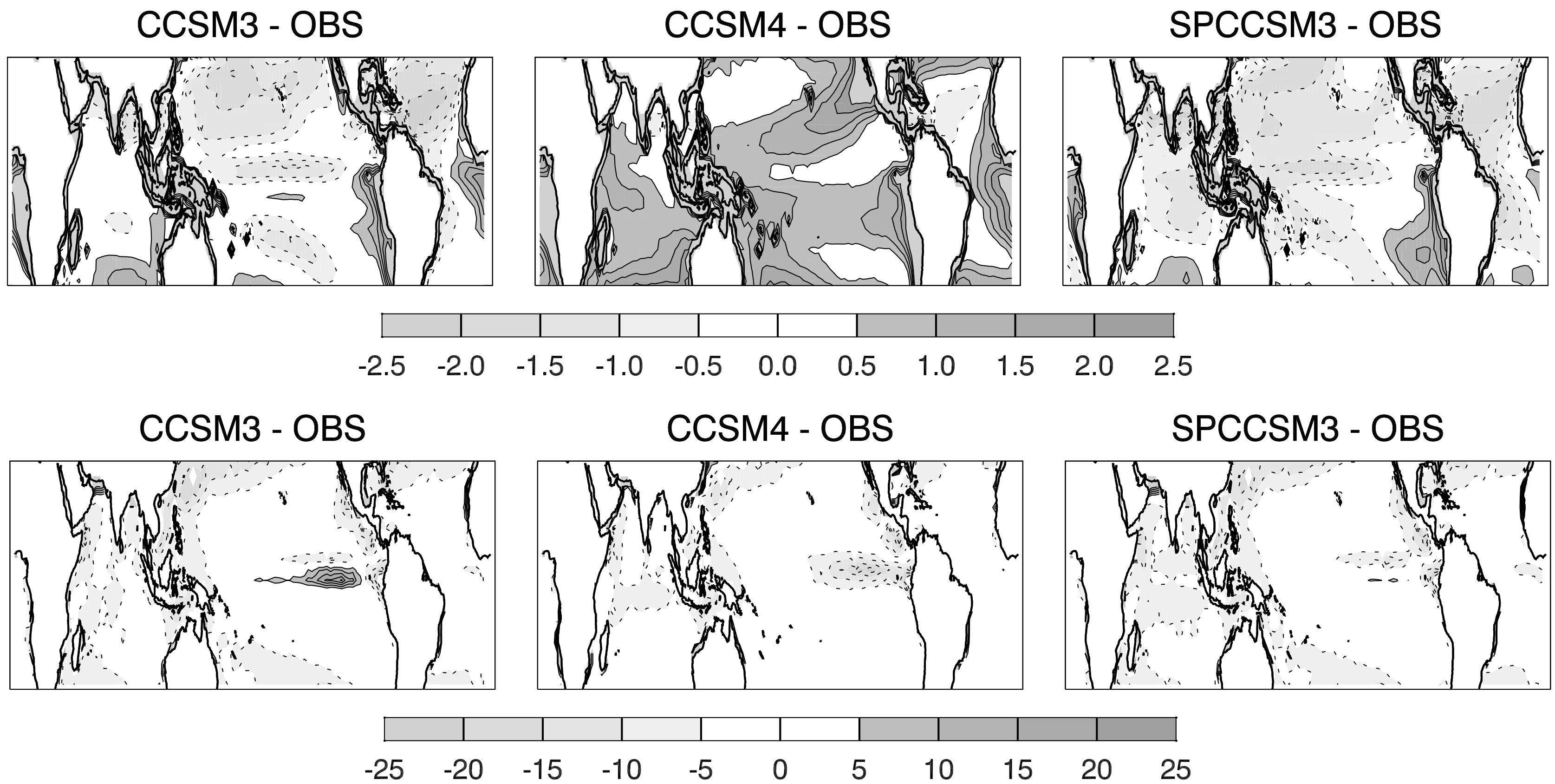
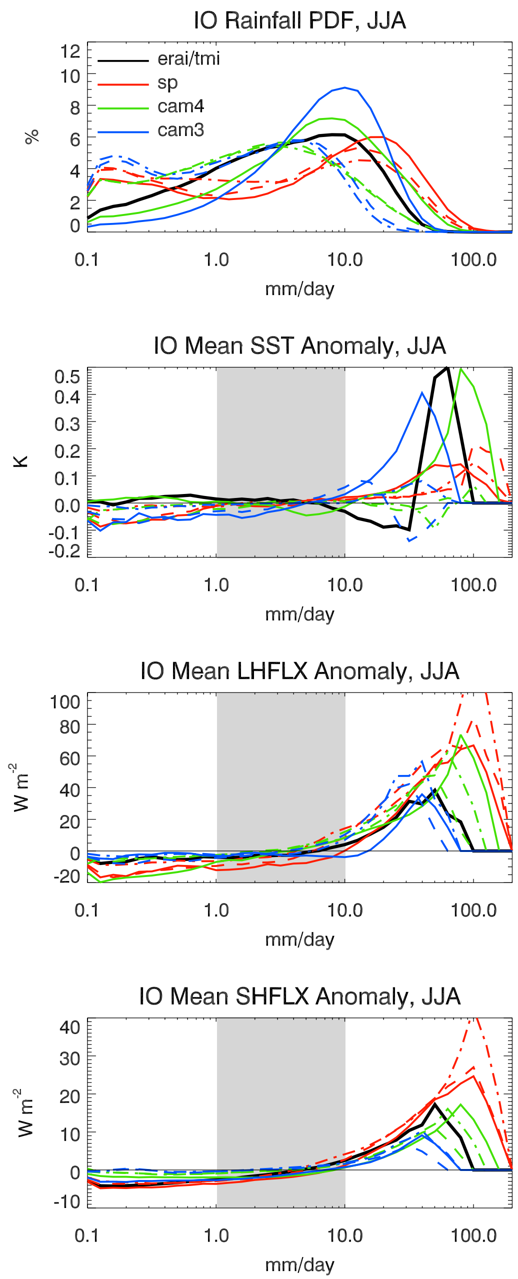
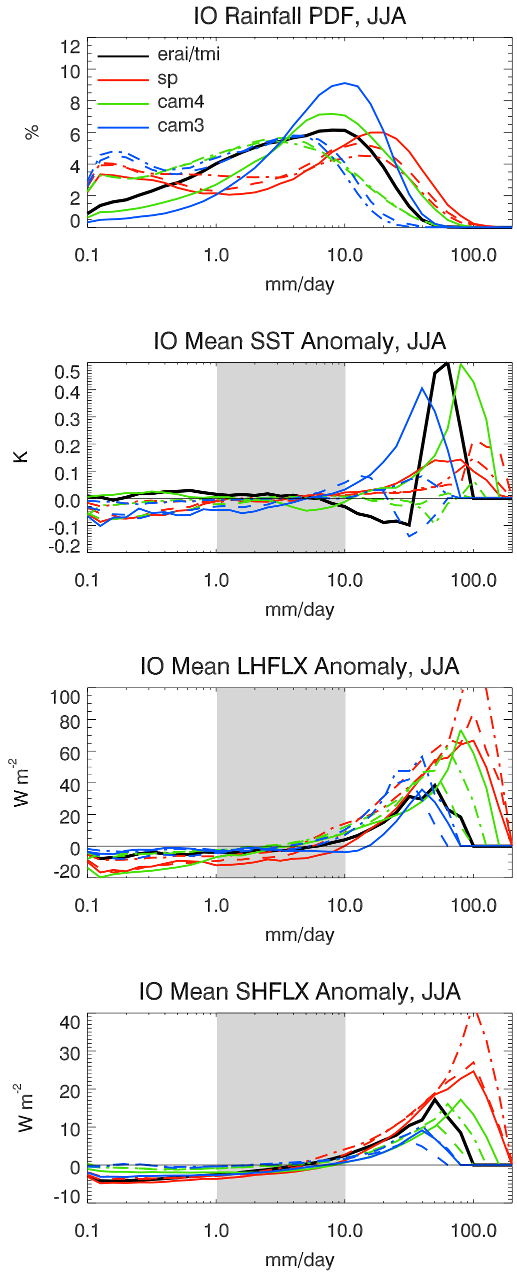


Fig. 3. Annual mean SST bias compared to HadISST (top row) and 20-100 day SST variance bias compared to HadISST (bottom row)

Air-Sea Interactions as a Function of Rainfall Rate



Air-Sea Interactions as a Function of Rainfall Rate



- Surface anomalies tend to change sign with increasing rainrate.

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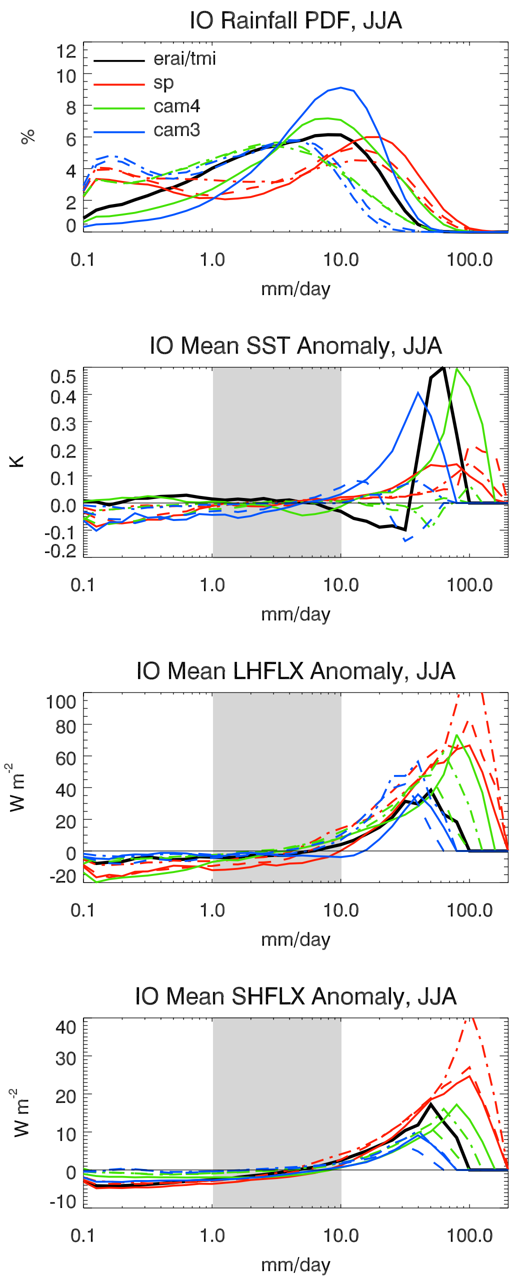

- Surface anomalies tend to change sign with increasing rainrate.
- How do these distributions change with time?