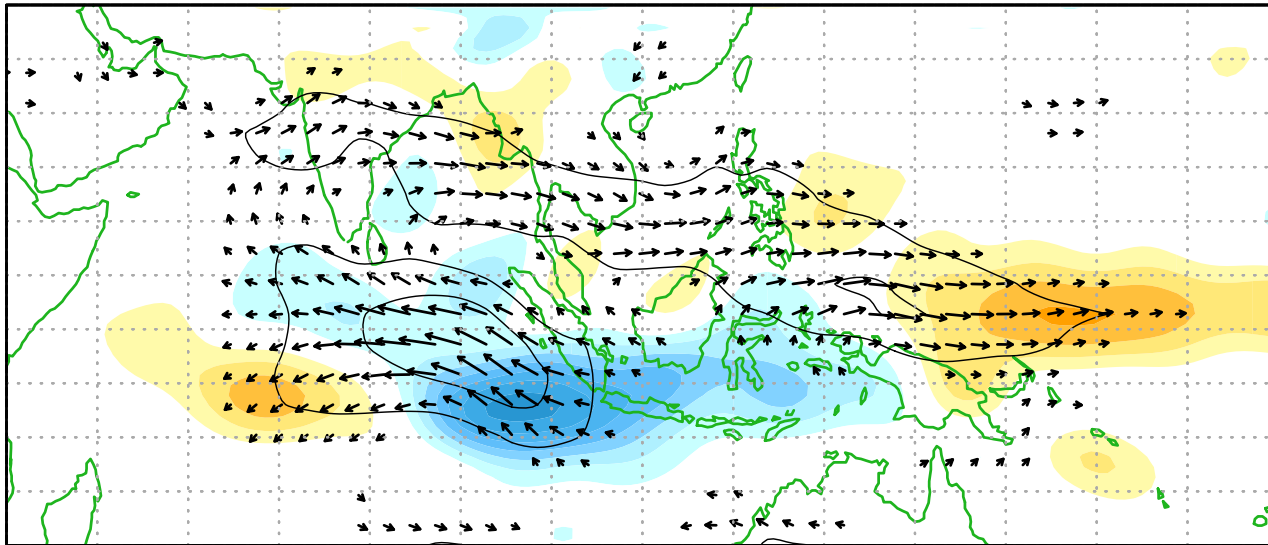


Monsoon teleconnections and impact of correcting tropical diabatic heating



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Outline

- Model and re-forecast experiments
- What happens to SST in re-forecasts when we intervene with atmospheric heating above it?
- Improvement in representation of heating related to ENSO and EQWIN
- Impact on model representation of monsoon teleconnections
- Prediction of monsoon circulation

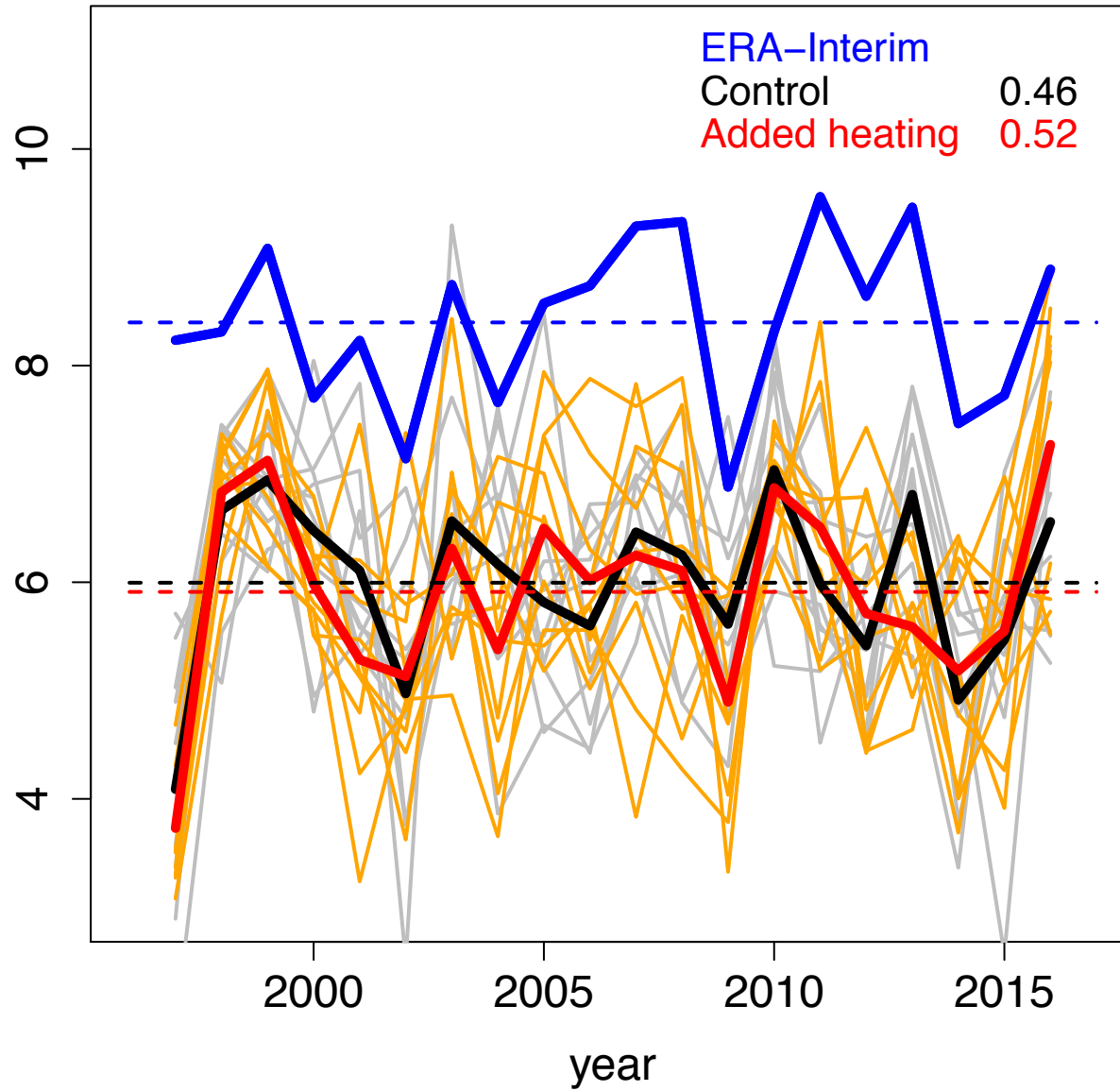
CFSv2 re-forecasts

- NCEP Climate Forecast System, version 2 (CFSv2)
- 1° horizontal resolution (T126), 64 vertical layers
- Summer re-forecasts made each year for 20 years (1997-2016)
- Initialized from CFSR on May 1st-10th (10 ensemble members)
- Analyze June – September (JJAS)

Added heating experiments

- *Control*: Control set of re-forecasts with no added heating
- *Added Heating*: Re-forecasts repeated in same manner, but with an additional temperature tendency applied over the tropical Indo-Pacific such that the total diabatic heating rate is much closer to estimate from ERA-Interim
- Domain: Indian Ocean (60°E–120°E, 15°S–5°N) and Pacific Ocean (120°E–100°W, 15°S–20°N) decaying outside boundaries (5° e-folding scale); all vertical variation at and above 850 hPa level ($p < 850$ hPa)
- Target: JJAS mean + trend + parabolic fit during season
- 10-day turn-on period prior to 00Z01Jun

ISMR (mm/day)



Tropical indices in CFSv2 ensemble mean

Correcting the tropical heating →

- Reduces tropical mean biases
- Increases SST variance (in ensemble spread also)

Index	Nino3.4		EMI		DMI		EQWIN	
	MEAN	VAR	MEAN	VAR	MEAN	VAR	MEAN	VAR
1997-2016								
Control	-0.82	1.47	-0.93	0.82	-0.26	0.54	-1.72	0.68
Added Heating	-0.70	1.74	-0.80	0.88	-0.04	1.25	0.02	0.47

MEAN = mean bias

VAR = variance of index normalized by observed

Prediction of tropical indices with CFSv2 ensemble mean

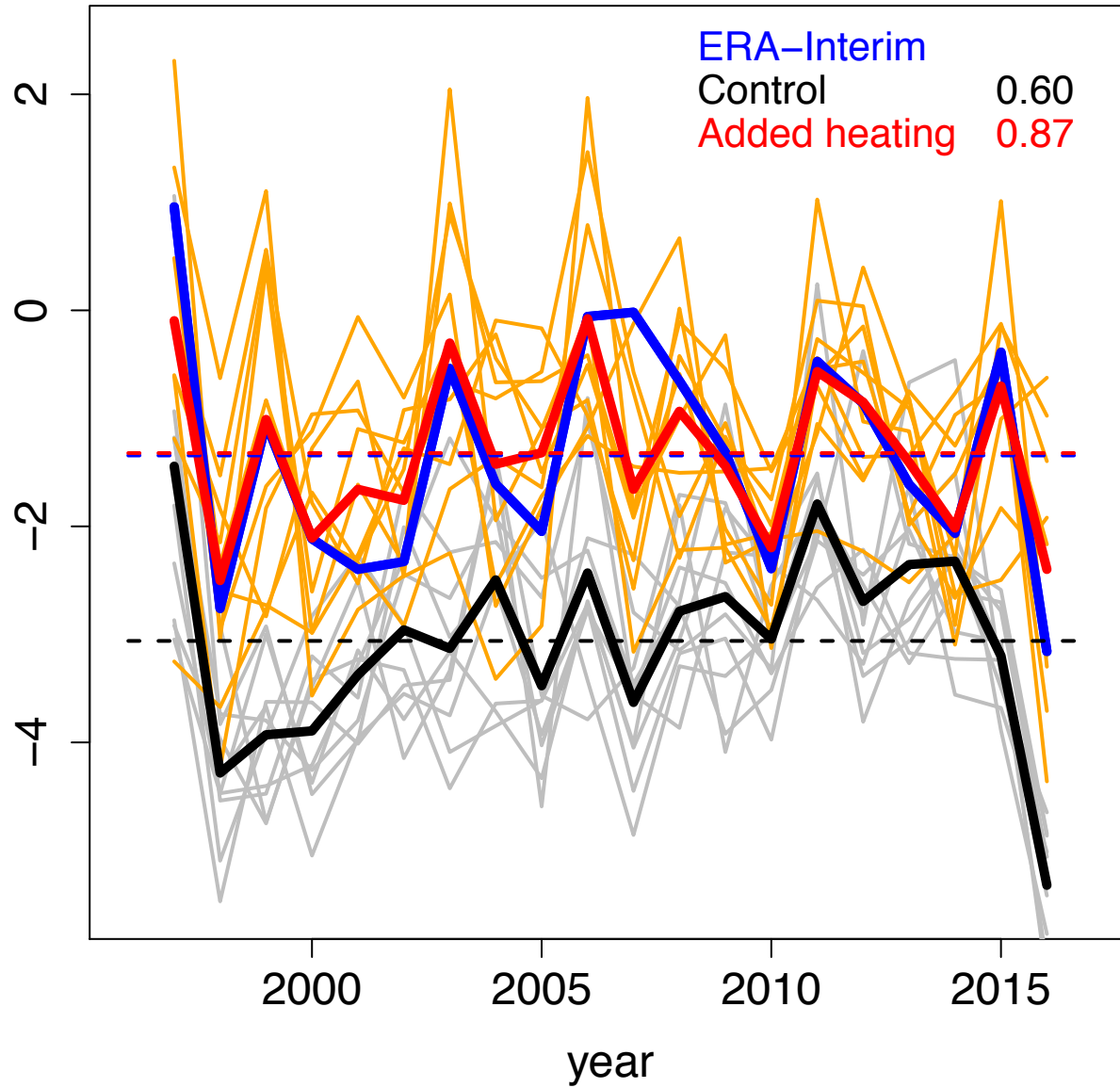
Correcting the tropical heating →

- Improves interannual prediction of SST, especially in Indian Ocean (and with EQWIN)

Index	Nino3.4		EMI		DMI		EQWIN	
	FVE	COR	FVE	COR	FVE	COR	FVE	COR
1997-2016								
Control	0.61	0.86	0.53	0.75	0.23	0.52	0.31	0.60
Added Heating	0.60	0.89	0.61	0.80	0.66	0.86	0.72	0.87

FVE = fraction of observed variance explained
 COR = correlation with observed index

EQWIN (m/s)



CFSv2 teleconnections with tropical indices

Correcting the tropical heating →

- Consistent with Vishnu et al. (2019)
- Overly strong relationship with Pacific not improved
- Weakens artificial negative relationship with Indian Ocean dipole and equatorial easterlies

1997-2016	Nino3.4	EMI	DMI	EQWIN
Observed	-0.50	-0.28	0.2	0.28
Control mean	-0.8	-0.67	-0.58	-0.57
Control dev.	-0.18	-0.16	-0.10	-0.09
Control total	-0.52	-0.43	-0.30	-0.31
Add htg mean	-0.87	-0.67	-0.26	-0.32
Add htg dev.	-0.14	-0.12	0.11	0.13
Add htg total	-0.60	-0.45	-0.08	-0.05

Observed teleconnections in tropical heating

- What remote tropical diabatic heating modes of variability explain the most inter-annual variance of Indian rainfall?
- Partial least-squares (PLS) regression (Smoliak et al. 2010)

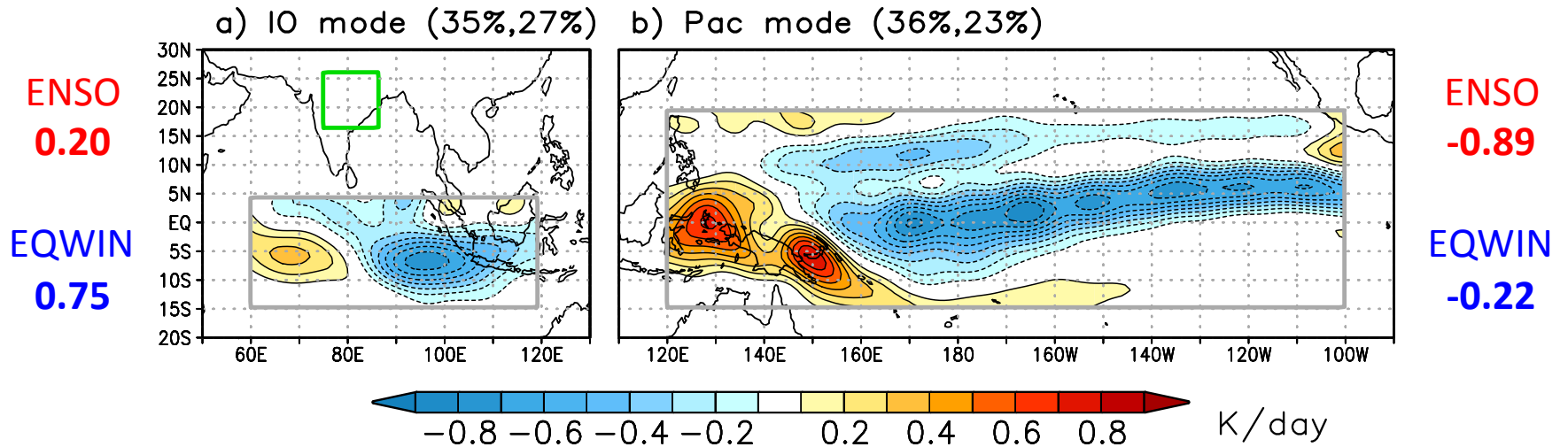
GPCP rainfall central India average (74.5°–86.5°E, 16.5°–26.5°N) \mathbf{y}

ERA-Interim residual diabatic heating vertical average ($p \leq 850$ hPa)
over Pacific Ocean (120°E–100°W, 15°S–20°N) \mathbf{X}_{PAC}

and Indian Ocean (60°E–120°E, 15°S–5°N) \mathbf{X}_{IO}

- 1) PLS-1 ($\mathbf{X}_{\text{PAC}}, \mathbf{y}$) \rightarrow Pac mode (ENSO signal)
- 2) Regress Pac mode out of \mathbf{X}_{IO} and $\mathbf{y} \rightarrow \mathbf{X}'_{\text{IO}}$ and \mathbf{y}'
- 3) PLS-1 ($\mathbf{X}'_{\text{IO}}, \mathbf{y}'$) \rightarrow IO mode (dipole/EQWIN)

Teleconnections in ERA-Interim tropical heating



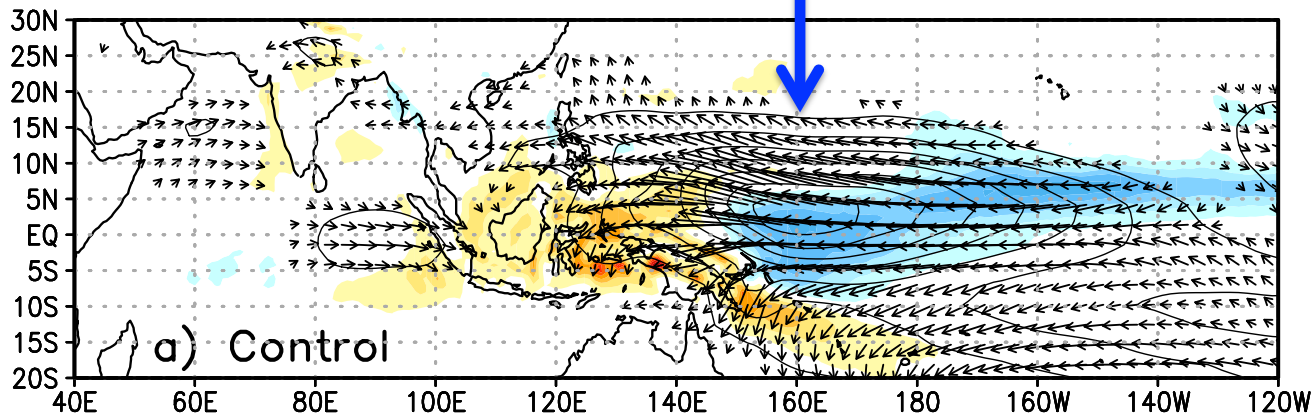
CFSv2	IO mode		
1997-2016	VAR	COR _Q	COR _P
Control	0.46+0.68	0.55	-0.69
Added Heating	1.18+0.97	0.96	-0.07
ERA-Interim	1.05		0.69

Pac mode		
VAR	COR _Q	COR _P
0.86+0.08	0.96	0.76
1.25+0.13	0.99	0.77
1.20		0.61

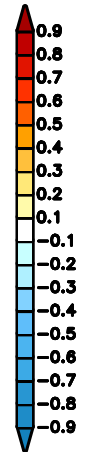
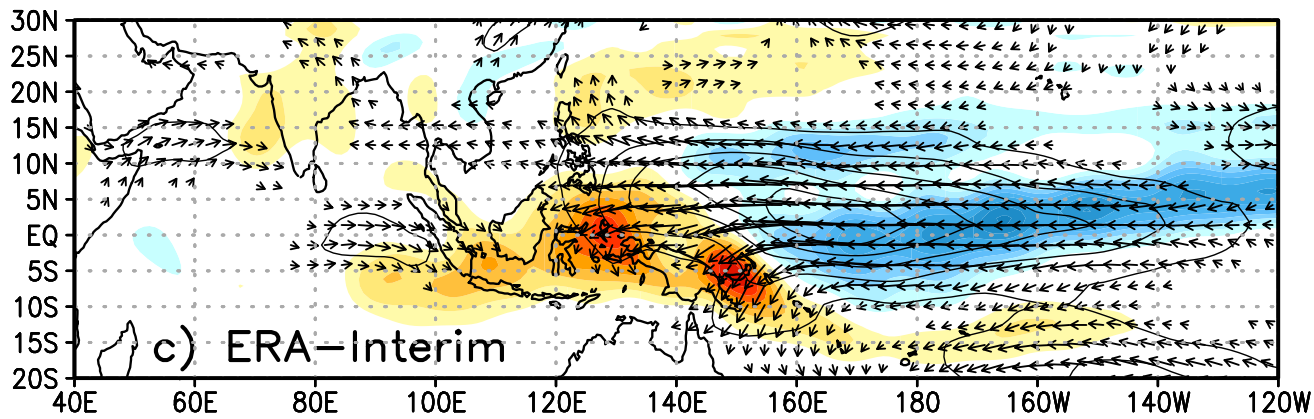
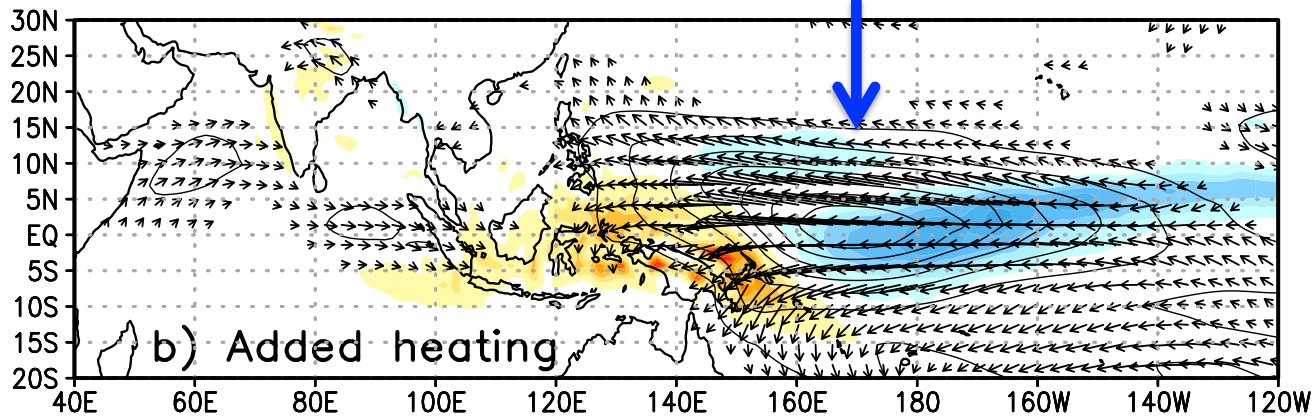
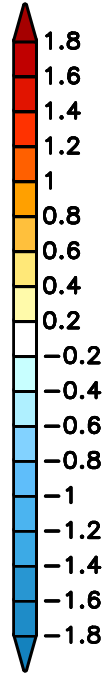
VAR = variance of index normalized by observed

COR_Q (COR_P) = correlation between model and observed mode (mode and ISMR)

Pac mode ens mean



K/day

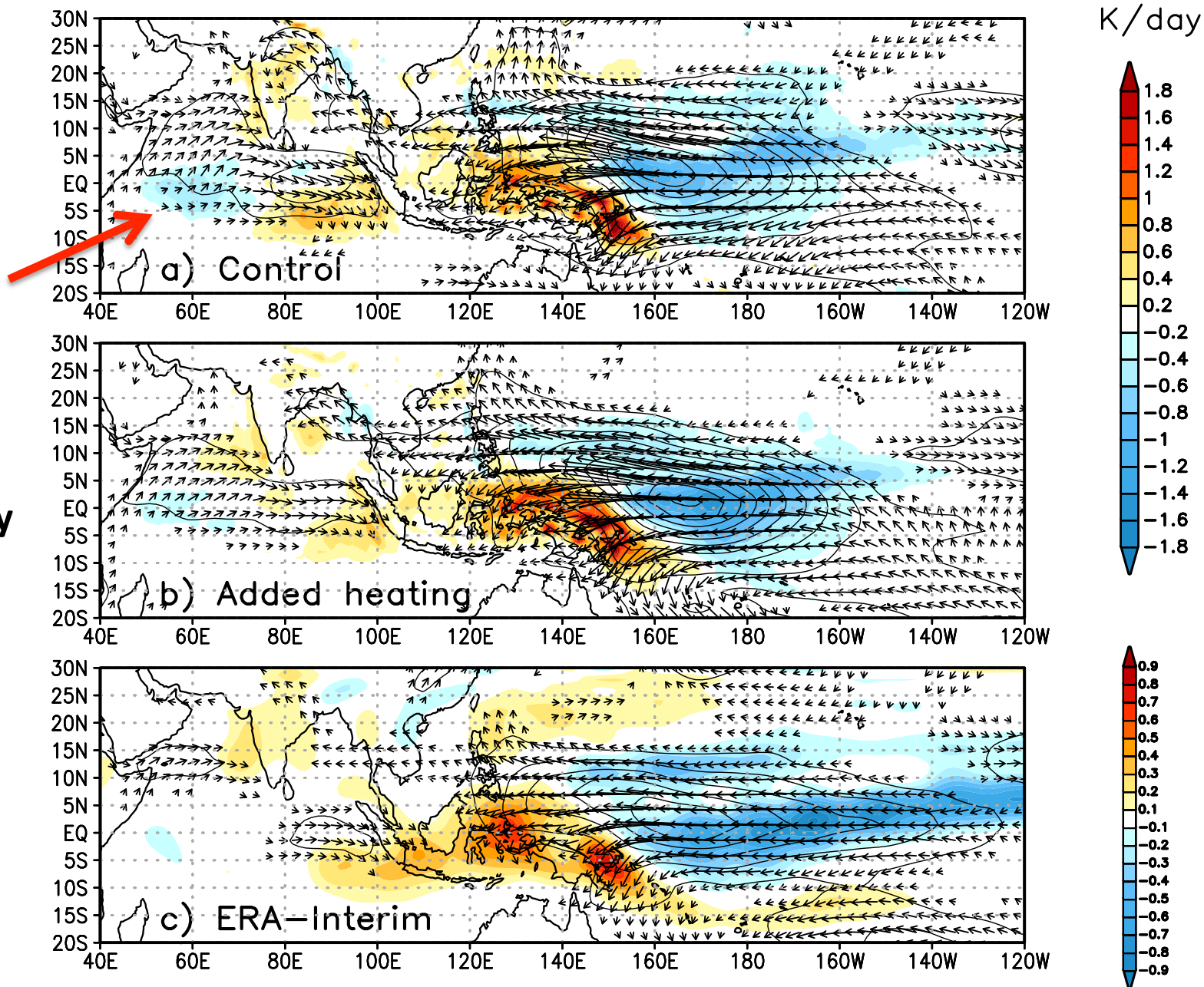


Shift in
westerlies
and heating/
cooling in
west/central
Pacific

Pac mode ens dev

Dipole

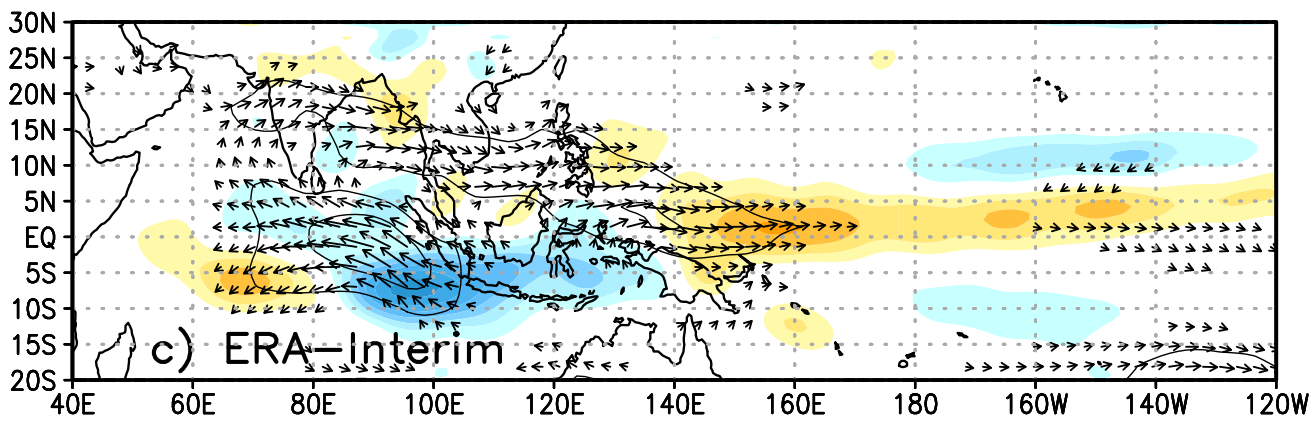
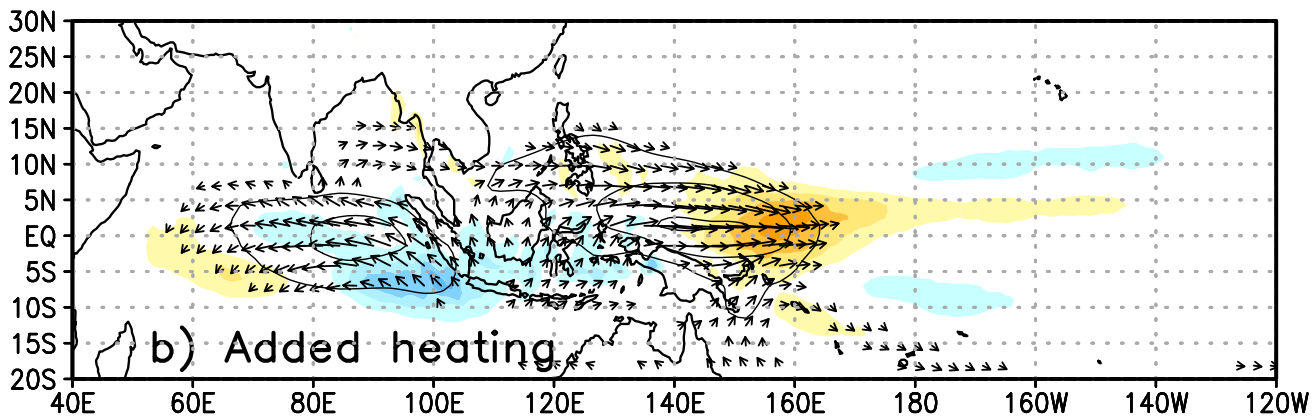
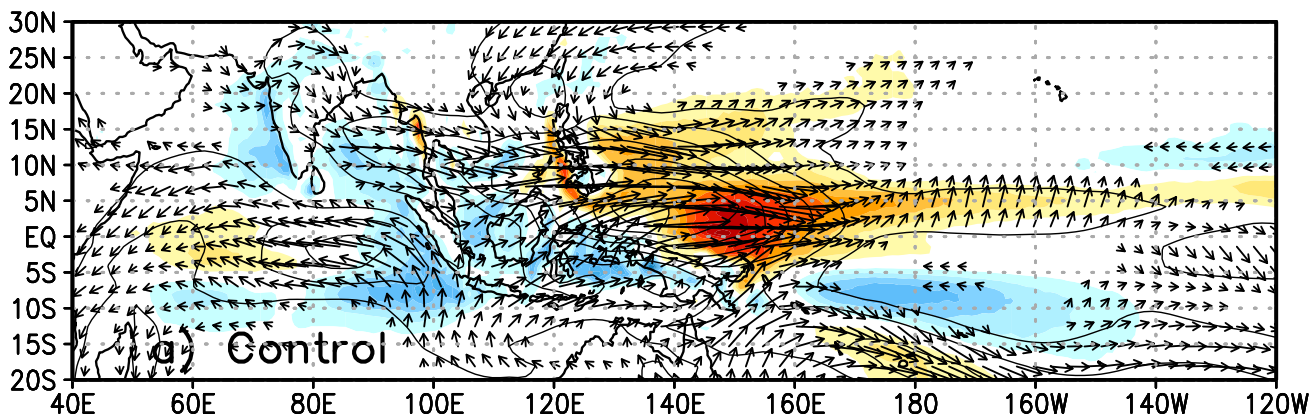
large
internal
variability
in both



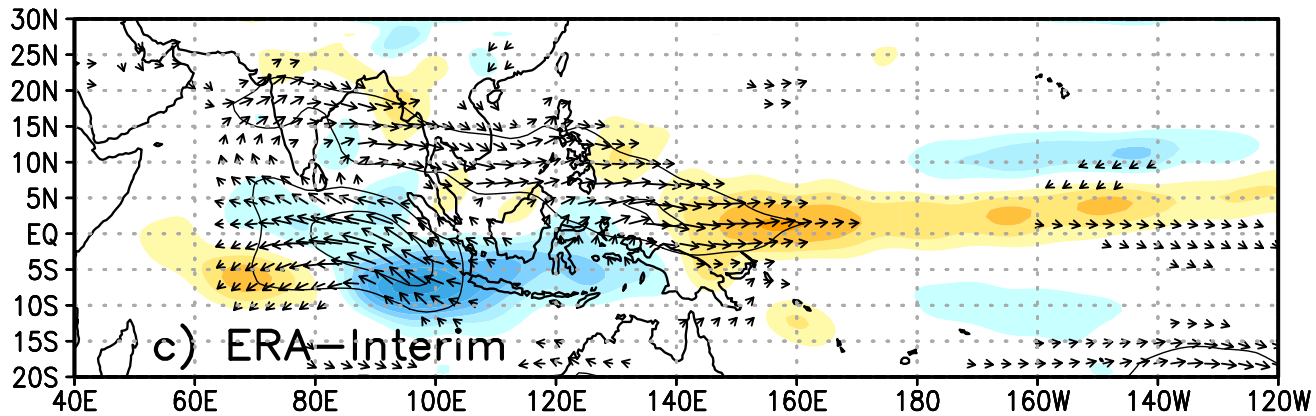
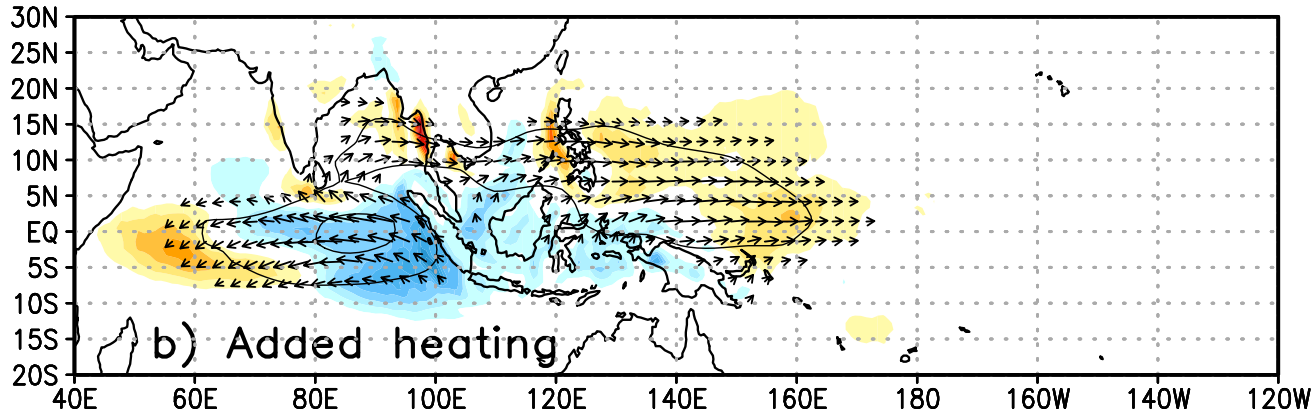
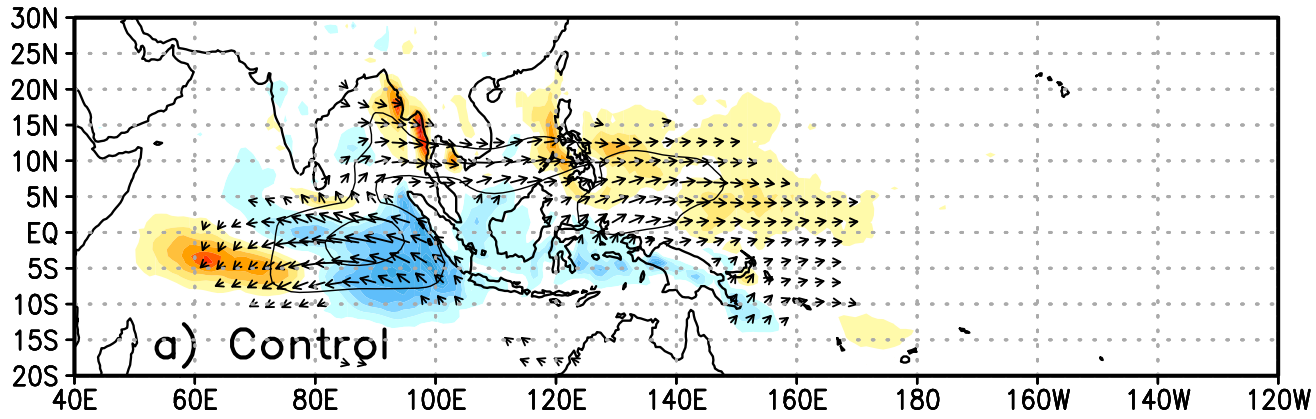
IO mode ens mean

**too strong
association
with West
Pacific;
opposite
relationship
with
monsoon**

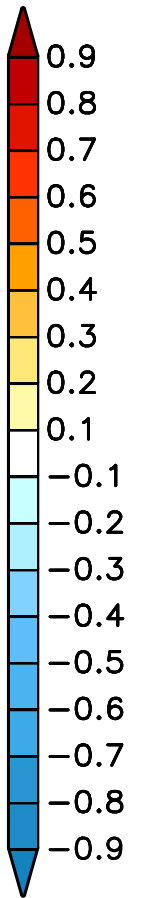
**opposite
relationship
broken**



IO mode ens dev

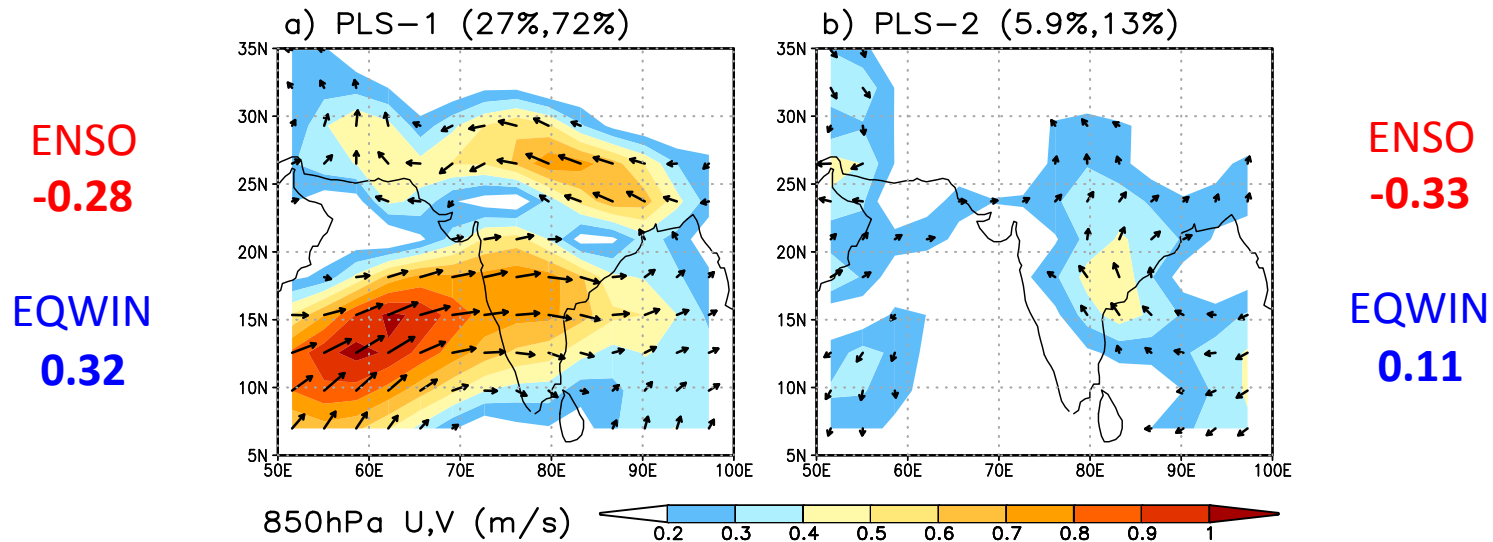


K/day



dipole is
more noise
than signal

Monsoonal circulation patterns



CFSv2	PLS-1		
1997-2016	VAR	COR _V	COR _p
Control	0.27+0.44	0.10	0.77
Added Heating	0.33+0.49	0.45	0.92
ERA-Interim	0.82		0.82

PLS-2		
VAR	COR _V	COR _p
0.33+0.28	0.52	0.66
0.23+0.42	0.71	0.57
1.13		0.42

VAR = variance of index normalized by observed

COR_V (COR_p) = correlation between model and observed mode (mode and ISMR)

Summary

- Correcting tropical heating doesn't screw up the ocean – improves SST mean bias and interannual prediction of SST
- Improved representation of ENSO heating and especially for heating dipole in tropical IO; associated low-level winds greatly improved for both
- Heating dipole in IO is quite noisy in CFSv2
- CFSv2 monsoon over-dependence on ENSO not reduced
- CFSv2 has a strong opposite relationship between Indian rainfall and IO heating – possibly related to overly-strong co-occurrence of West Pacific heating/cooling (dipole forced by West Pacific in CFSv2?)
- Correcting tropical heating kills this bad relationship, but does not reverse it as is observed
- Correcting tropical heating only leads to modest improvement in Indian rainfall prediction, but more significant improvement in monsoon circulation