The Influence of a Weakened AMOC on the El Niño-Southern Oscillation

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ENSO variability found to increase in response to freshwater hosing in 4/5 GCM simulations

Hosing run

Control run

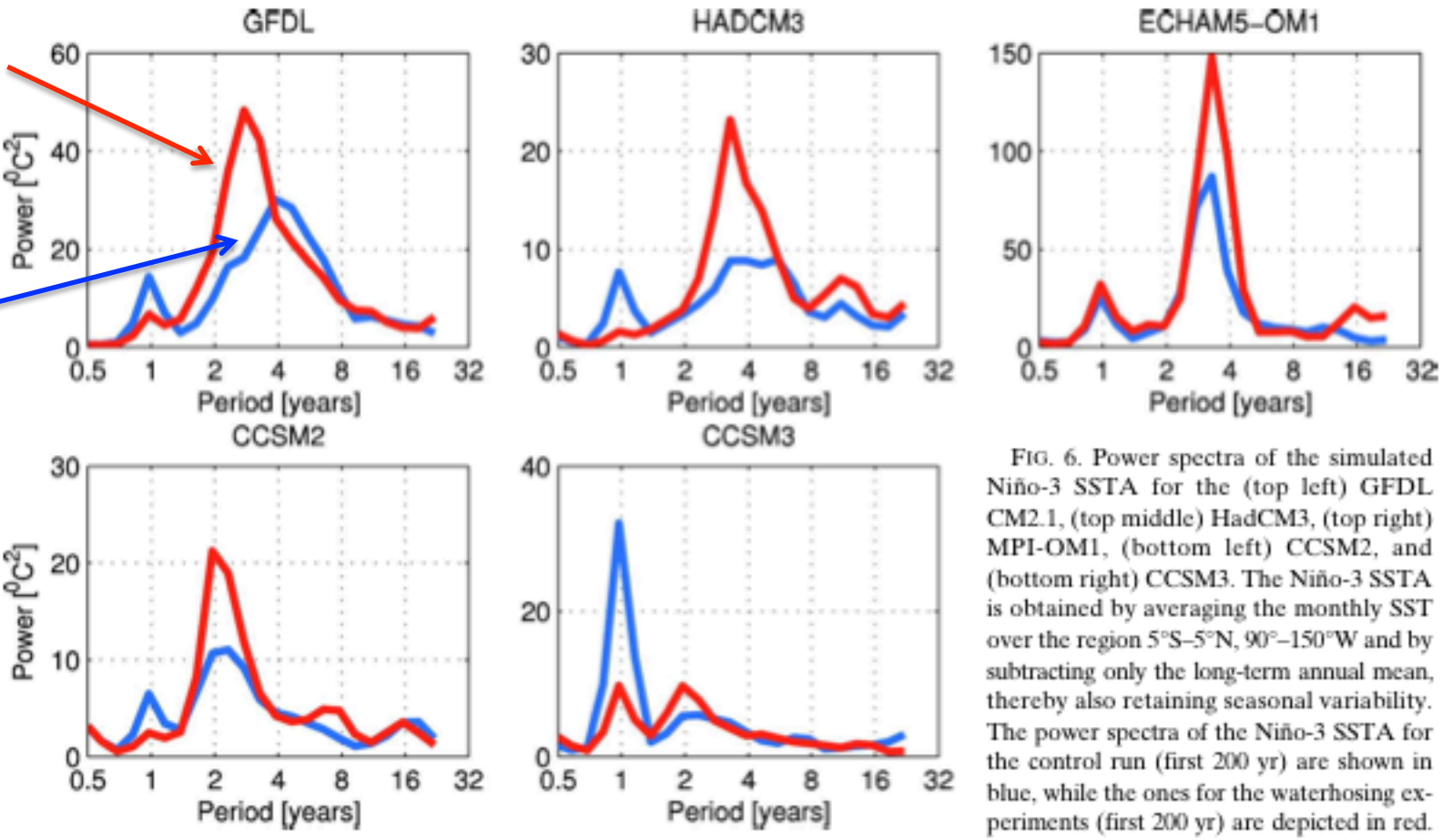


FIG. 6. Power spectra of the simulated Niño-3 SSTA for the (top left) GFDL CM2.1, (top middle) HadCM3, (top right) MPI-OM1, (bottom left) CCSM2, and (bottom right) CCSM3. The Niño-3 SSTA is obtained by averaging the monthly SST over the region 5°S–5°N, 90°–150°W and by subtracting only the long-term annual mean, thereby also retaining seasonal variability. The power spectra of the Niño-3 SSTA for the control run (first 200 yr) are shown in blue, while the ones for the waterhosing experiments (first 200 yr) are depicted in red.

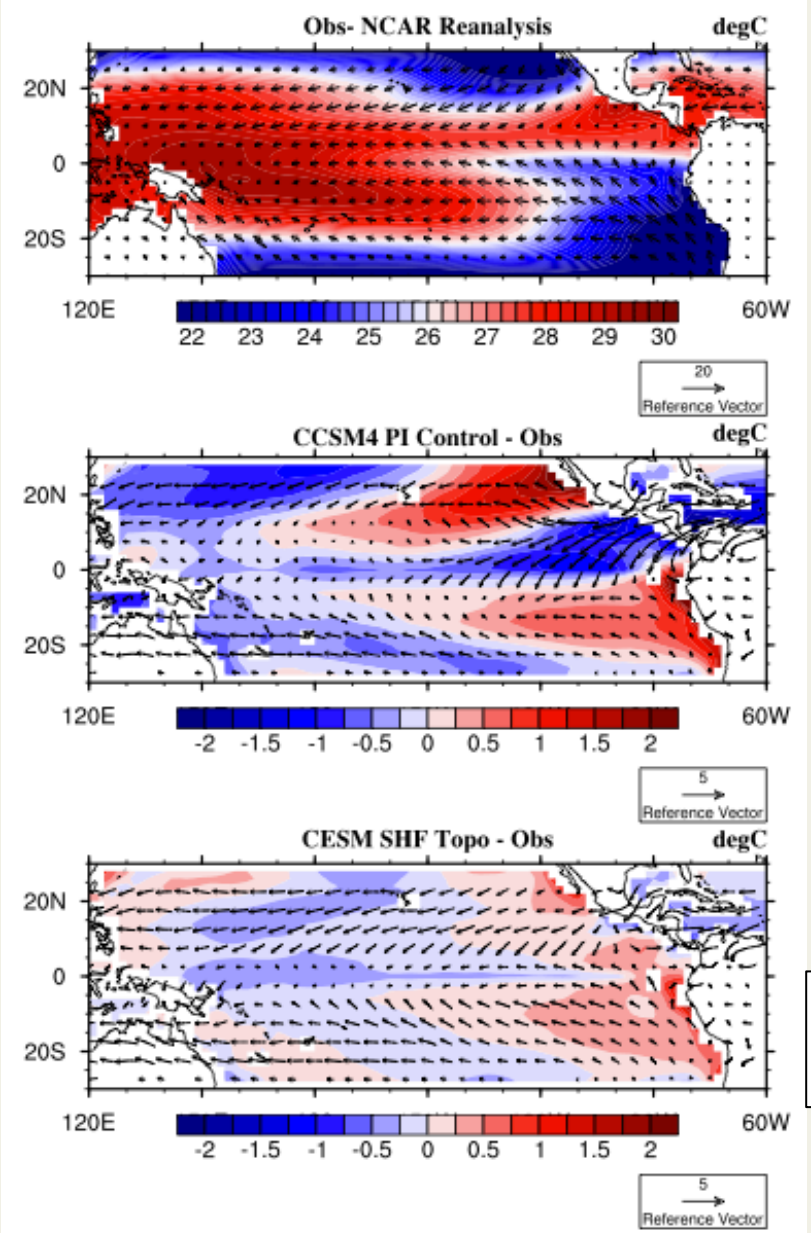
Timmermann et al. (2007)

Hosing Experiments with CESM

- CESM Experiments
  - **Prescribe 1 Sv freshwater perturbation in N. Atlantic for 100 years**
  - **Hose with and w/out flux corrections to reduce tropical Pacific mean state biases**
- Apply tropical Pacific mean states to the Linearized Ocean Atmosphere Model (LOAM)
- Evaluate ENSO response in GCM and in LOAM

Influence of Flux Corrections

Improved trop. Pac. mean state in flux corrected run

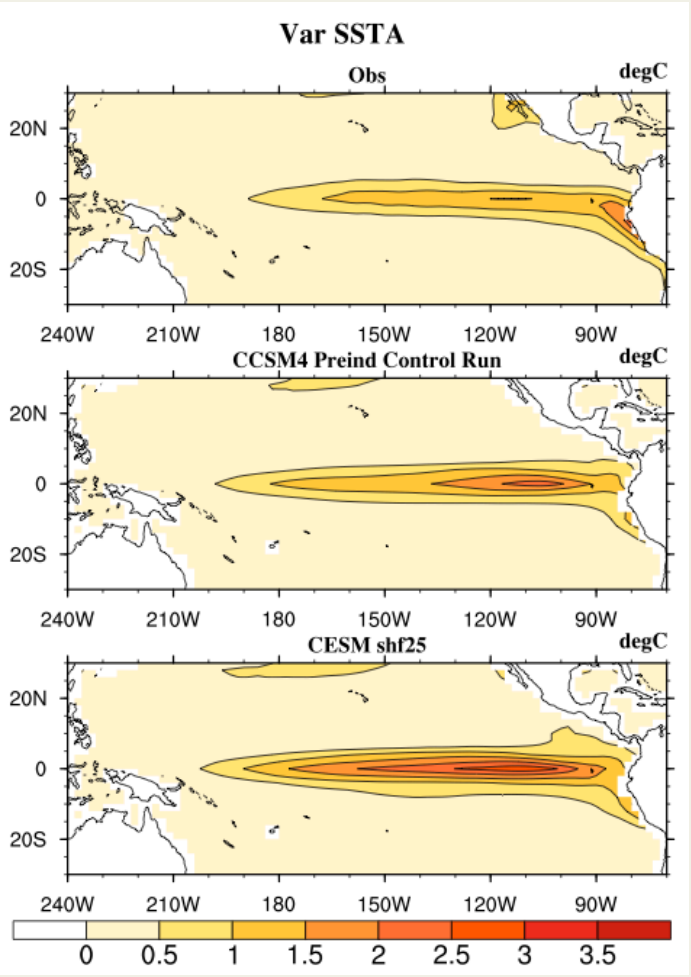


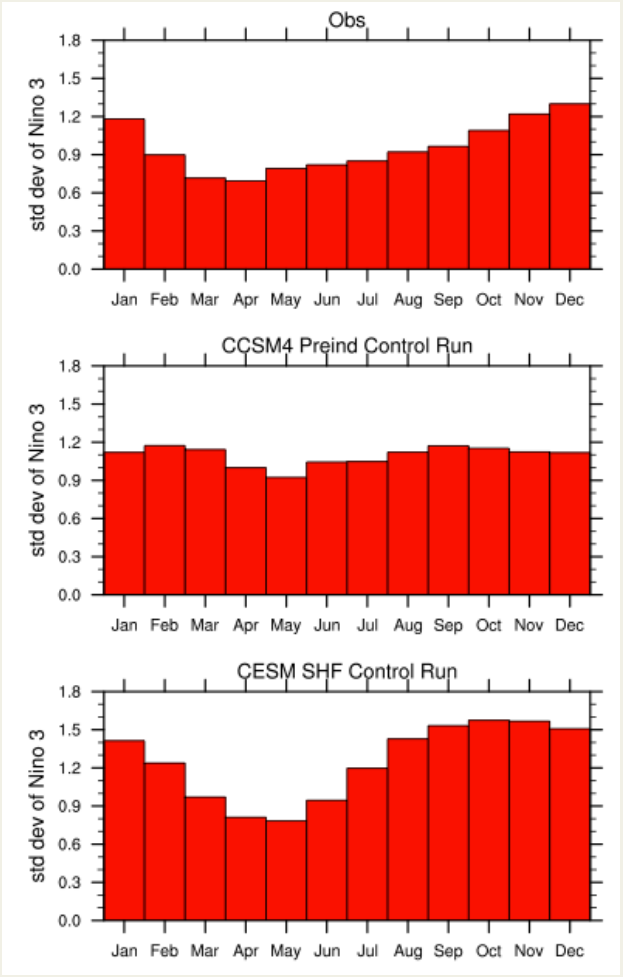
Obs

Non-flux Corrected Control - Obs

Flux Corrected Control - Obs

Improved ENSO phase-locking to annual cycle





Obs (last 40 yrs NOAA ERSST v3b)

CCSM4 Preind Control Run

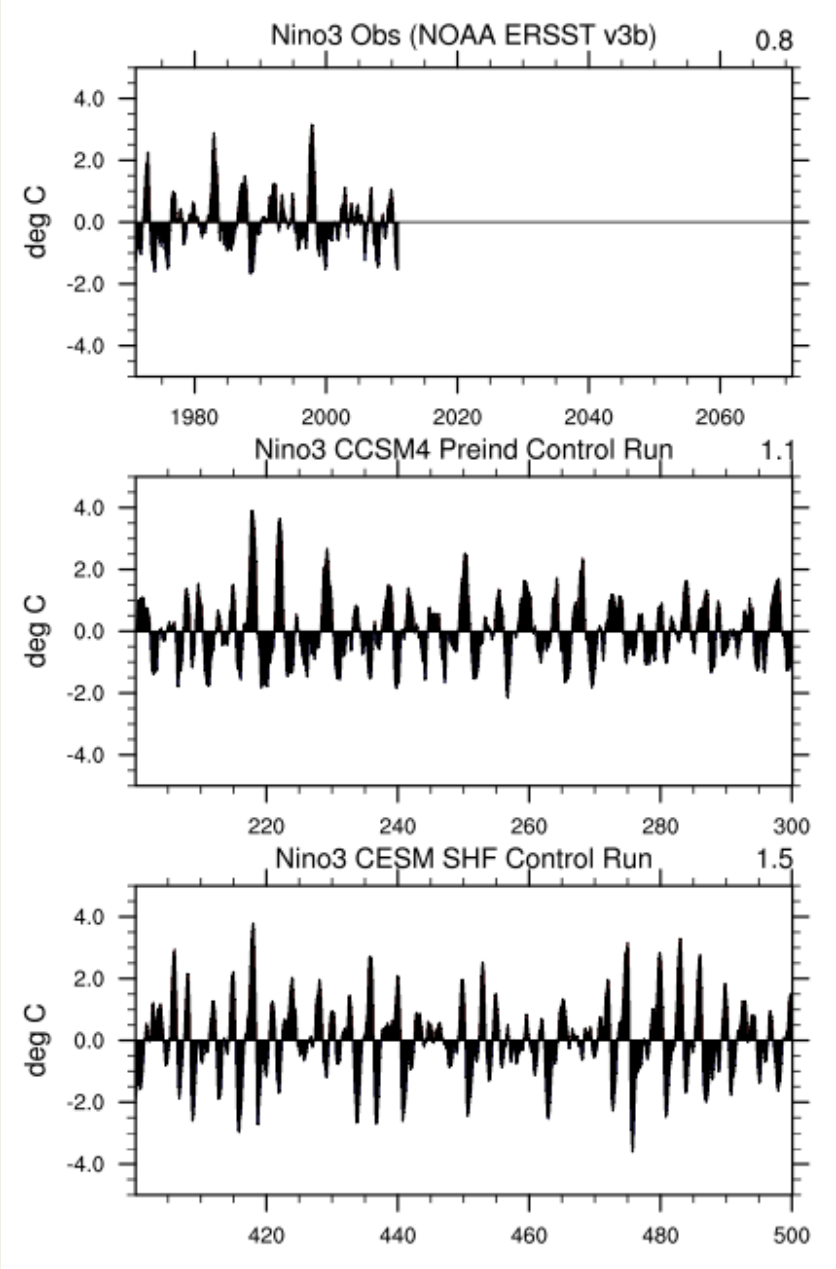
CESM Flux Corrected Run

Increased ENSO variability in flux-corrected run

$\sigma^2 = 0.8$

$\sigma^2 = 1.1$

$\sigma^2 = 1.5$



Obs (last 40 yrs NOAA ERSST v3b)

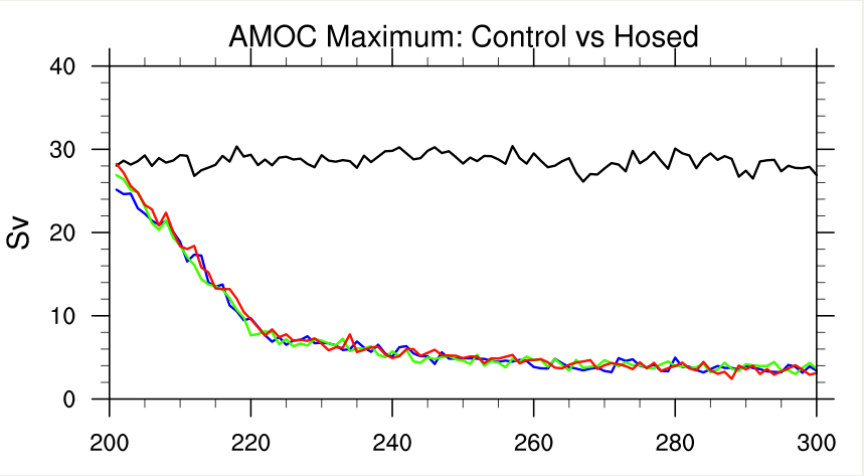
Non-flux corrected control run

Flux Corrected Control Run

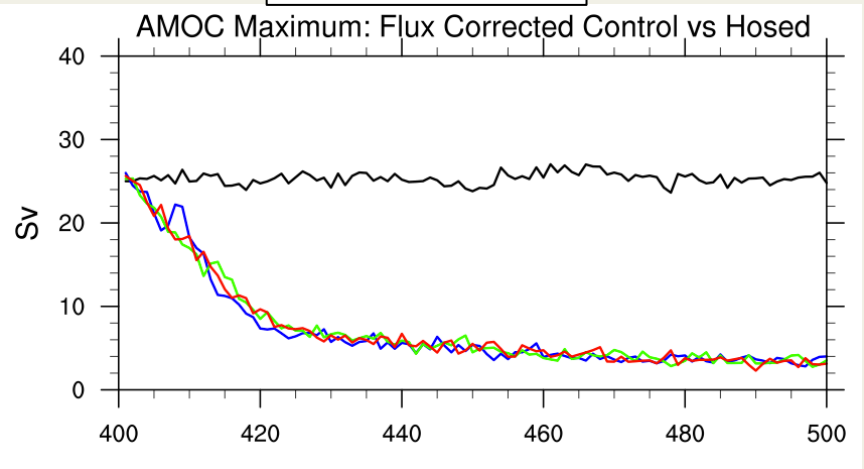
Hosing Simulations

AMOC shutdown in all hosing runs

Non-flux corrected

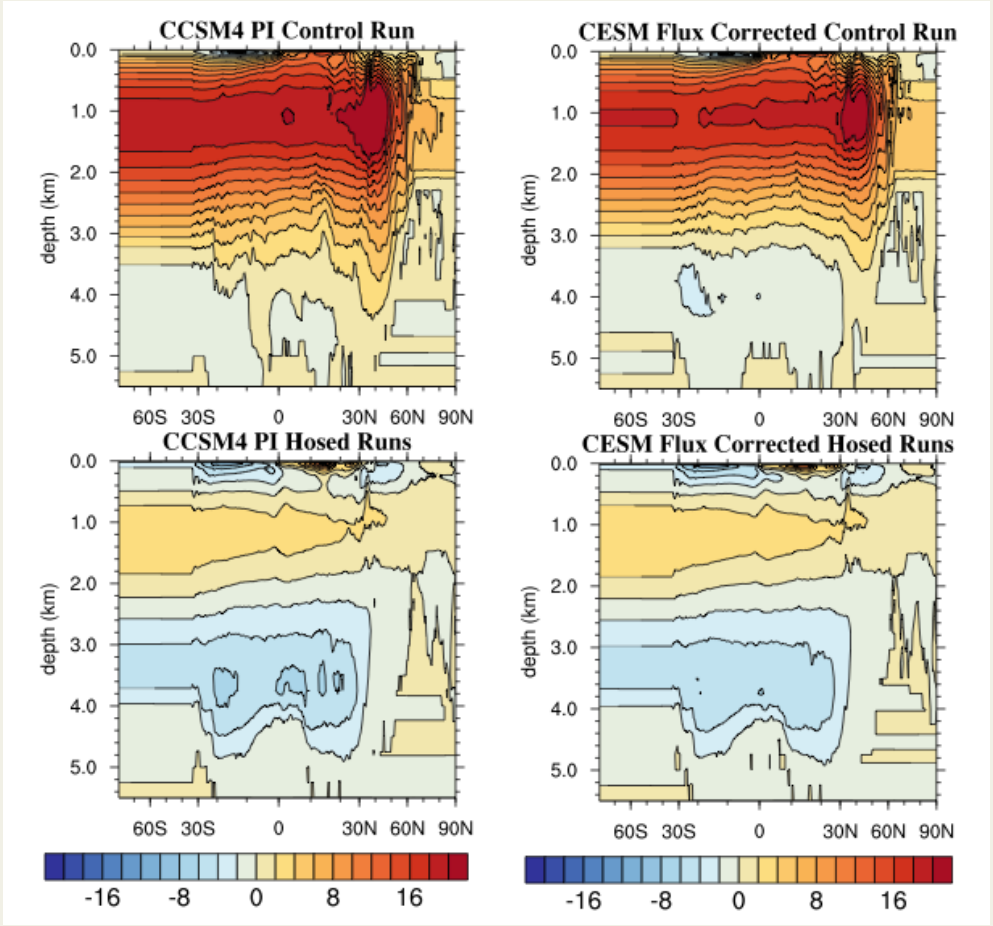


Flux corrected



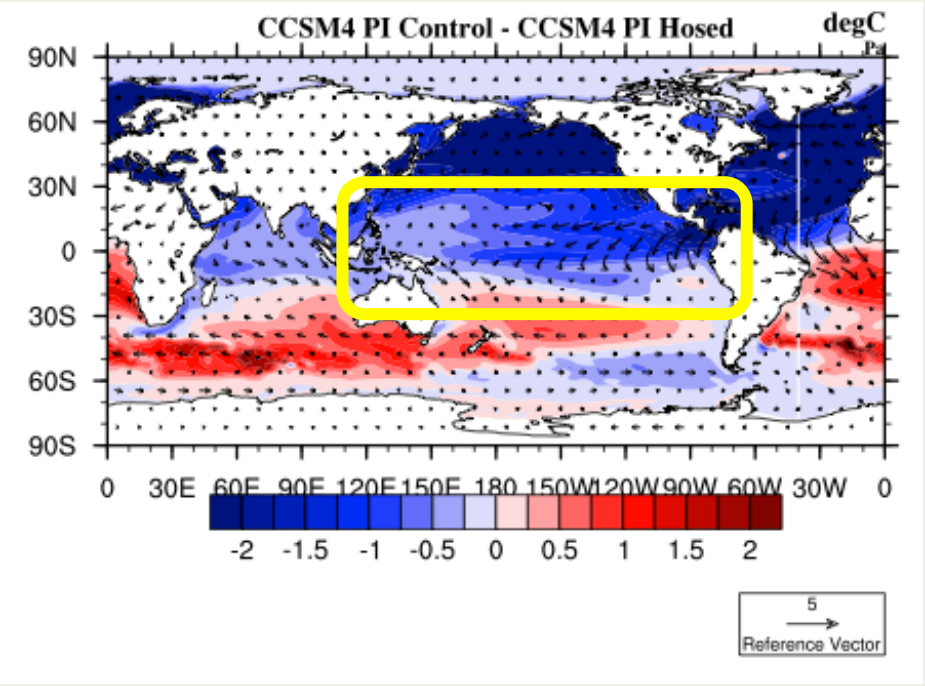
Non-flux corrected

Flux corrected

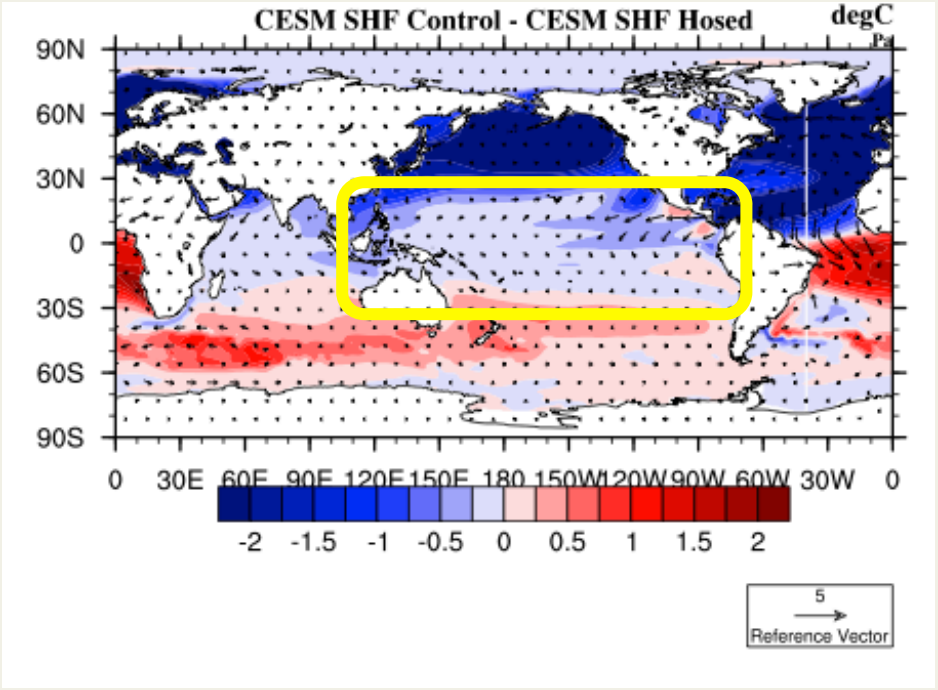


AMOC shutdown causes tropical Pacific cooling and incr. surface winds in EEP

Non-flux corrected: Hosed - Control



Flux Corrected: Hosed - Control

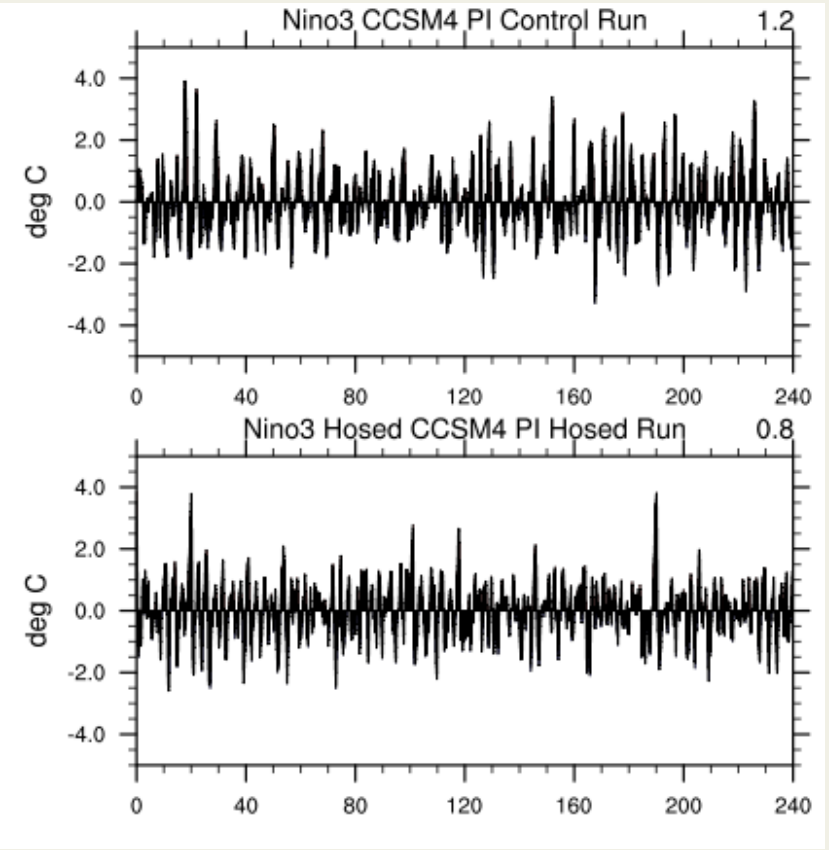


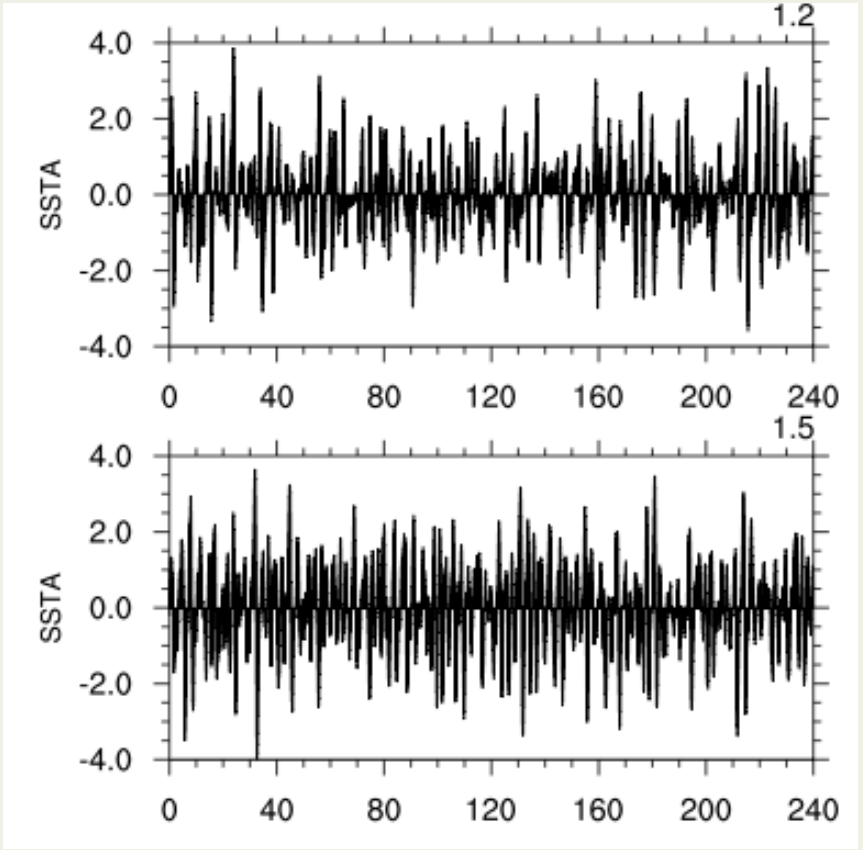
Tropical Pacific cooling much larger in non-flux corrected run

ENSO variance **decreases** under hosing in preindustrial run run but **increases** under hosing in flux corrected run

Non-flux corrected

Flux Corrected





Control

Hosed

ENSO response is highly sensitive to mean state biases in the tropical Pacific

Tool: LOAM

Linearized Ocean Atmosphere Model

(Thompson and Battisti, 2000)

- Linearized intermediate model of the tropical Pacific coupled atmosphere-ocean system (similar to Zebiak Cane Model)

- Input a prescribed climatological mean state (SST, surface winds, upper ocean currents, and upwelling)

-Describes anomalies about the mean state

LOAM: Model Formulation

$$\frac{\partial T}{\partial t} = -u_1 \frac{\partial}{\partial x}\overline{T} - v_1 \frac{\partial}{\partial y}\overline{T} - \left[\overline{u_1}\frac{\partial}{\partial x} + \overline{v_1}\frac{\partial}{\partial y}\right]T$$
$$- K_w(x,y)w_1 - K_T(x,y)h - d(x,y)T,$$

Ocean thermodynamics

$$au - \beta y v + g'\frac{\partial h}{\partial x} = -\frac{\partial u}{\partial t} + K_S^x U + K_S^c V,$$

$$\beta y u + av + g'\frac{\partial h}{\partial y} = K_S^y V + K_S^c U,$$

forcing of upper layer currents and thermocline depth by winds

$$c_a^2\frac{\partial U}{\partial x} + c_a^2\frac{\partial V}{\partial y} + A\varphi = -K_Q T + K_C\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right)$$

Atm thermodynamics

Roberts and Battisti, 2011

LOAM: Evolution of System

$$d\mathbf{x}/dt = \mathbf{M}\mathbf{x} + F_N$$

$$d\mathbf{x}/dt = \mathbf{M}\mathbf{x}$$

$$\boxed{\mathbf{x}(t) = e^{\mathbf{M}t}\mathbf{x}(0) = \mathbf{R}x(0)}$$

x = state vector = [T u v w h]

R = propagator matrix

LOAM results consistent with ENSO response in CESM under hosing

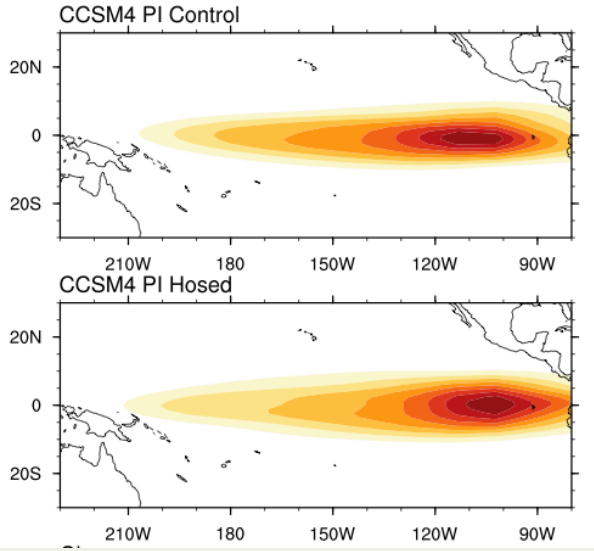
Non-flux corrected runs

Model	Mode Period (yr)	Mode Growth (yr^{-1})	Variance ($°C^2$)
CCSM4 *pi cont*			1.20
CCSM4 *hosed*			0.80
LOAM *pi cont*	3.19	0.63	1.20
LOAM *hosed*	3.07	0.43	0.62

ENSO Mode

Non-flux corrected LOAM **control run**

Non-flux corrected **hosed run**



ENSO variance **decreases** under hosing in non-flux corrected run

What mean field(s) are responsible for the increased stability of ENSO in the non-flux corrected hosing run?

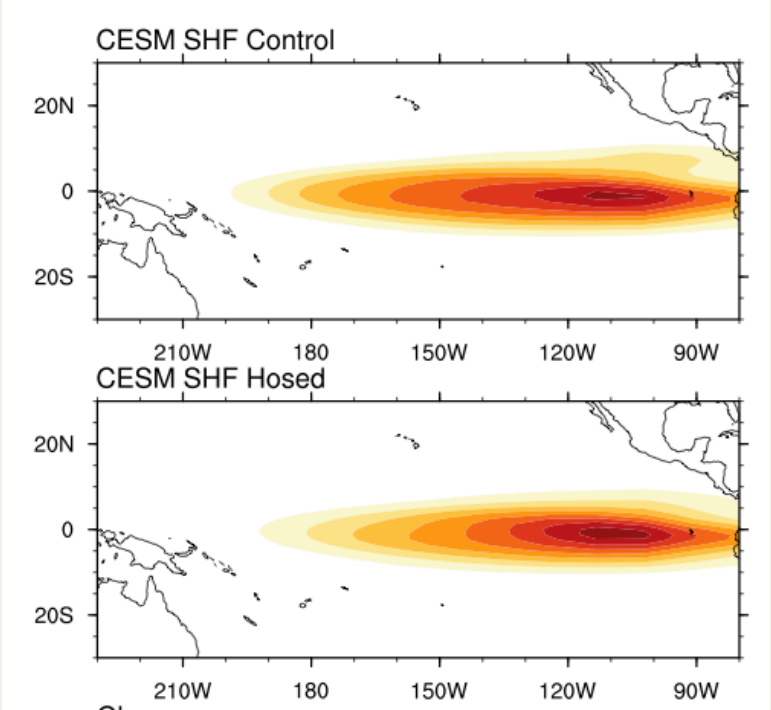
Model	Mode Period (yr)	Mode Growth (yr^{-1})	Variance ($°C^2$)
CCSM4 *pi*			1.20
CCSM4 *hosed*			0.80
LOAM *pi*	3.19	0.63	1.20
LOAM *hosed*	3.07	0.43	0.62
CCSM4 pi + SST	3.05	0.56	0.84
CCSM4 pi + currents	3.77	0.60	1.28
CCSM4 pi + winds	3.15	0.83	1.63
CCSM4 pi + subsfc temp	3.04	0.38	0.46

ENSO variance **decreases** due to combination of mean SST and subsurface temp changes

LOAM results consistent with ENSO response in CESM under hosing

Flux corrected runs

Model	Mode Period (yr)	Mode Growth (yr^{-1})	Variance ($°C^2$)
CESM *pi cont*			1.20
CCSM4 *hosed*			1.50
LOAM *pi cont*	3.23	0.59	1.18
LOAM *hosed*	3.42	0.64	1.36



LOAM control run: flux corrected

LOAM hosed run: flux corrected

ENSO variance **increases** under hosing in flux corrected run

What mean field(s) are responsible for the increased stability of ENSO in the non-flux corrected hosing run?

Model	Mode Period (yr)	Mode Growth (yr^{-1})	Variance ($°C^2$)
CCSM4 *pi*			1.20
CCSM4 *hosed*			0.80
LOAM *pi*	3.23	0.59	1.18
LOAM *hosed*	3.42	0.64	1.36
CCSM4 pi + SST	3.23	0.58	1.18
CCSM4 pi + currents	3.63	0.65	1.57
CCSM4 pi + winds	3.02	0.59	1.09
CCSM4 pi + subsfc temp	3.32	0.58	1.16

ENSO variance **increases** due to changes in mean upwelling and ocean currents

Conclusions

- ENSO response is well-represented by the influence of mean state changes under hosing on linear ENSO dynamics

- ENSO response to hosing:
  - **decreases** in CCSM4 w/out flux corrections due to colder SSTs and changes in the mean subsurface temperatures
  - **increases** in CCSM4 w/ flux corrections due to changes in mean upwelling and ocean currents

- Response of ENSO to AMOC shutdown is sensitive to mean state biases in the tropical Pacific

Next Steps

- Better characterize the mechanisms responsible for the mean state changes and ENSO in CESM
- Assess sensitivity of ENSO response to different hosing magnitudes
  - Initial results say yes!
- Use LOAM to evaluate ENSO response after remove tropical Pacific mean state biases by adding changes to obs. climatology

Thank you!

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