Equatorial-extratropical dipole structure of the Atlantic Niño

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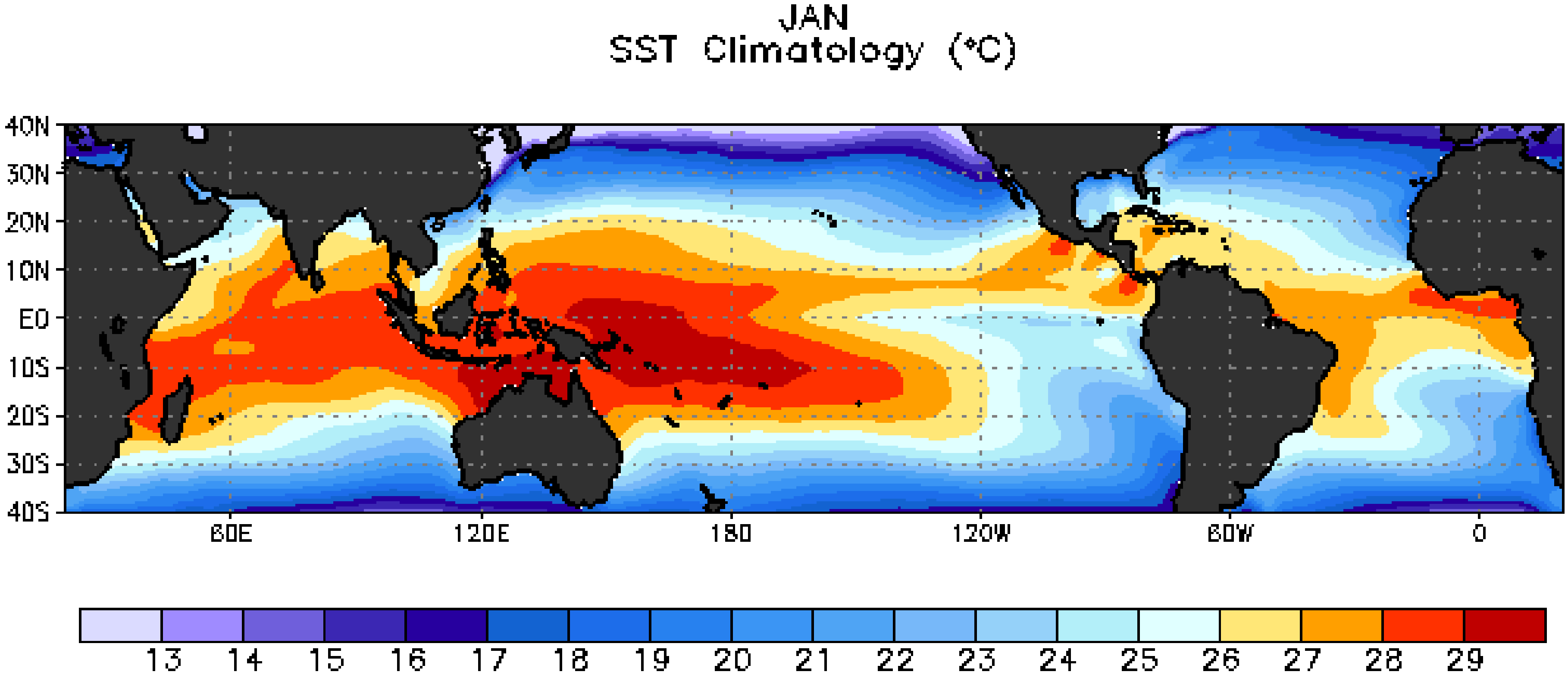
Outline

- Background
- Thermodynamic origins, and;
- Equatorial-extratropical dipole structure of the Atlantic Niño
- Summary

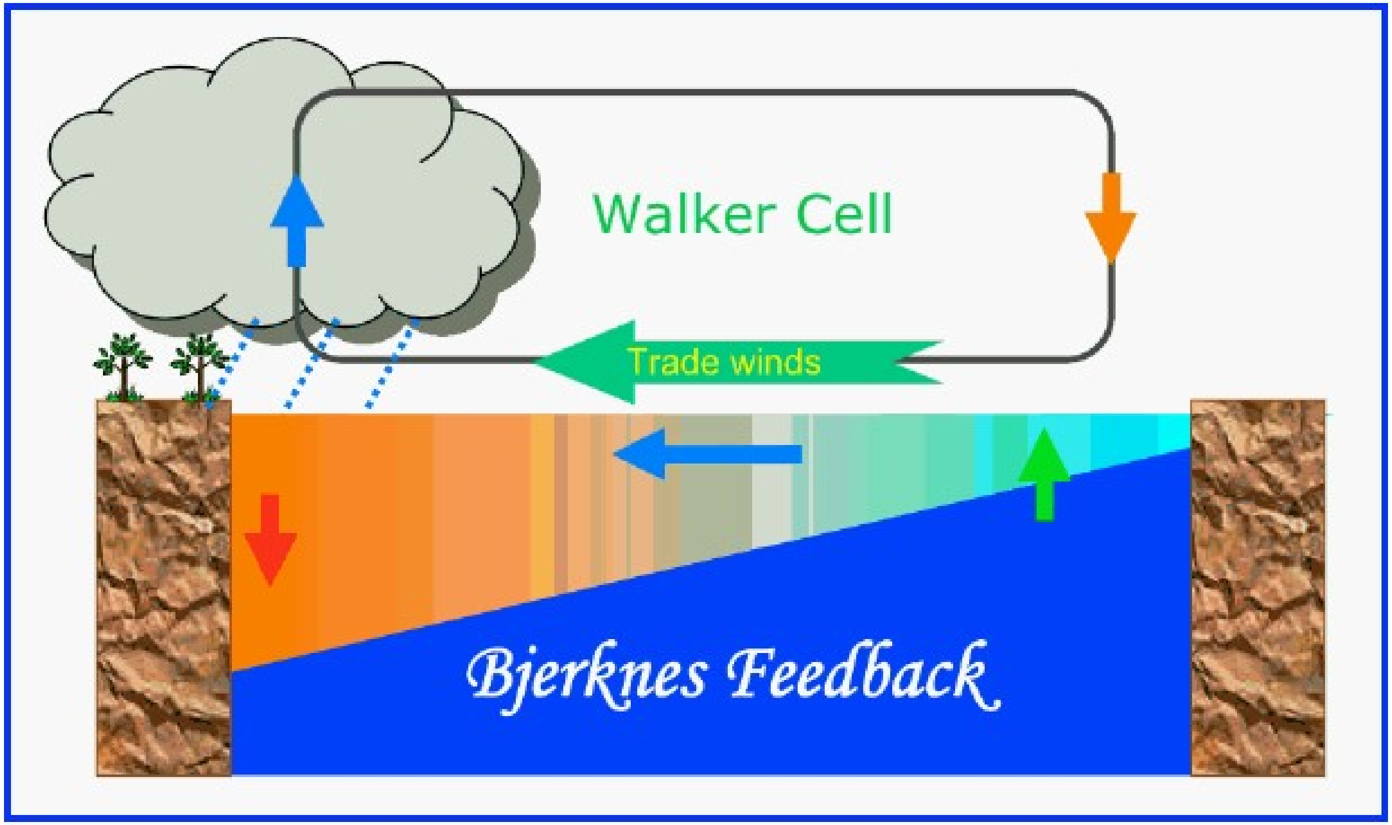
Equatorial Atlantic in Global Context

Striking similarities between equatorial Pacific and Atlantic oceans.

Upwelling similar to the Pacific ***<u>but peaking in boreal summer</u>***



From **M L'Heureux**



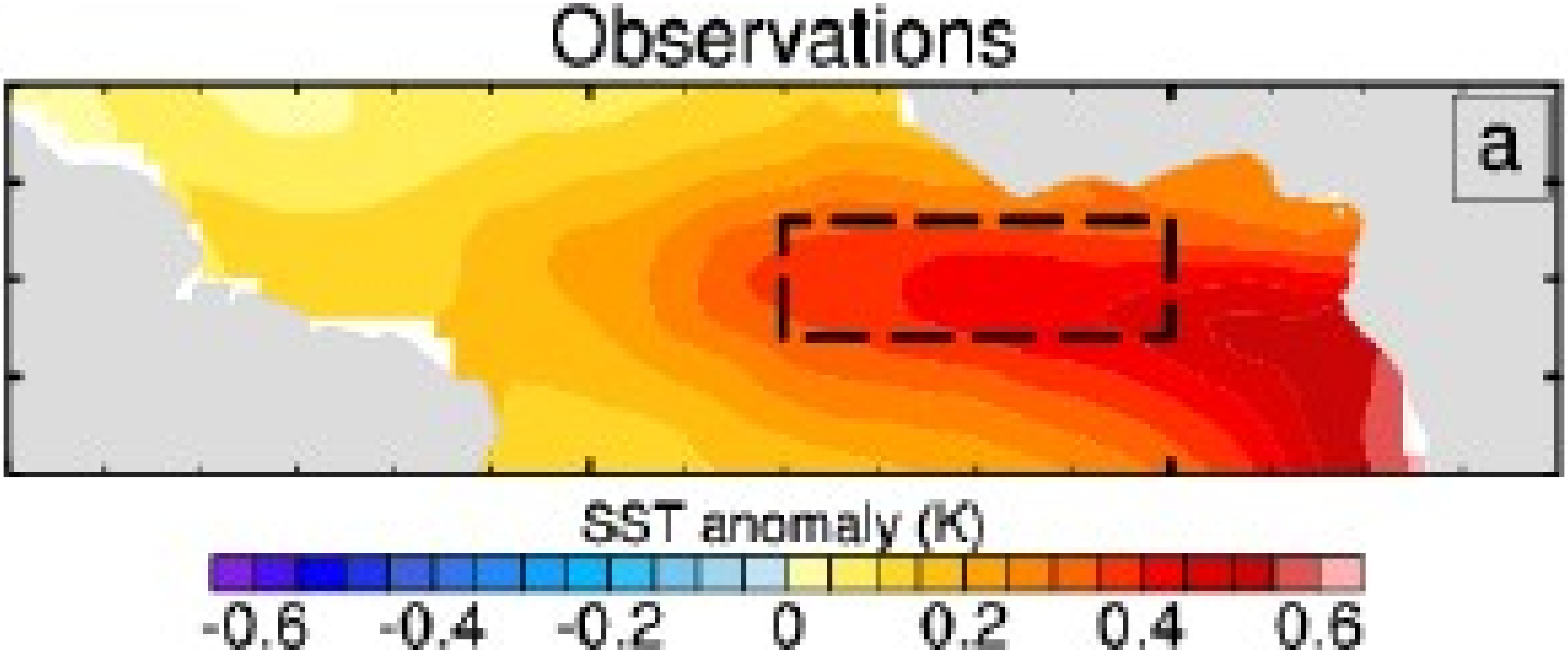
From **S-P Xie**

Atmospheric component: strong convection confined to the warmer western basin creates east-west pressure gradient which drives equatorial easterlies.

Oceanic component: The easterlies shoal the thermocline, induces upwelling keeping the eastern basin cool.

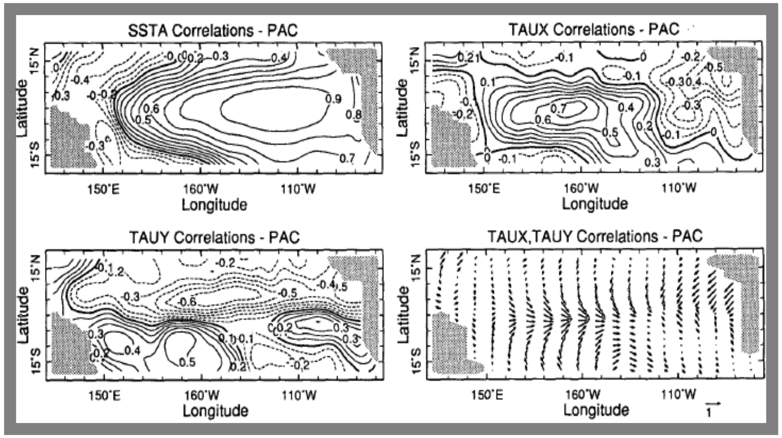
Coupled system: The oceanic and atmospheric processes constitute a fully coupled system and may only be fully understood as such.

El Niño-type SST “anomalies”

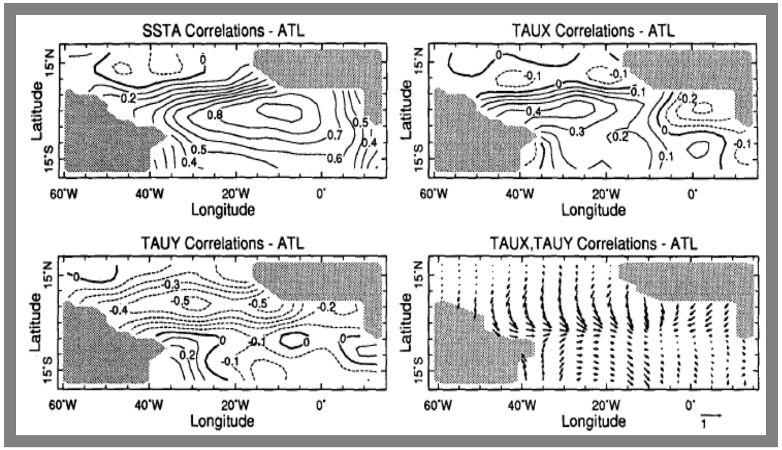


Bjerknes theory in Pacific and Atlantic Oceans

Pacific Ocean



Atlantic Ocean



From: Zebiak, 1993; J. Climate.

-Bjerknes coupling is ~50% weaker in the Atlantic Ocean.

-Atlantic Niño amplitude is weaker, typically ~0.5K.

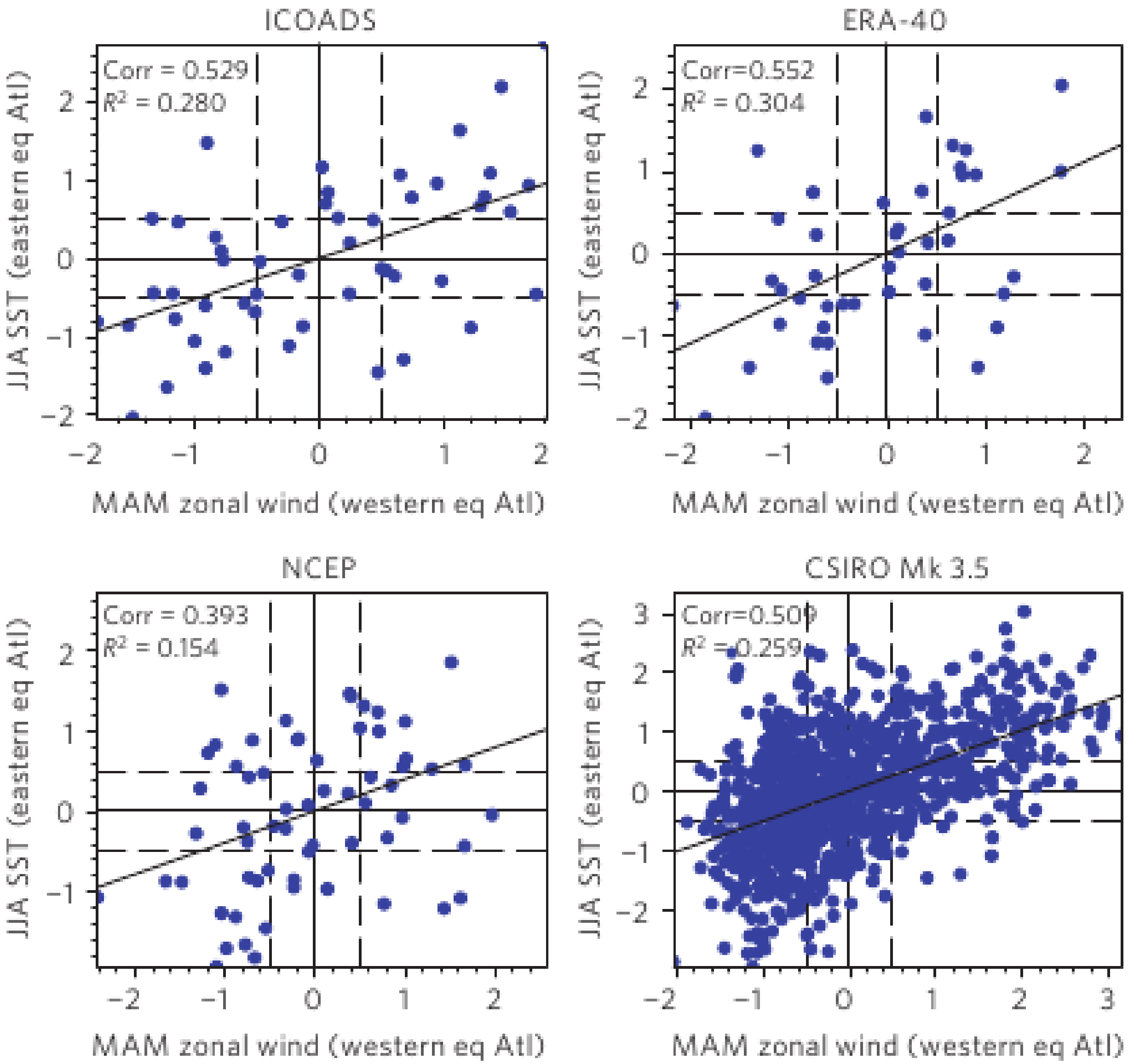
-Atlantic Niño peaks in boreal summer (June-July-August), Pacific El Niño peaks in winter (December-January-February).

-Atlantic Nino is more frequent ~1.6-4.5 yr.

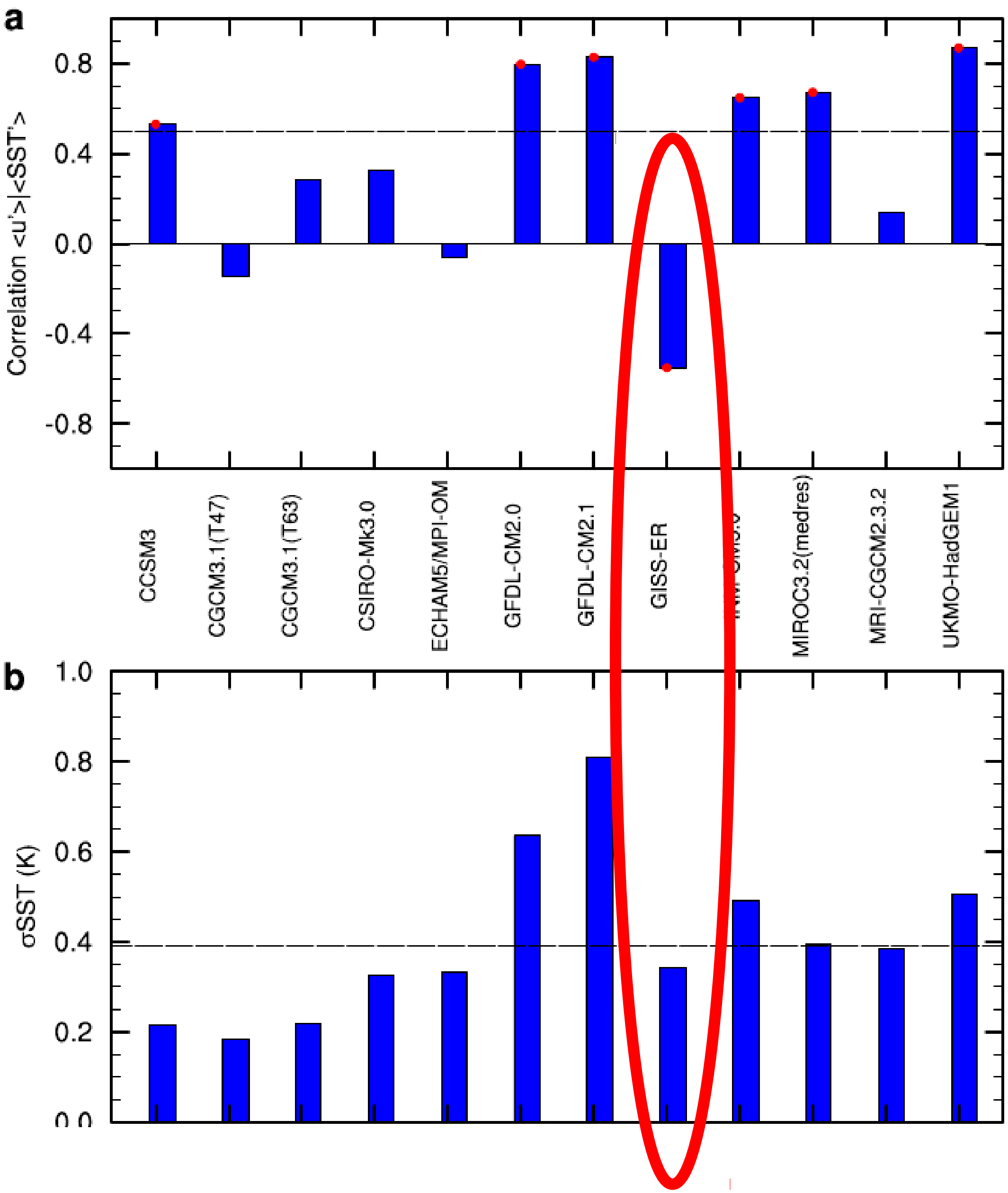
-Etc.

Weak Bjerknes feedback

- Zonal winds {*u*}' preconditioning can explain only ~15-35% of the observed Atlantic Niño *(Richter et al., 2013, Nature Geoscience)*.

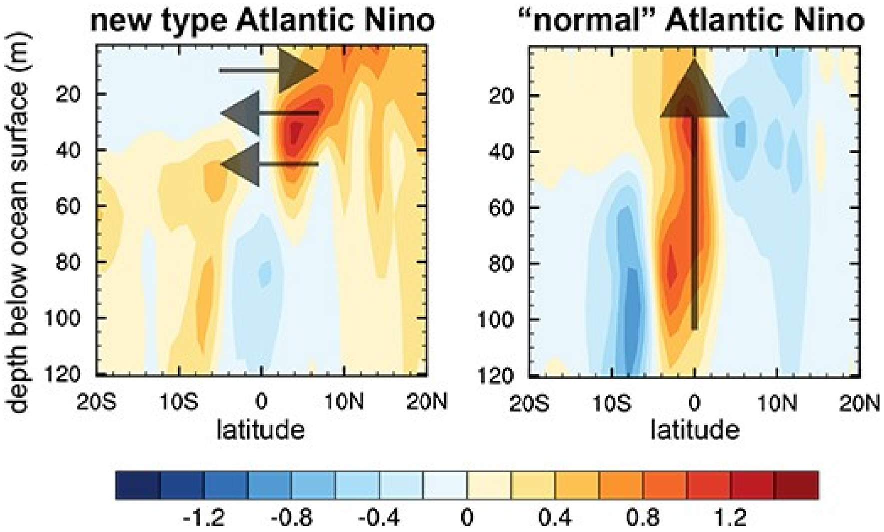


Bjerknes feedbacks not required *in models*?

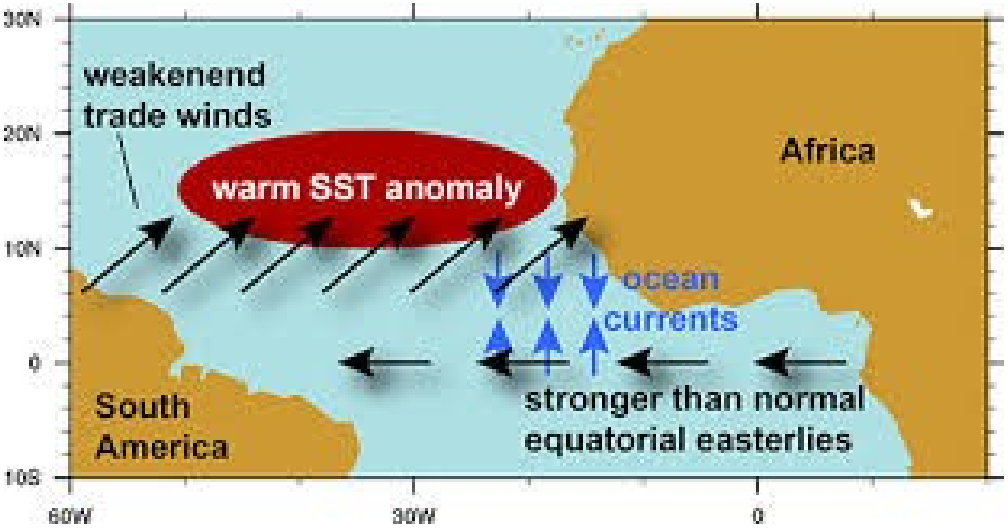


From Nnamchi *et al.*, 2015

Meridional advection

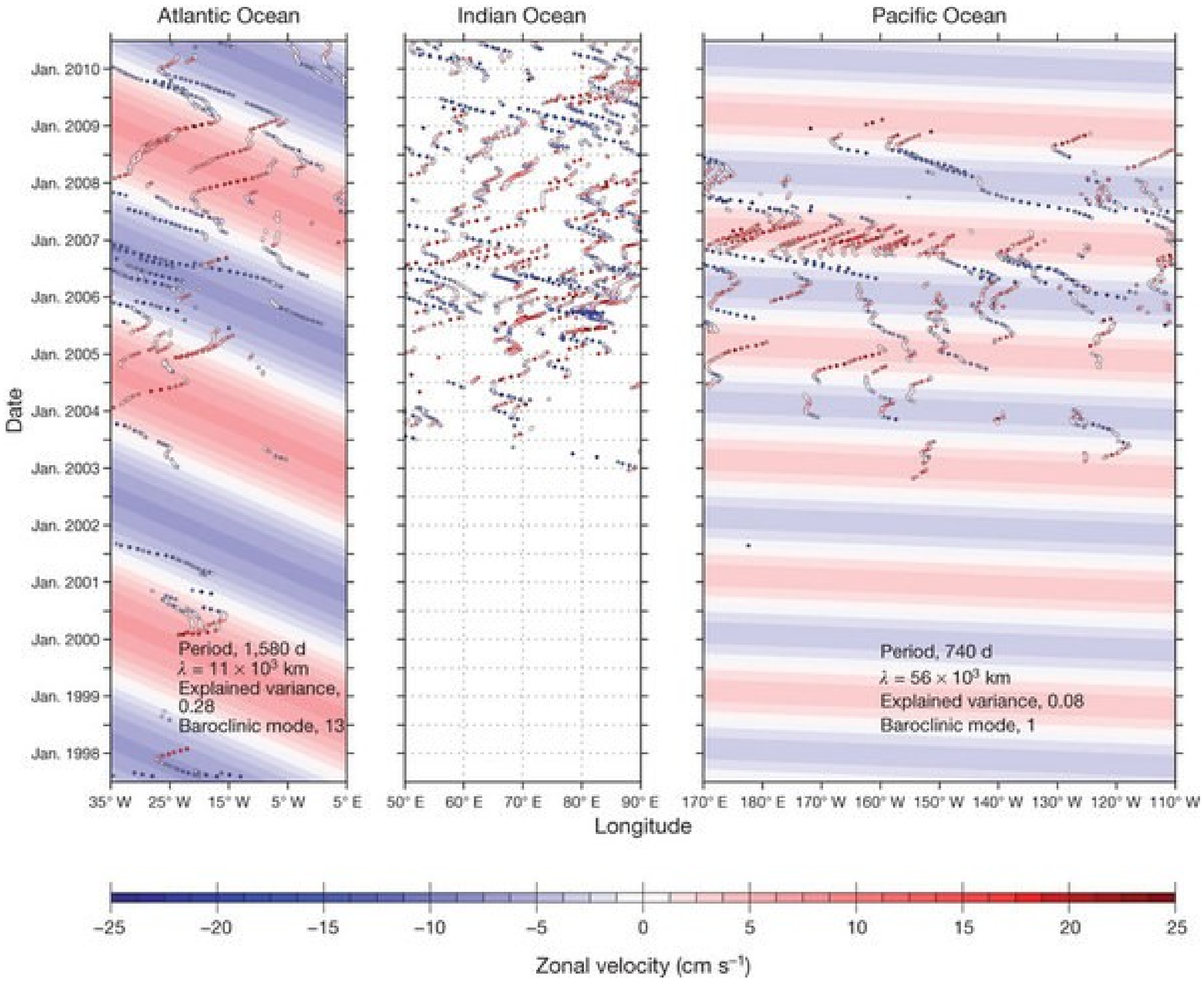


- **New Atlantic Niño:** **driven by mixed layer temperature advection from north tropical Atlantic Ocean.**



***Richter et al., 2013, Nature Geoscience*.**

Equatorial Kelvin waves



Equatorial Atlantic Kelvin waves: deep zonal jets oscillate at 4.5yrs causing Atlantic Niño SST anomalies. Similar jets in Indian and Pacific oceans do not oscillation on interannual time scales.

Brandt et al., 2011, Nature

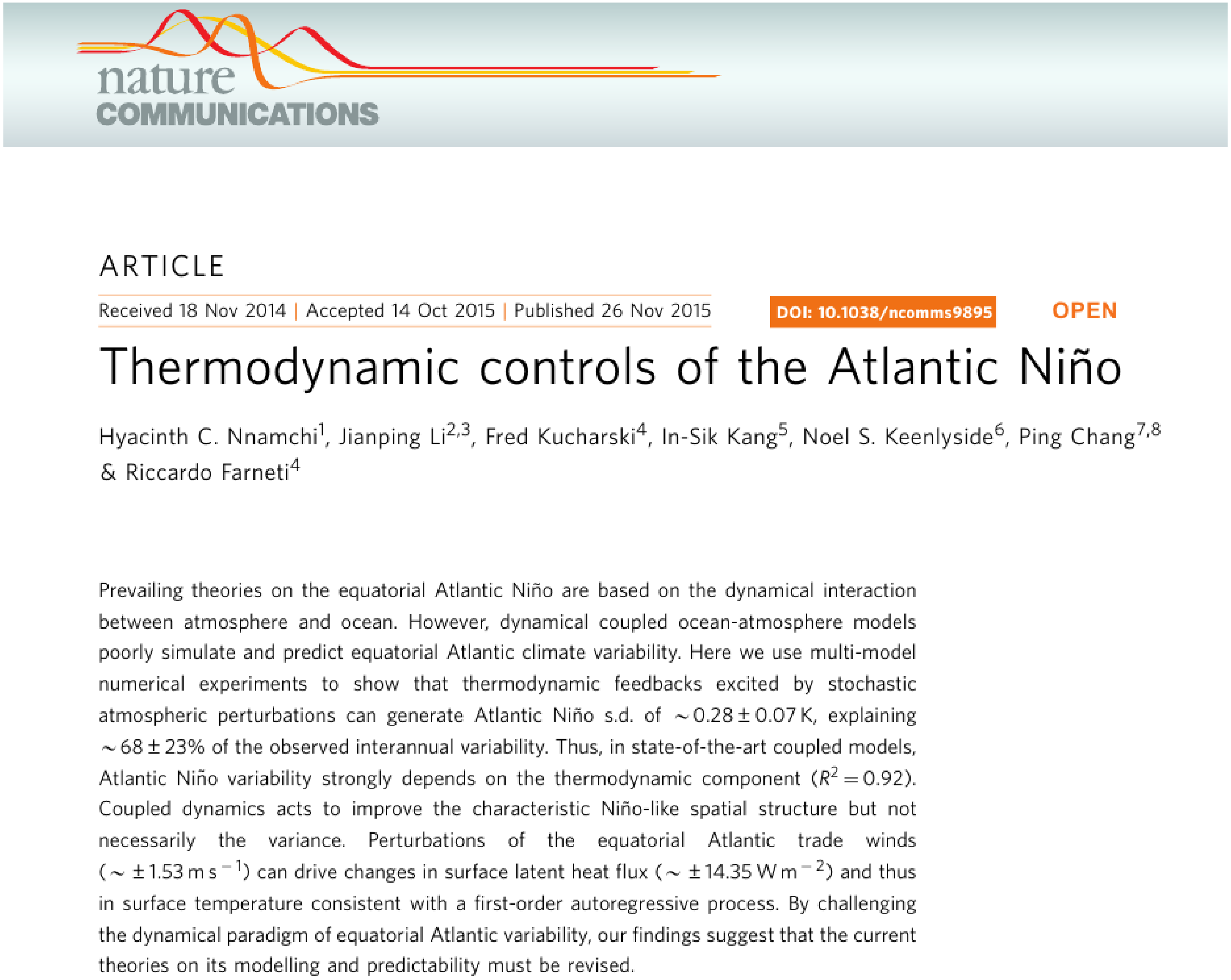
Current theories: based on dynamical feedbacks

+Bjerknes feedback
+Meridional advection
+Equatorial Kelvin waves

How important is ***dynamical*** coupling between the ocean and atmosphere for equatorial Atlantic variability?

Thermodynamic origins of the Atlantic Niño

Part 1:



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Thermodynamic controls of the Atlantic Niño

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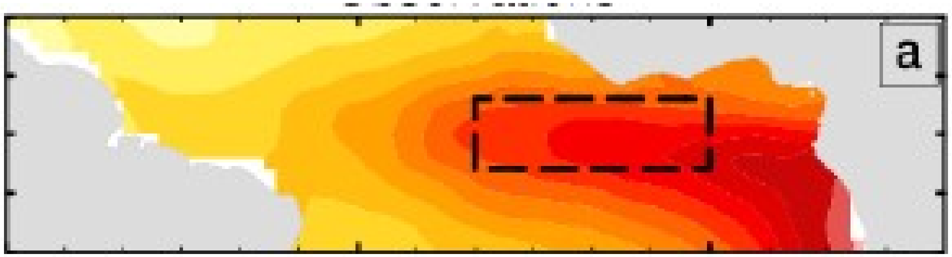
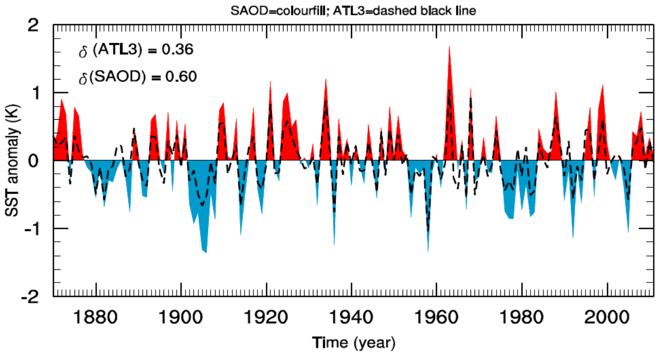
Prevailing theories on the equatorial Atlantic Niño are based on the dynamical interaction between atmosphere and ocean. However, dynamical coupled ocean-atmosphere models poorly simulate and predict equatorial Atlantic climate variability. Here we use multi-model numerical experiments to show that thermodynamic feedbacks excited by stochastic atmospheric perturbations can generate Atlantic Niño s.d. of $\sim 0.28 \pm 0.07$ K, explaining $\sim 68 \pm 23\%$ of the observed interannual variability. Thus, in state-of-the-art coupled models, Atlantic Niño variability strongly depends on the thermodynamic component ($R^2 = 0.92$). Coupled dynamics acts to improve the characteristic Niño-like spatial structure but not necessarily the variance. Perturbations of the equatorial Atlantic trade winds ($\sim \pm 1.53\,\mathrm{m\,s^{-1}}$) can drive changes in surface latent heat flux ($\sim \pm 14.35\,\mathrm{W\,m^{-2}}$) and thus in surface temperature consistent with a first-order autoregressive process. By challenging the dynamical paradigm of equatorial Atlantic variability, our findings suggest that the current theories on its modelling and predictability must be revised.

Understanding SST variability

In space



In time



$$\frac{\partial[T]}{\partial t} = -\left[u\frac{\partial T}{\partial x}\right] - \left[v\frac{\partial T}{\partial y}\right] - \left[w\frac{\partial T}{\partial z}\right] + \frac{Q_{SW}-Q_{LW}-Q_{LH}-Q_{SH}}{\rho C_w h} + R$$

ρ, sea water density; *Cw,* specific heat constant pressure; *h,* ocean mixed layer depth; *Qnet,* net radiation; R, unresolved physical processes (e.g., diffusion, entrainment at the base of the mixed layer, turbulent mixing etc.)

$$[\bullet] = \frac{1}{h}\int_0^h \bullet \, dz$$

How important is ocean dynamics?

Two levels of ocean-atmosphere coupling

1. Fully coupled model (dynamics + thermodynamics)

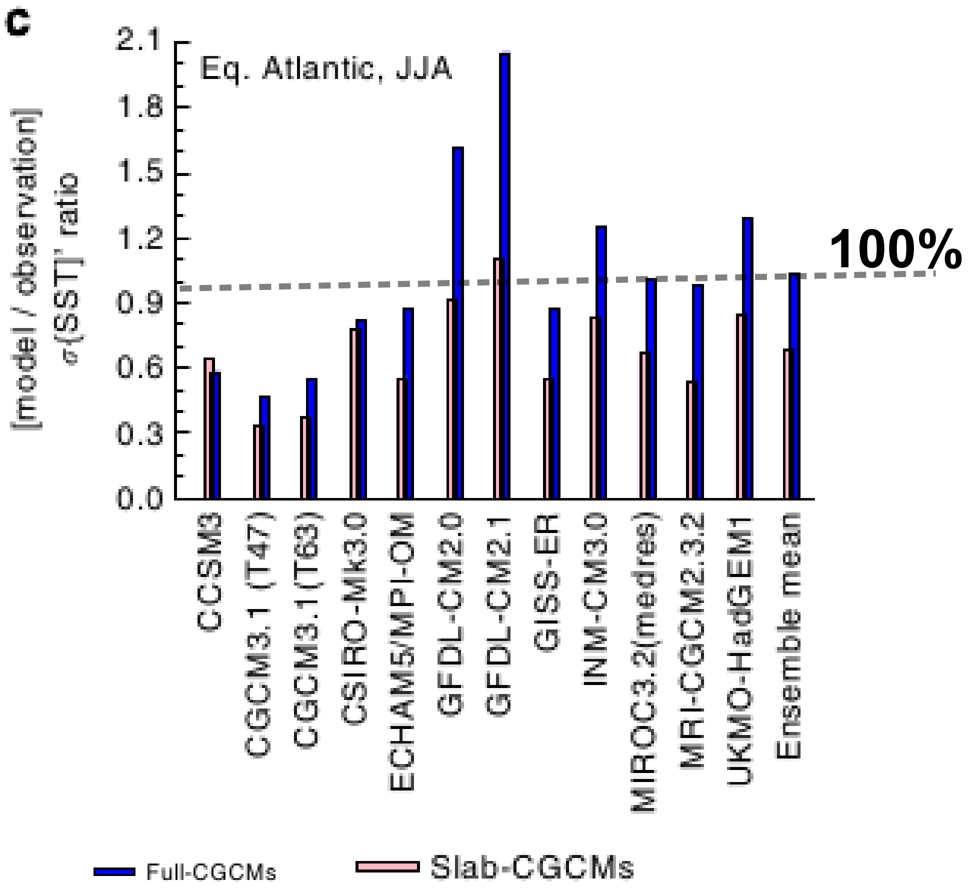
$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z} + \frac{Q_{SW} - Q_{LW} - Q_{LH} - Q_{SH}}{\rho C_w h} + R$$

2. Thermodynamic coupled model

$$\frac{\partial T}{\partial t} = \frac{Q_{SW} - Q_{LW} - Q_{LH} - Q_{SH}}{\rho C_w h} + Q_{flux}$$

***Qflux*, climatological-mean ocean heat flux.**

How important is ocean dynamics?

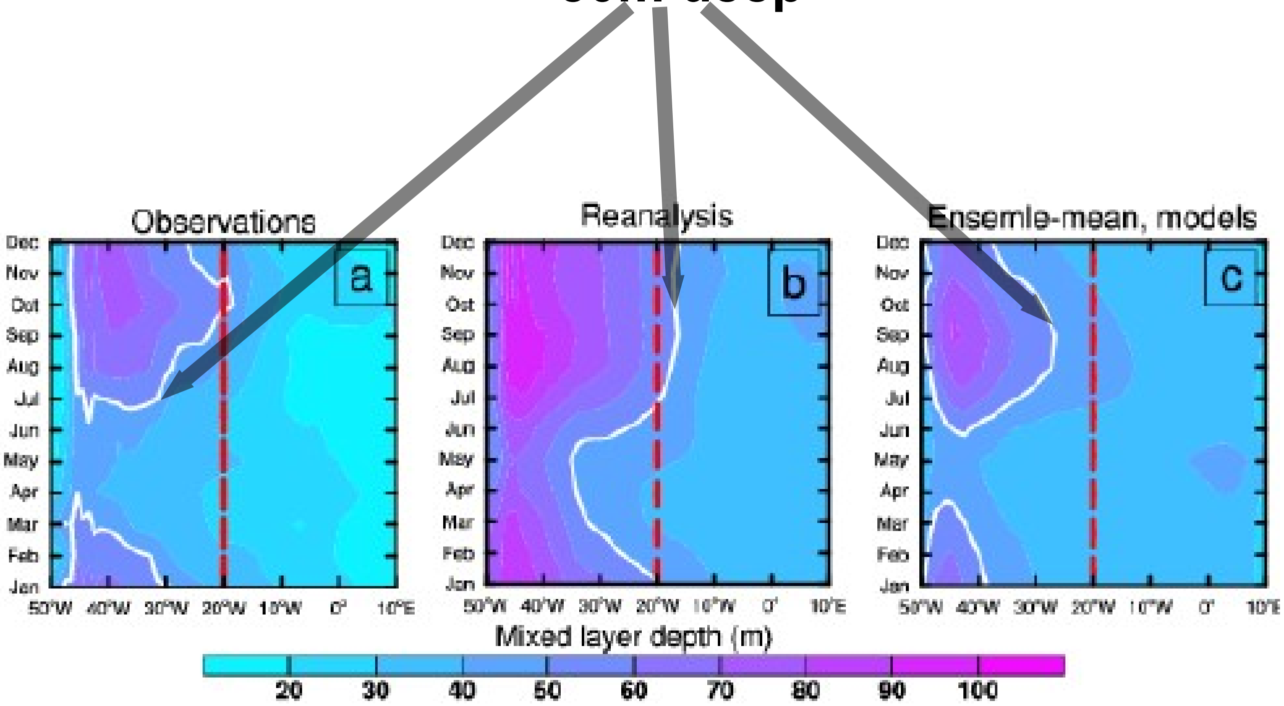


-Slab models simulate ~68±23% of the observed

Ocean Mixed Layer Depths

<u>Temperature criterion:</u> depth at which temperature of the ocean is 0.5 K less than the value at the surface.

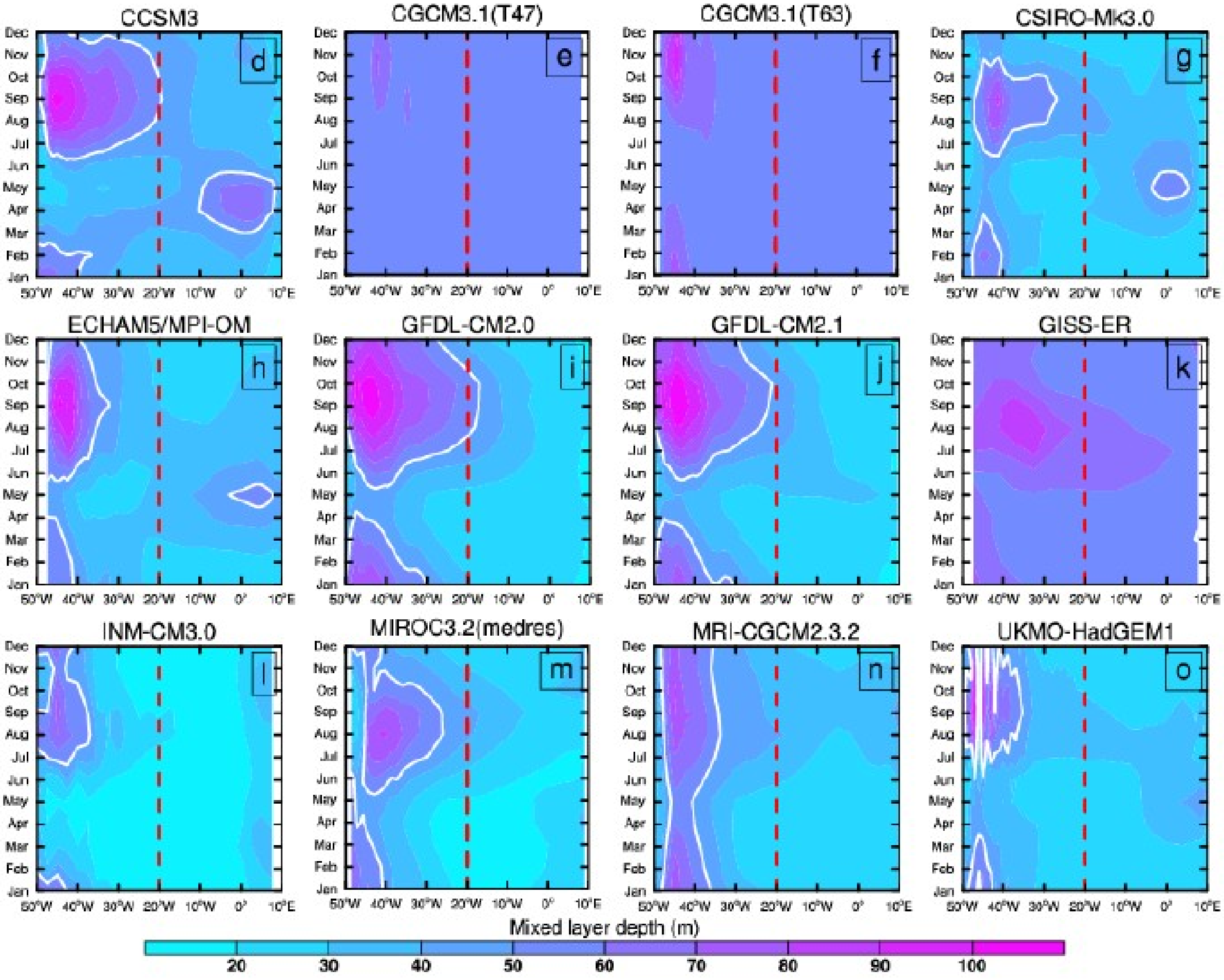
50m deep



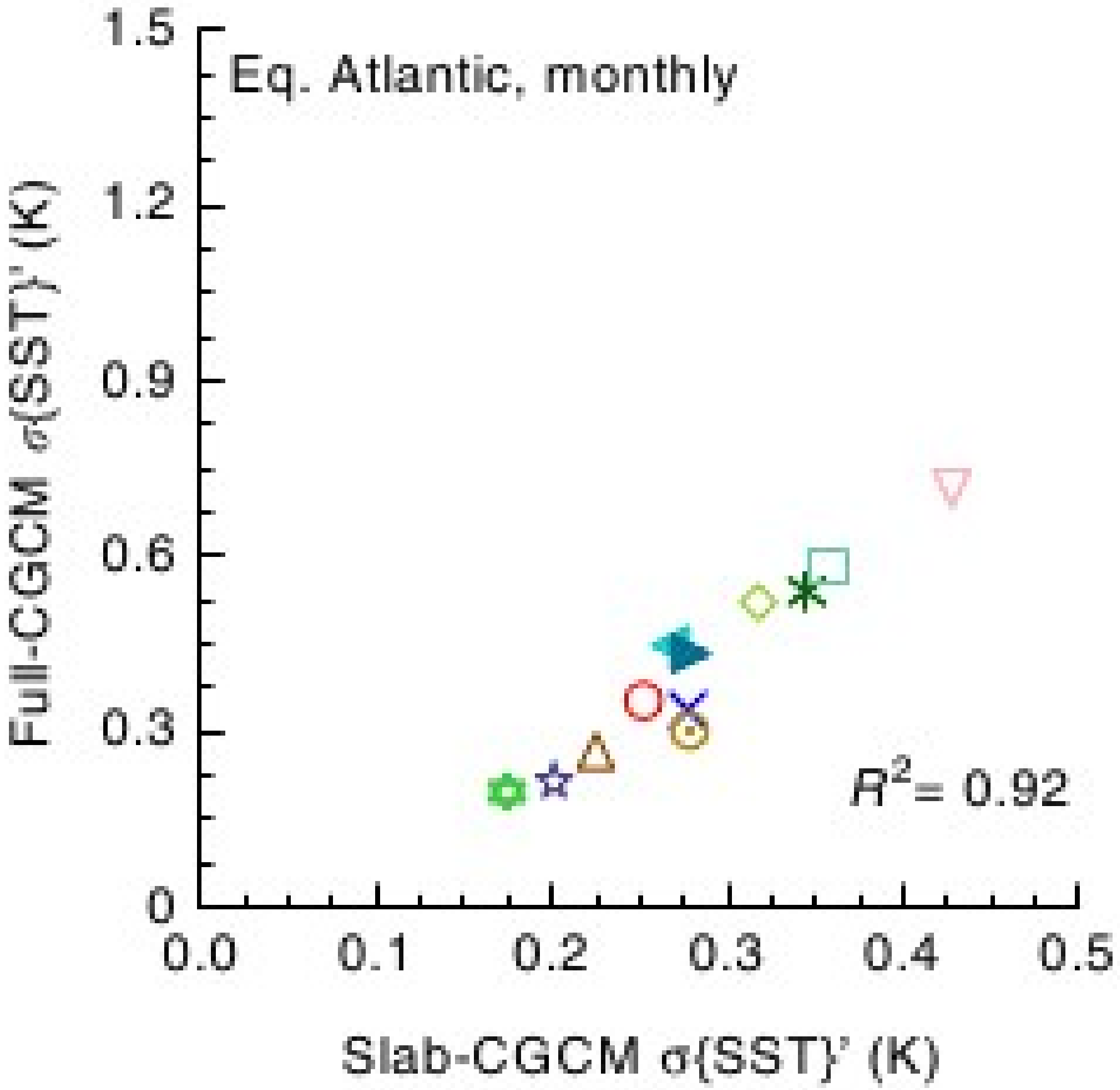
$$\frac{\partial T}{\partial t} = \frac{Q_{net}}{\rho h C_w}$$

Mixed layer in equatorial Atlantic (3°N-3°S) is actually shallower than assumed in the slab models !

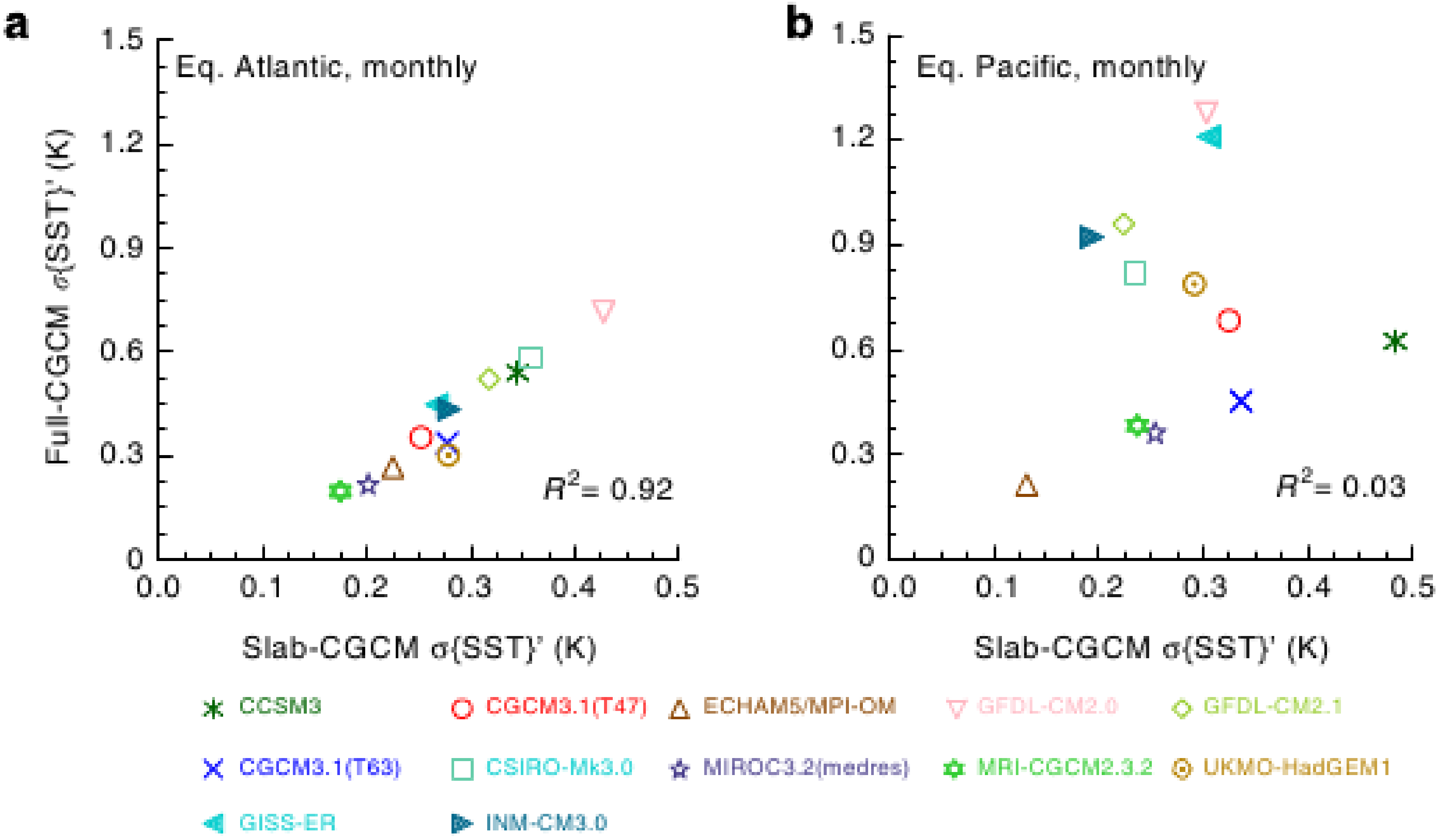
MLD in individual models



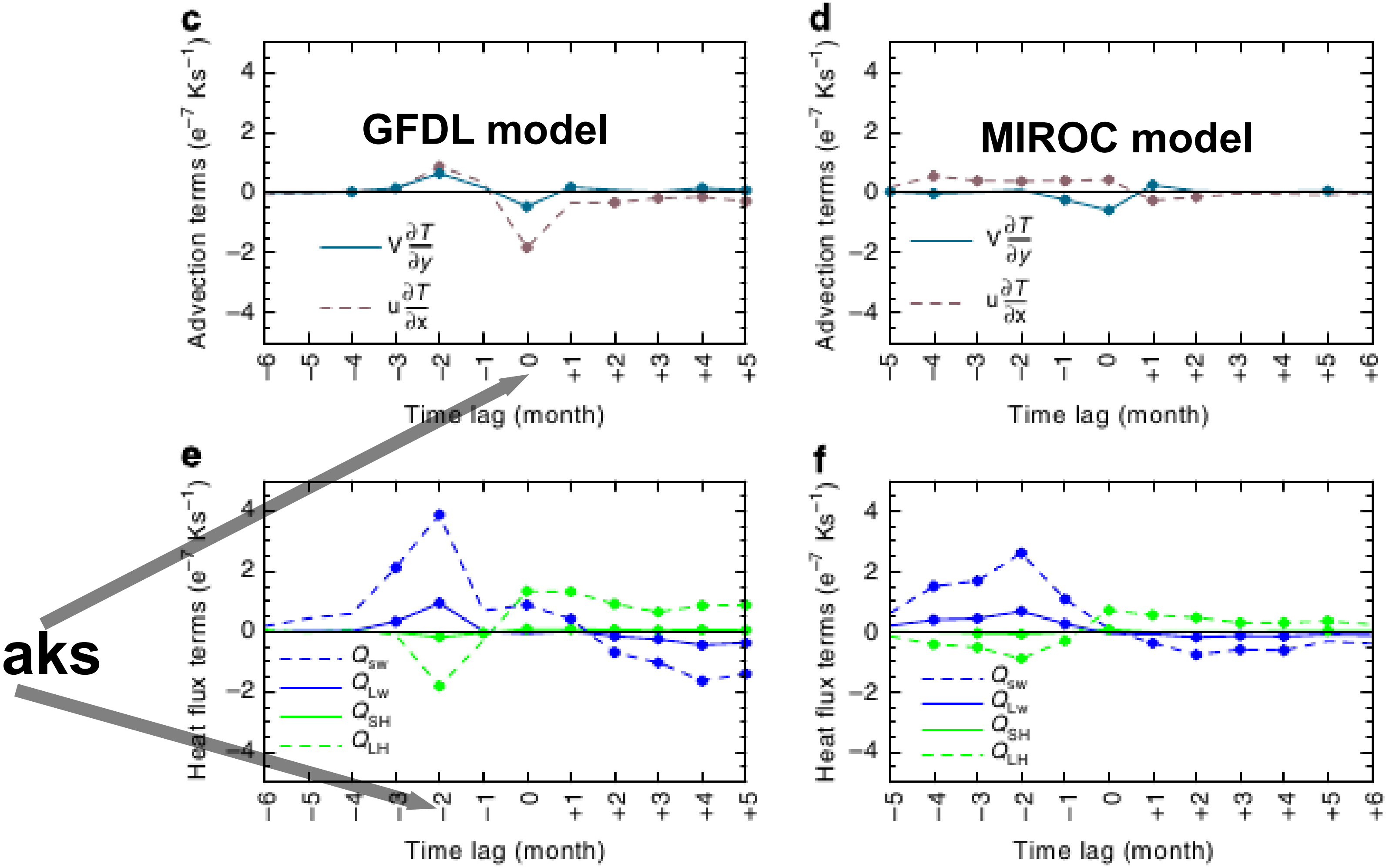
Atlantic Niño: a linear function of thermodynamic feedbacks



Atlantic Niño: a linear function of thermodynamic feedbacks



Ocean mixed layer heat budget

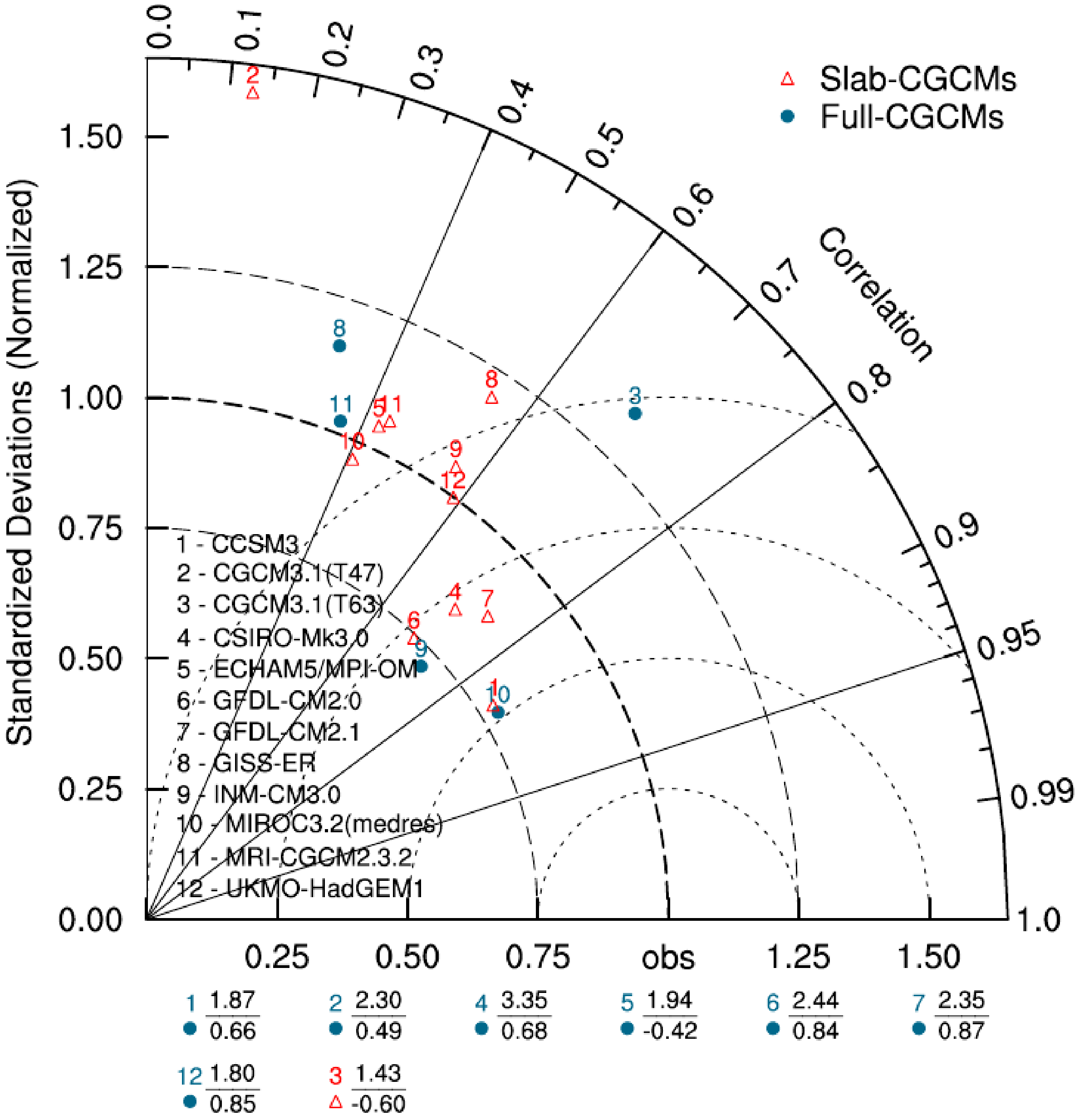


Peaks

$$\frac{\partial [T]}{\partial t} = -\left[u\frac{\partial T}{\partial x}\right] - \left[v\frac{\partial T}{\partial y}\right] - \left[w\frac{\partial T}{\partial z}\right] + \frac{Q_{SW} - Q_{LW} - Q_{LH} - Q_{SH}}{\rho C_w h} + R$$

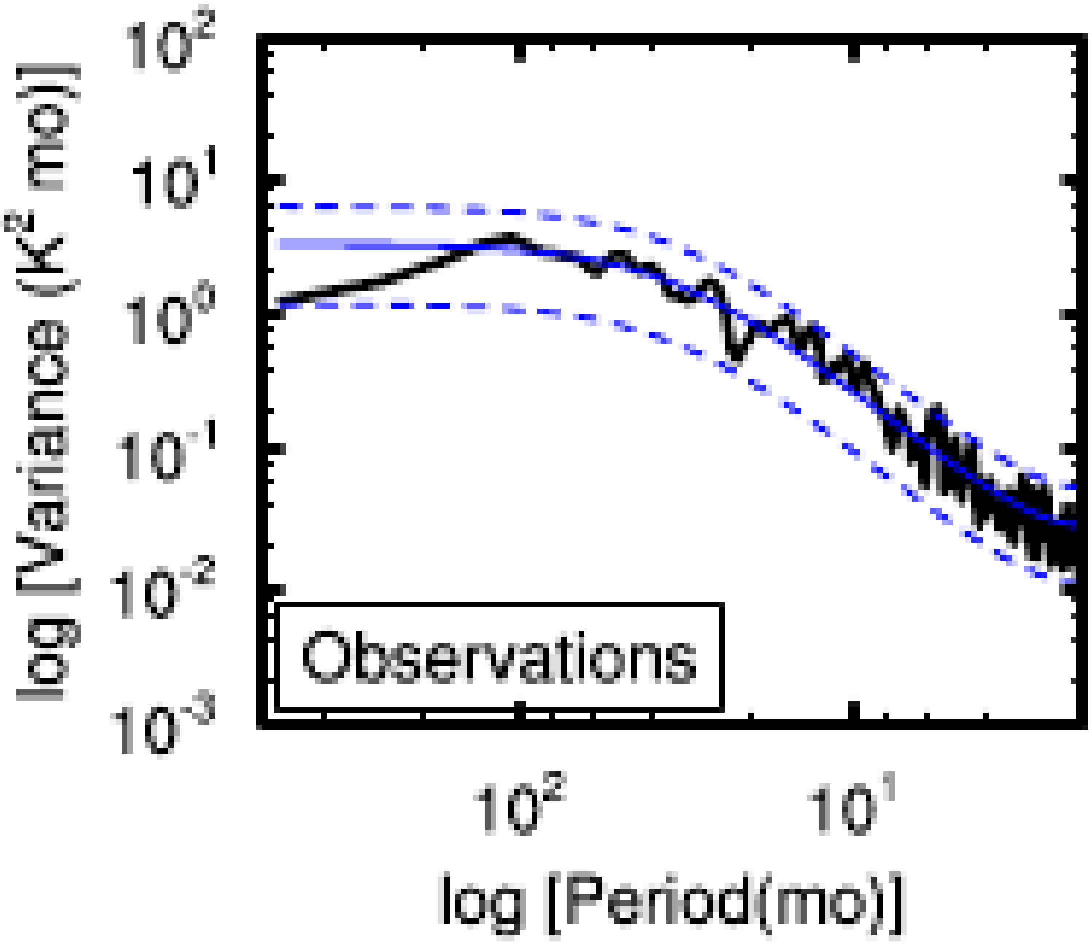
Heat flux terms *lead* ocean dynamics terms

Spatial structure of Atlantic Niño



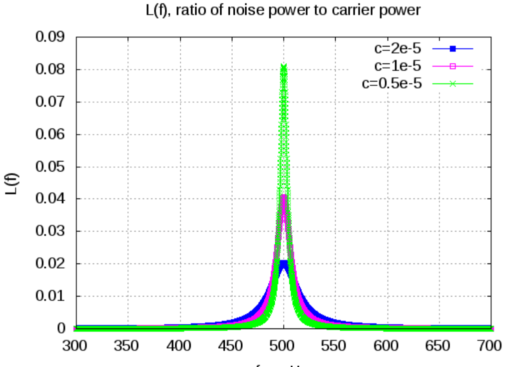
Fully coupled models *are no better than* the slab models in reproducing the spatial pattern of equatorial Atlantic (10°N-10°S) SST anomalies.

Atlantic Niño: a red noise (AR-1) process

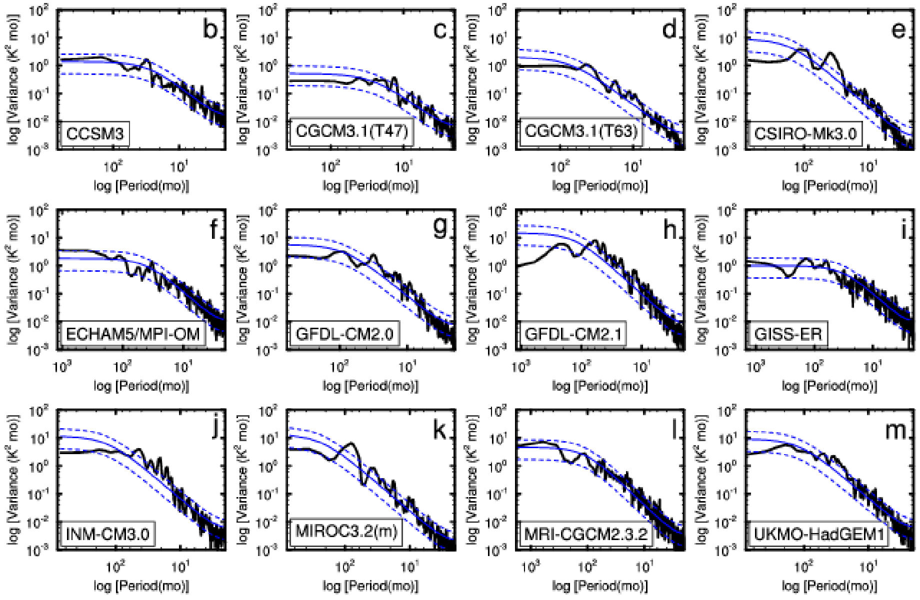


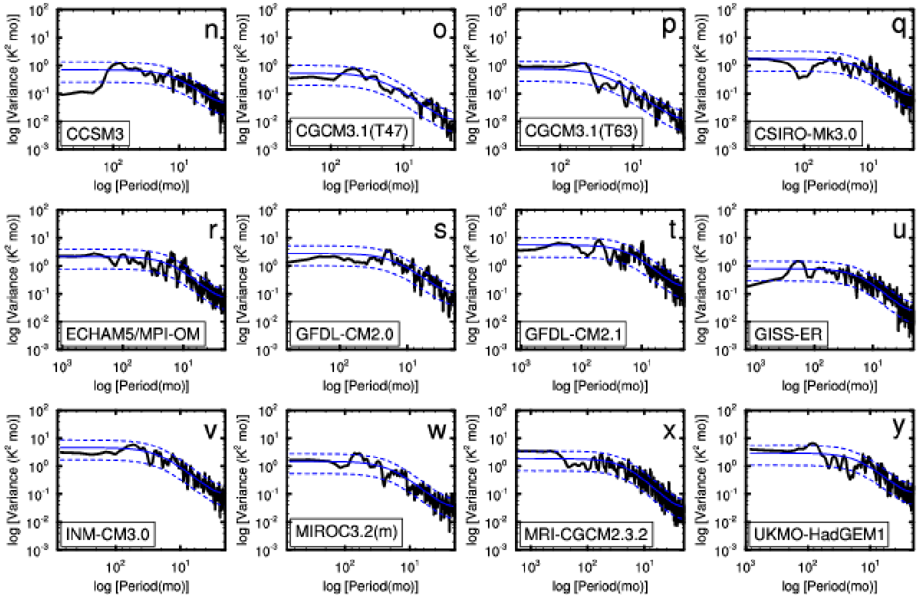
Nnamchi et al. 2015, *Nature Communications*

Dynamical oscillation



Atlantic Niño:
a red noise
(AR-1) process


Thermodynamic-only coupled models


Fully coupled models

Extratropical connections: *dipole structure of the Atlantic Niño*

Part 2:

An Equatorial–Extratropical Dipole Structure of the Atlantic Niño

HYACINTH C. NNAMCHI,[a] JIANPING LI,[b] FRED KUCHARSKI,[c] IN-SIK KANG,[d,e]
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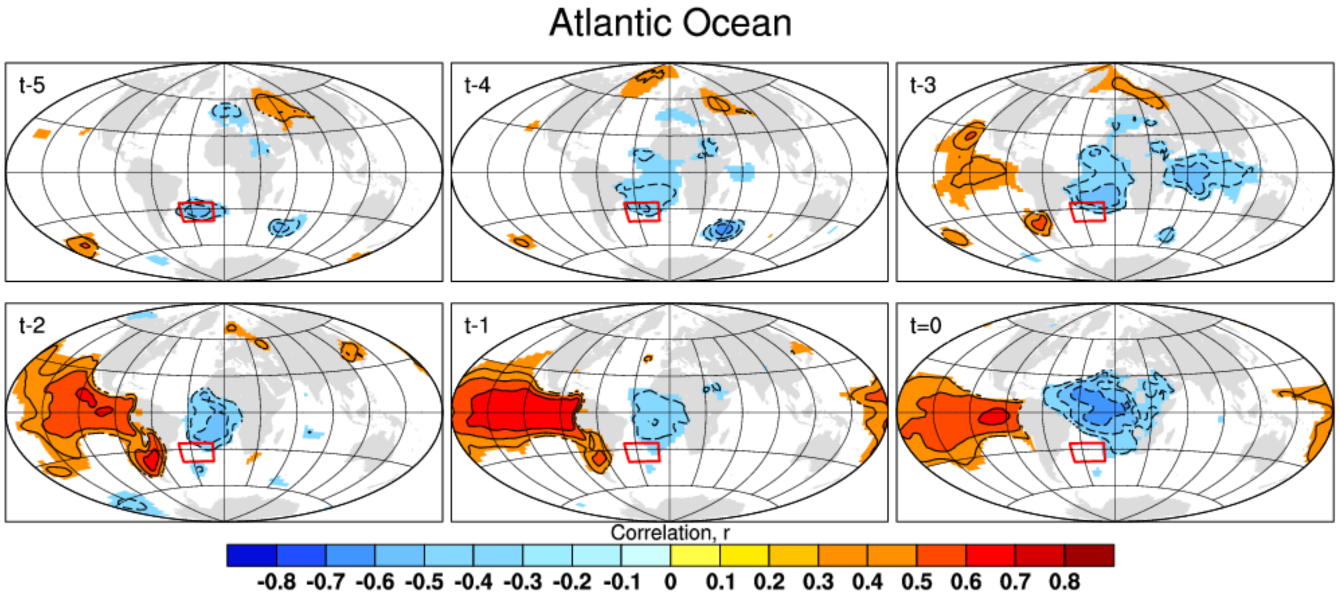
ABSTRACT

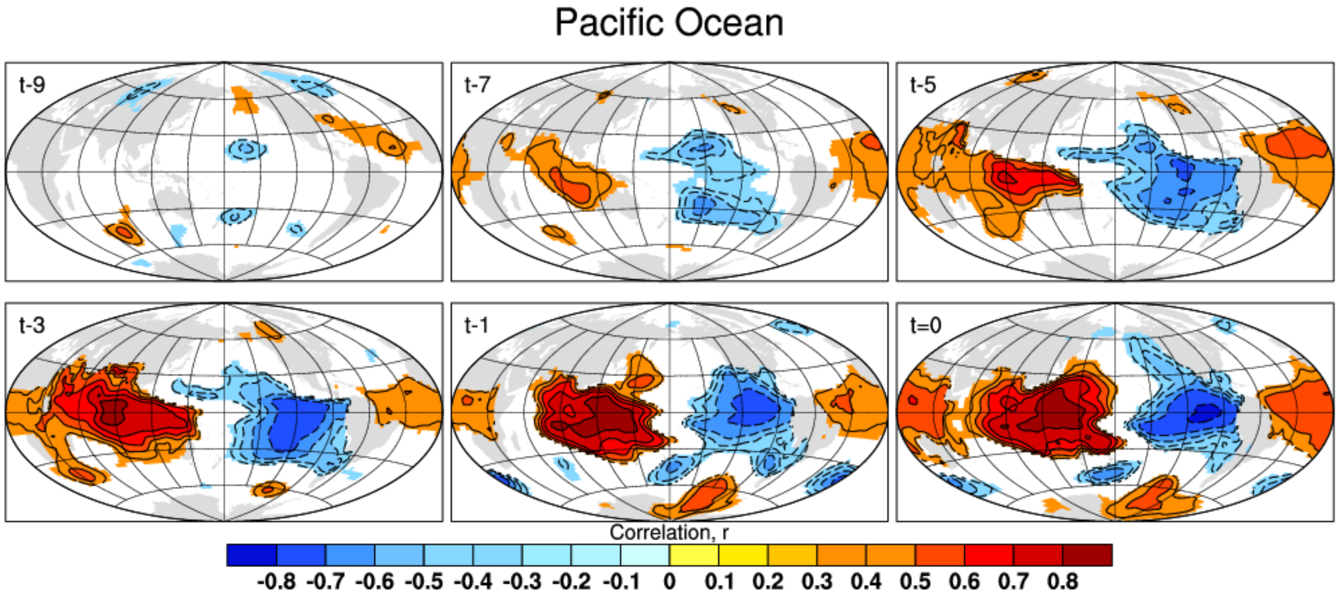
Equatorial Atlantic variability is dominated by the Atlantic Niño peaking during the boreal summer. Studies have shown robust links of the Atlantic Niño to fluctuations of the St. Helena subtropical anticyclone and Benguela Niño events. Furthermore, the occurrence of opposite sea surface temperature (SST) anomalies in the eastern equatorial and southwestern extratropical South Atlantic Ocean (SAO), also peaking in boreal summer, has recently been identified and termed the SAO dipole (SAOD). However, the extent to which and how the Atlantic Niño and SAOD are related remain unclear. Here, an analysis of historical observations reveals the Atlantic Niño as a possible intrinsic equatorial arm of the SAOD. Specifically, the observed sporadic equatorial warming characteristic of the Atlantic Niño ($\sim$0.4 K) is consistently linked to southwestern cooling (~ -0.4 K) of the Atlantic Ocean during the boreal summer. Heat budget calculations show that the SAOD is largely driven by the surface net heat flux anomalies while ocean dynamics may be of secondary importance. Perturbations of the St. Helena anticyclone appear to be the dominant mechanism triggering the surface heat flux anomalies. A weakening of the anticyclone will tend to weaken the prevailing northeasterlies and enhance evaporative cooling over the southwestern Atlantic Ocean. In the equatorial region, the southeast trade winds weaken, thereby suppressing evaporation and leading to net surface warming. Thus, it is hypothesized that the wind–evaporation–SST feedback may be responsible for the growth of the SAOD events linking southern extratropics and equatorial Atlantic variability via surface net heat flux anomalies.

Leading atmospheric teleconnections

Southern extratropical forcing of the Atlantic Niño

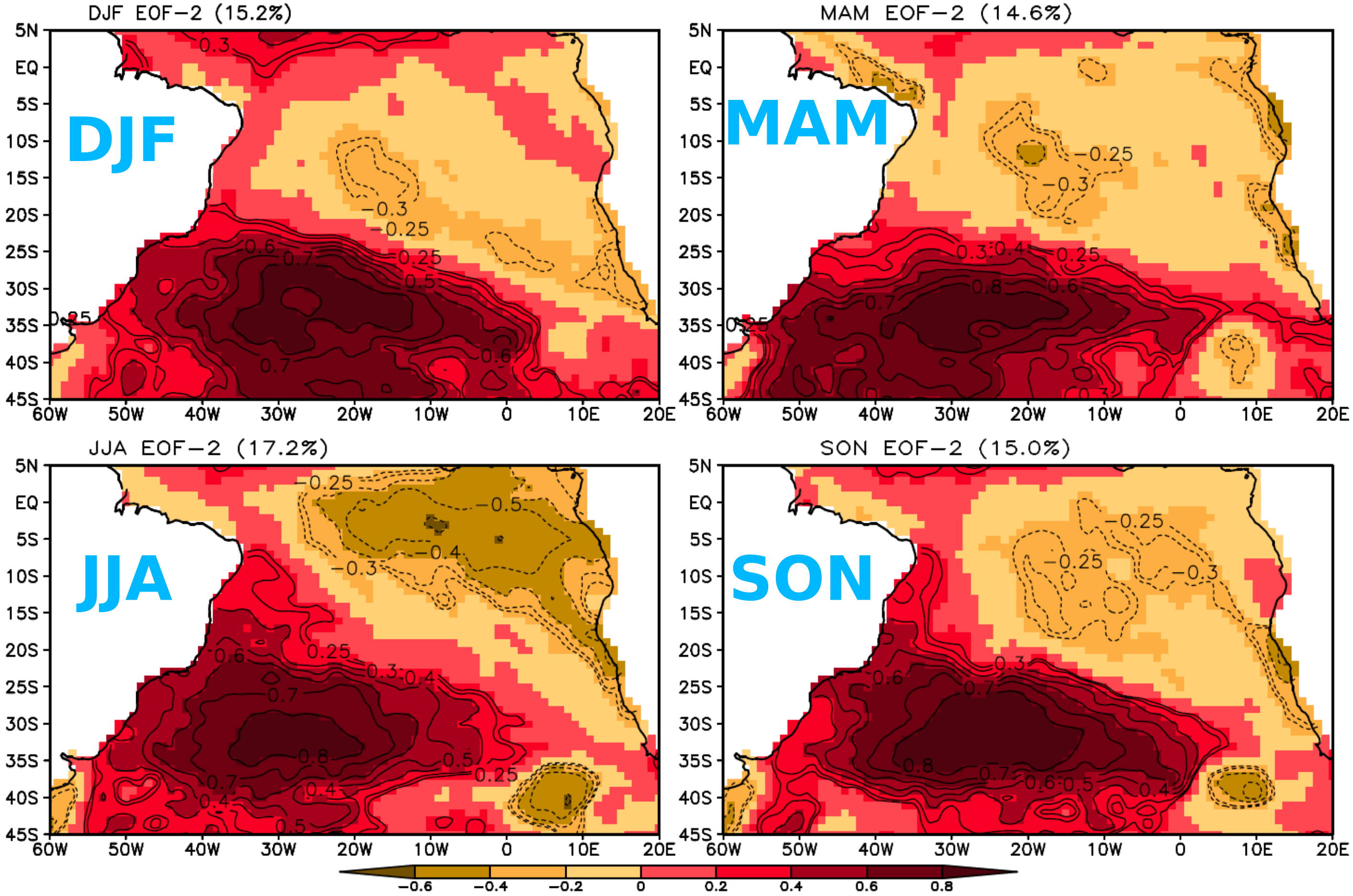


Pacific El Niño: *more symmetrical*



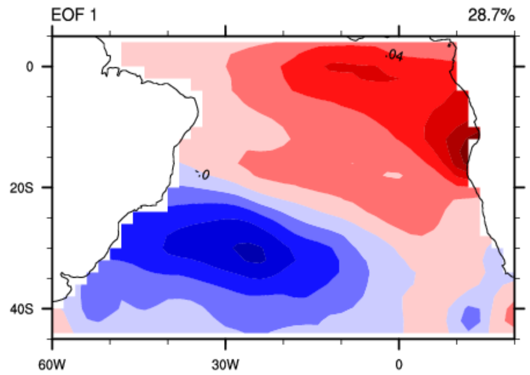
South Atlantic Ocean Dipole (SAOD): 2nd EOF

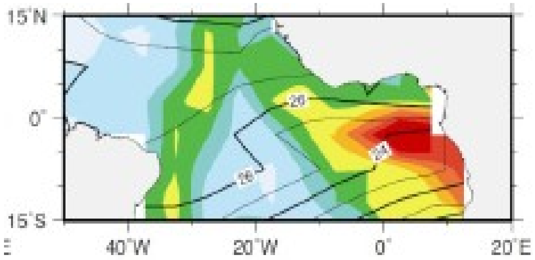
Peaks in JJA

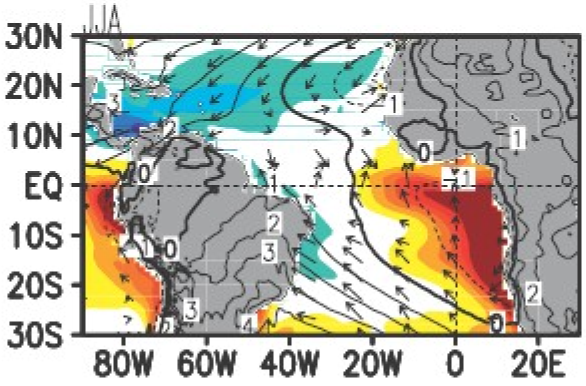


Nnamchi et al., (2011): Does a dipole mode really exist in the South Atlantic Ocean? *JGR–Atmospheres.*

Why do we tend to see only equatorial Atlantic Niño?







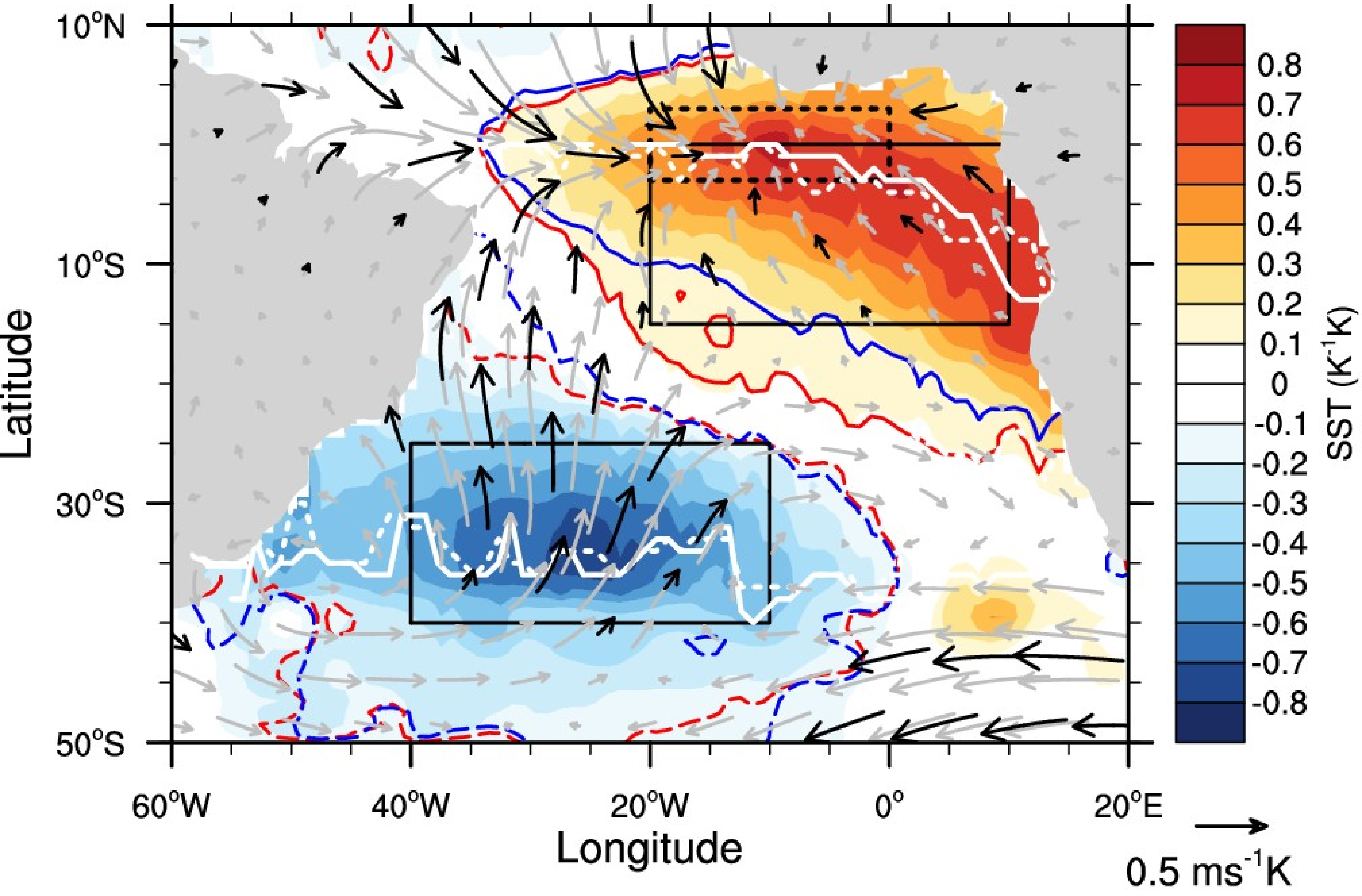
1. Space scale: Atlantic Niño is just ONE pole of the dipole.

2. Time scale: Warming trend is important over time.

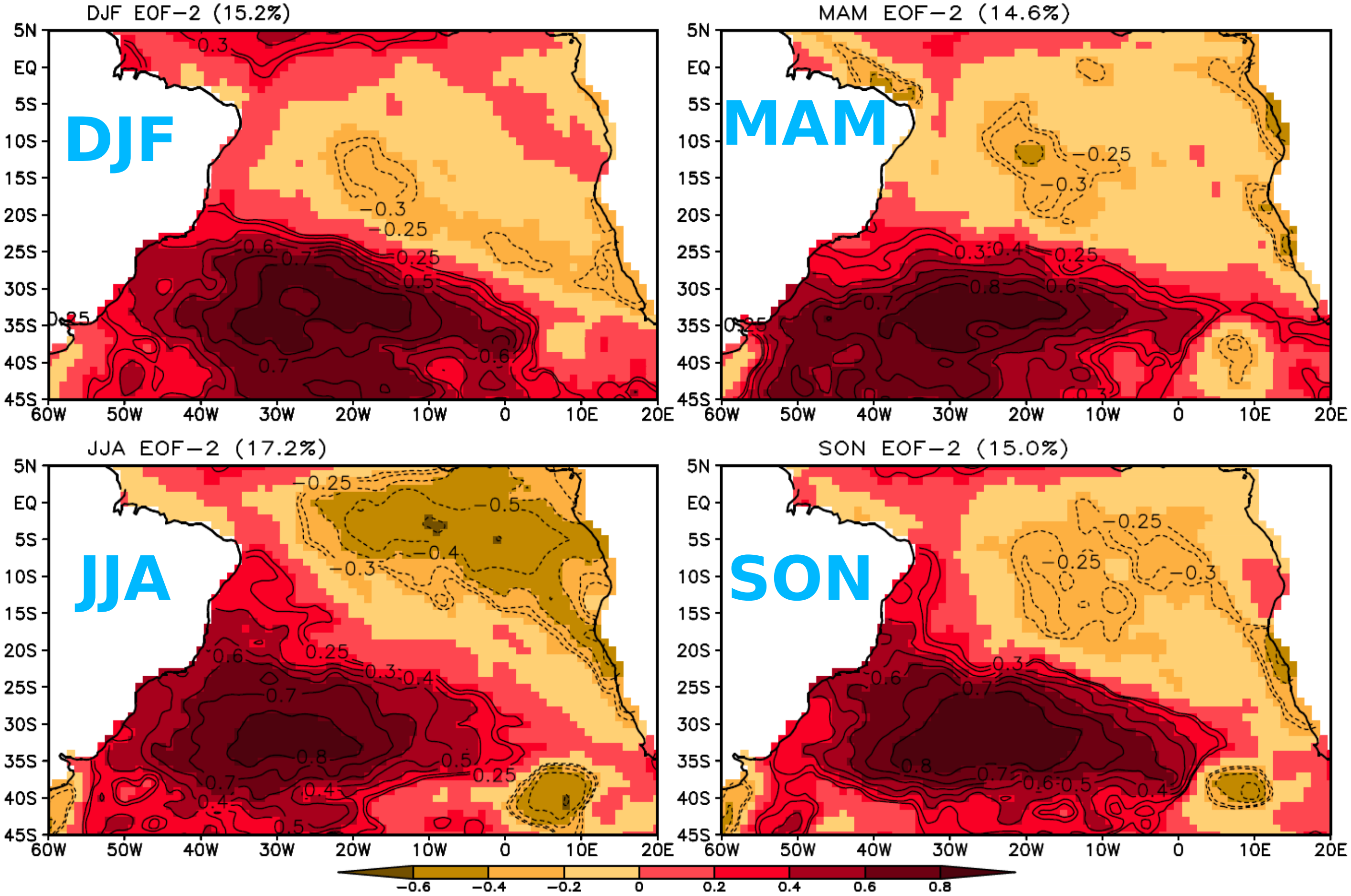
3. Model biases: Can further complicate detection of the dipole.

All 3 factors peak in JJA

Atlantic Niño ≈ Dipole ?

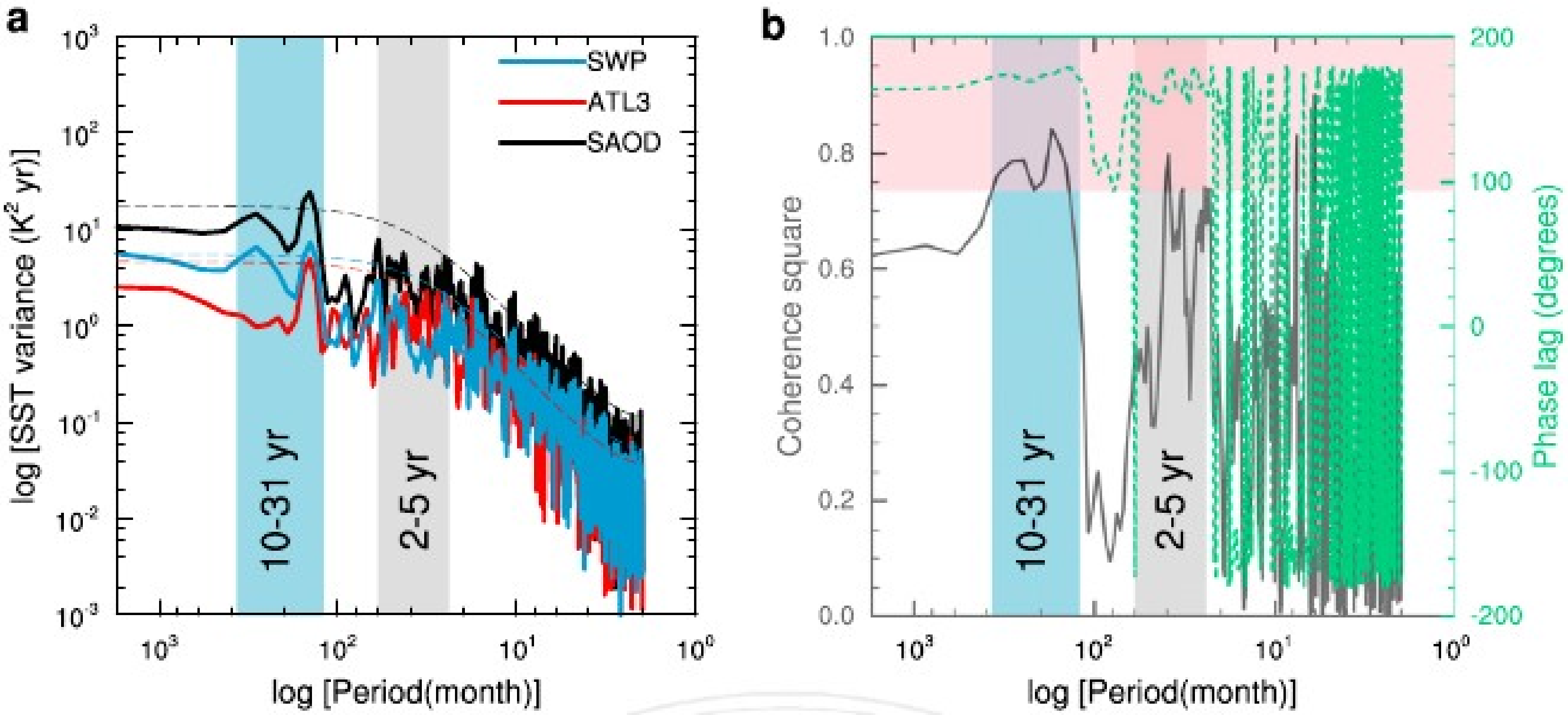


Why bother about the extratropics?



Anomalies in the extratropics are always present and so *may aid our understanding of equatorial variability.*

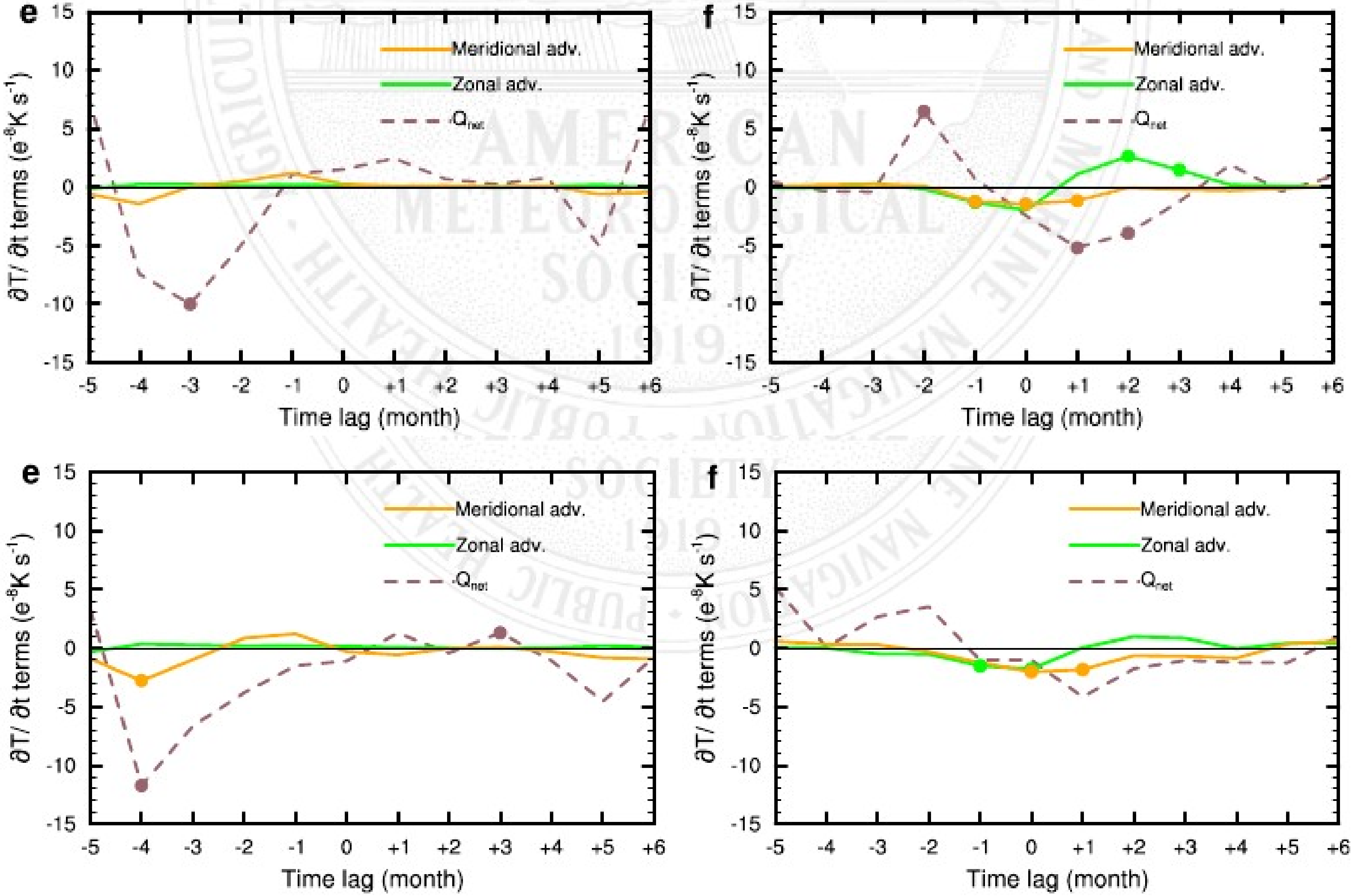
Spectral coherence



Heat flux dominates dipole SST anomalies, *extratropics leads in time.*

Extratropics

Atlantic Niño



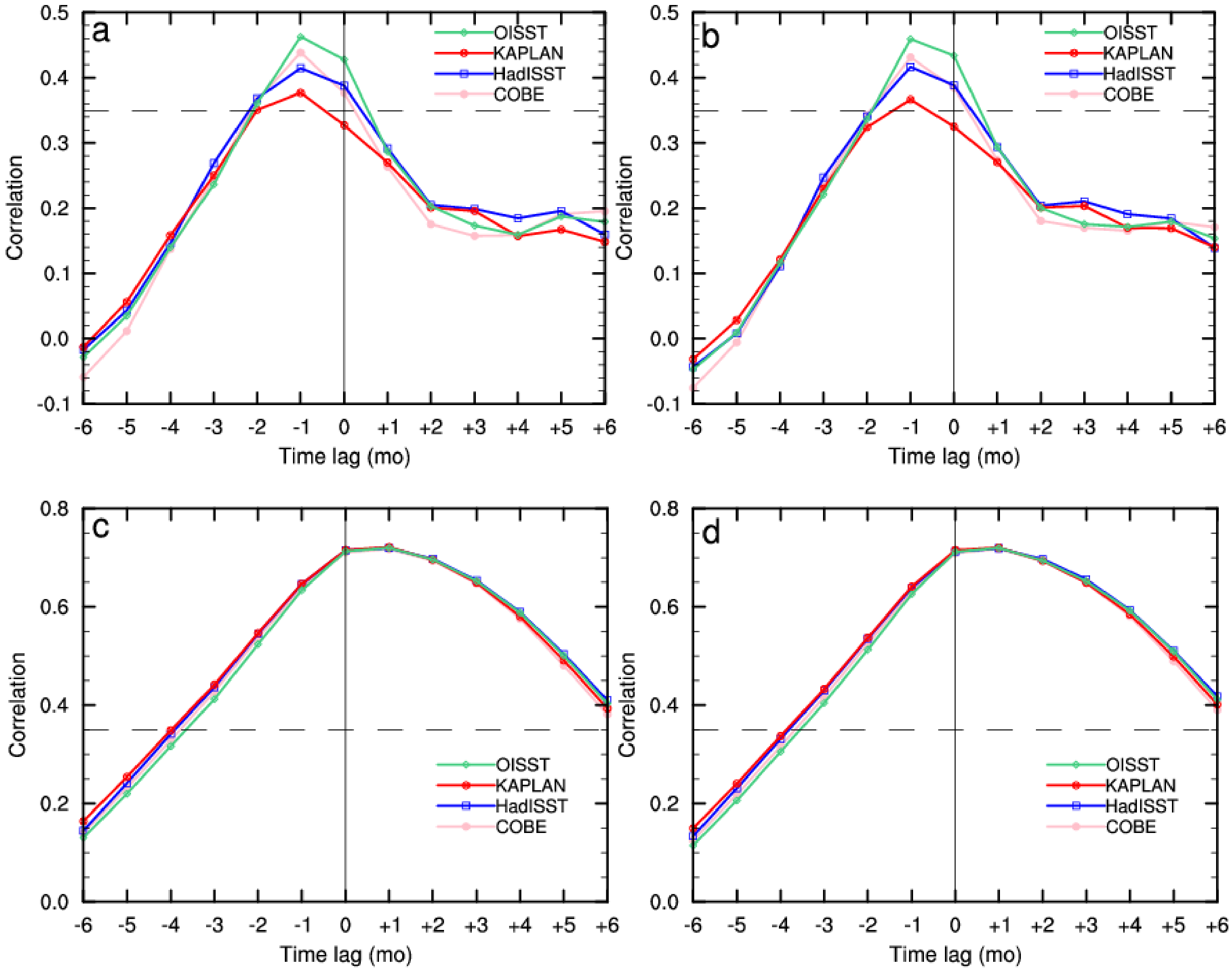
ORAS3
Reanalysis

GECCO2
Reanalysis

Summary and Outlook

- **Similarities of equatorial Atlantic and Pacific Oceans**
  -Basin geometry and annual cycle
- **Differences between equatorial Atlantic and Pacific variability**
  -Bjerknes (dynamical) theory
  -Meridional advection
  -Equatorial Kelvin waves
- **Ocean mixed layer heat budget for equatorial Atlantic**
  -Dynamical versus thermodynamic feedbacks
  -Slab model Atlantic Niño
  -Red noise (AR-1) spectrum of the Atlantic Niño
- **Extratropical connections**
  -Atlantic Niño: equatorial zonal or equatorial-extratropical dipole structure?
  -Decadal and Pacific modulations
  -Atmospheric influence
- **Concluding Discussions**
  -Summary
  -Implications for model error, predictability etc.

The predictability question



SST leads precipitation at positive lags