The AMO in Complex Models and a Very, Very Simple Model

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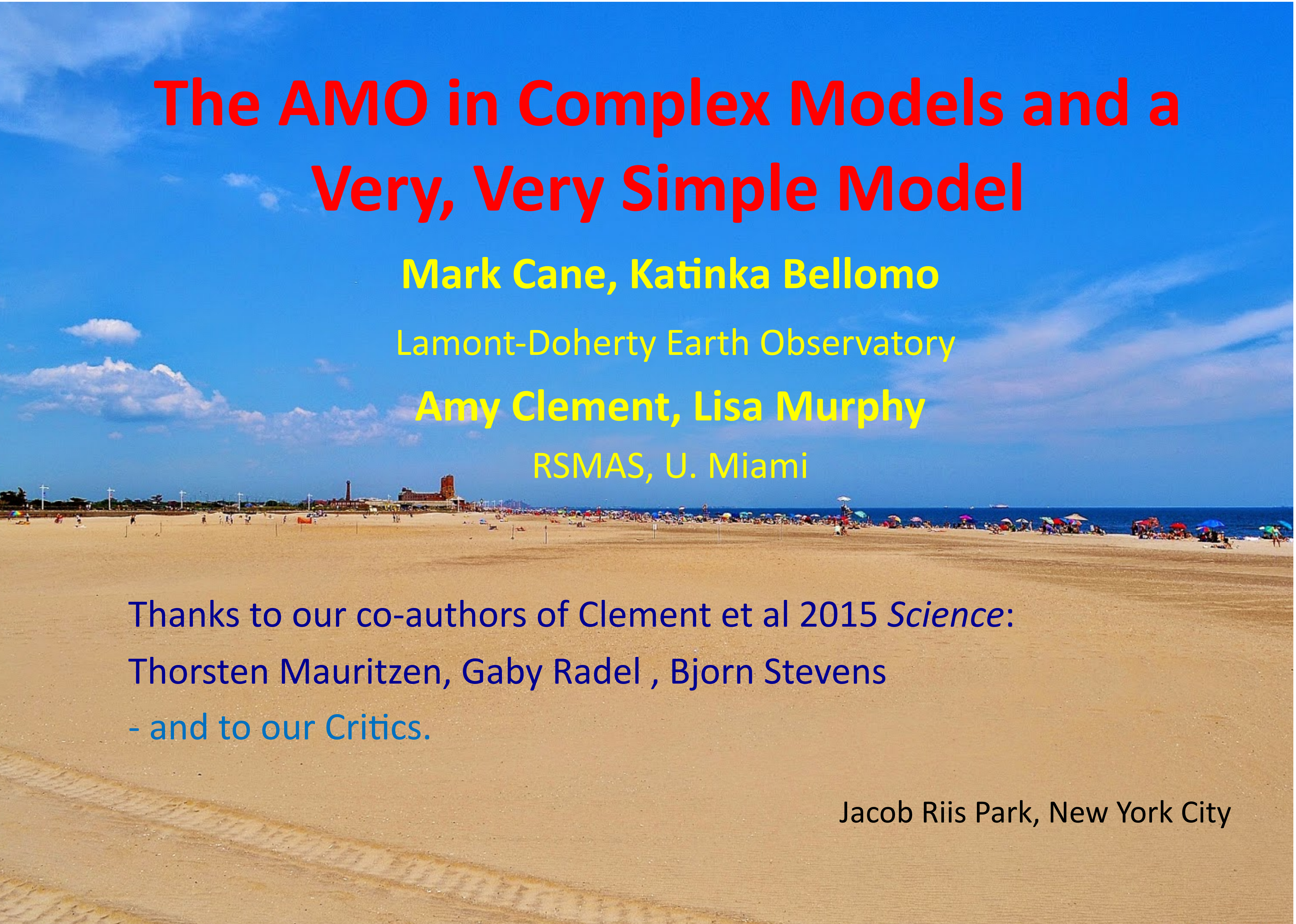
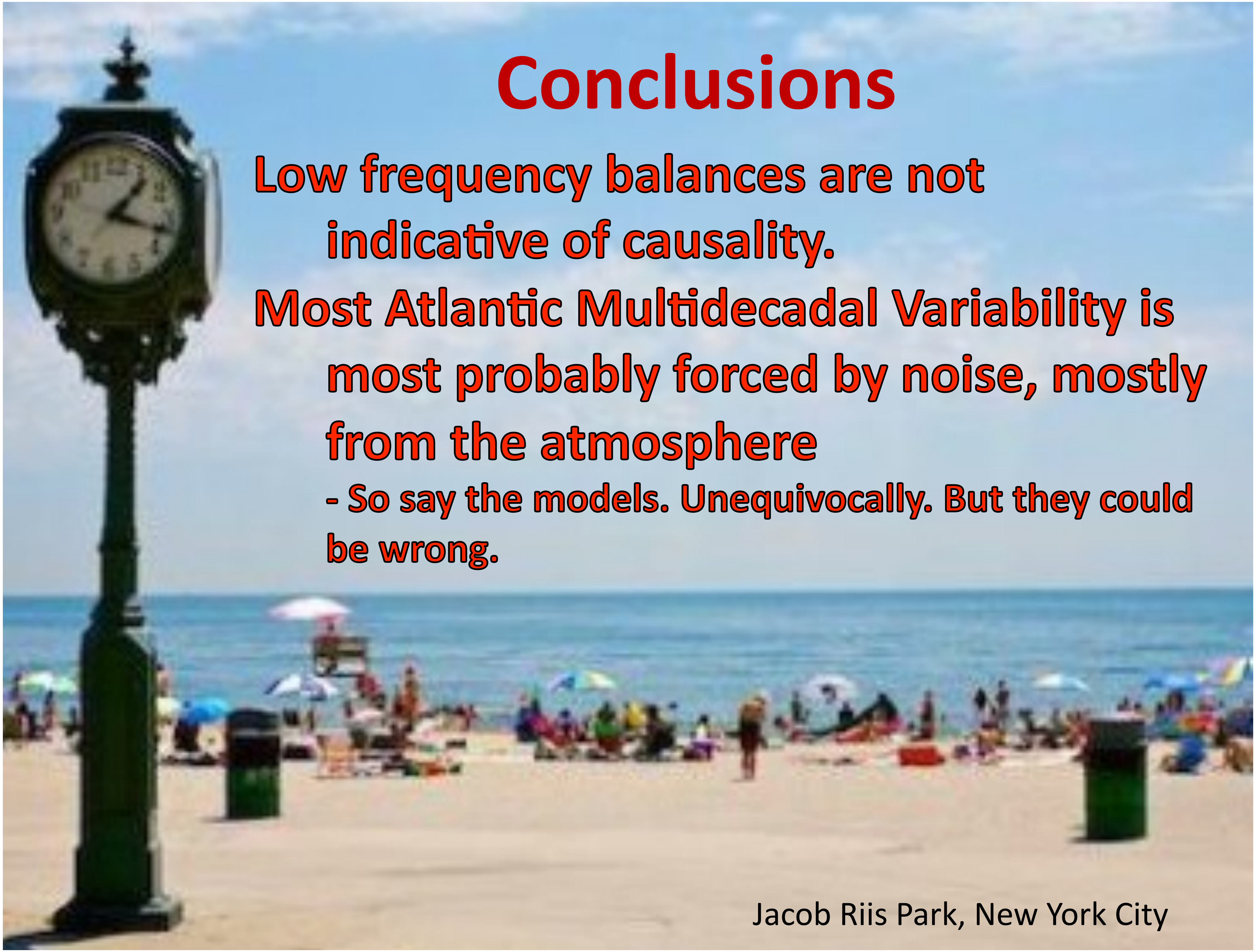
Thanks to our co-authors of Clement et al 2015 *Science*:

Thorsten Mauritzen, Gaby Radel , Bjorn Stevens

- and to our Critics.



Jacob Riis Park, New York City


Conclusions
Low frequency balances are not indicative of causality.
Most Atlantic Multidecadal Variability is most probably forced by noise, mostly from the atmosphere
- So say the models. Unequivocally. But they could be wrong.
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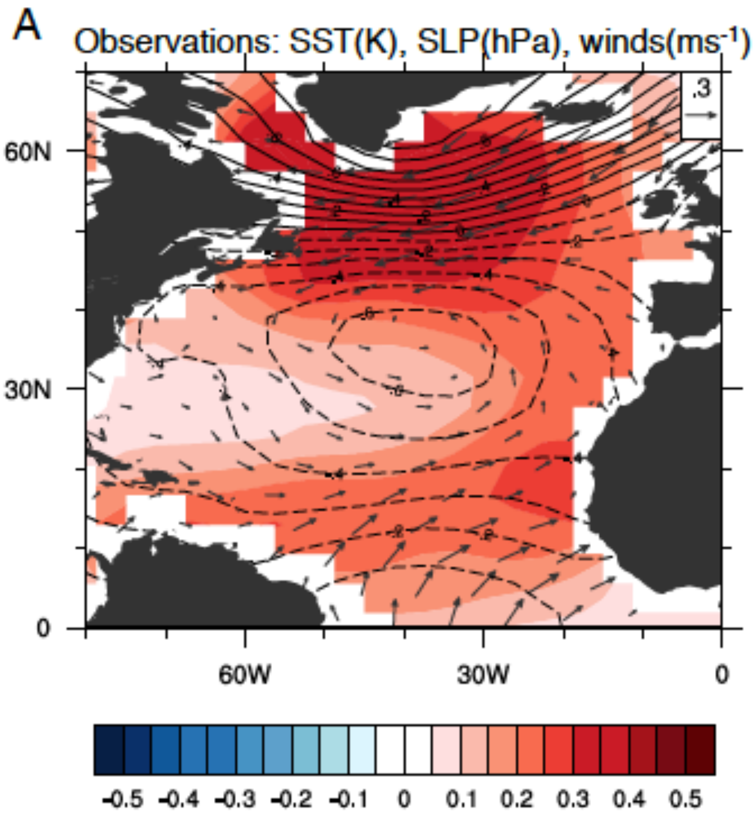
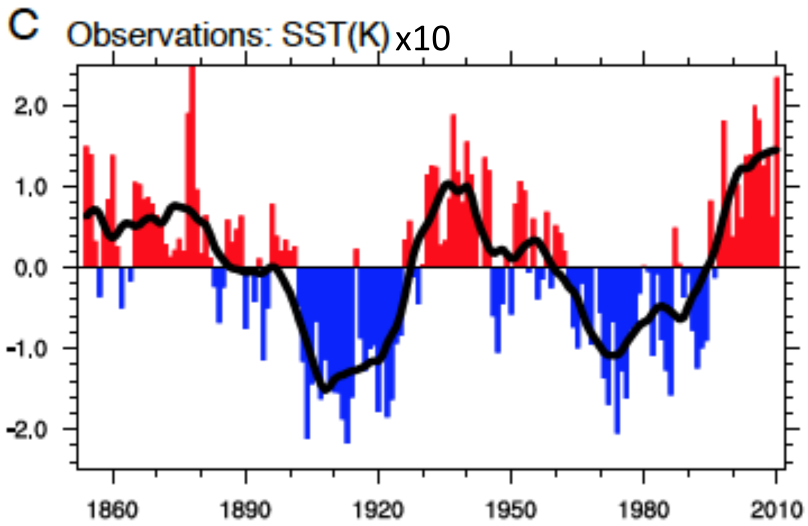


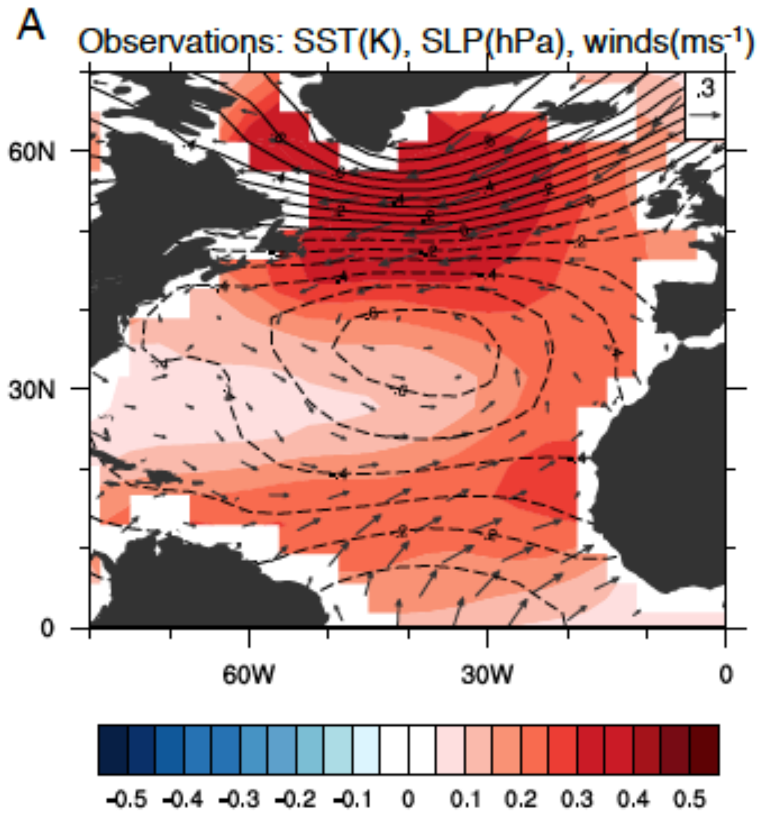


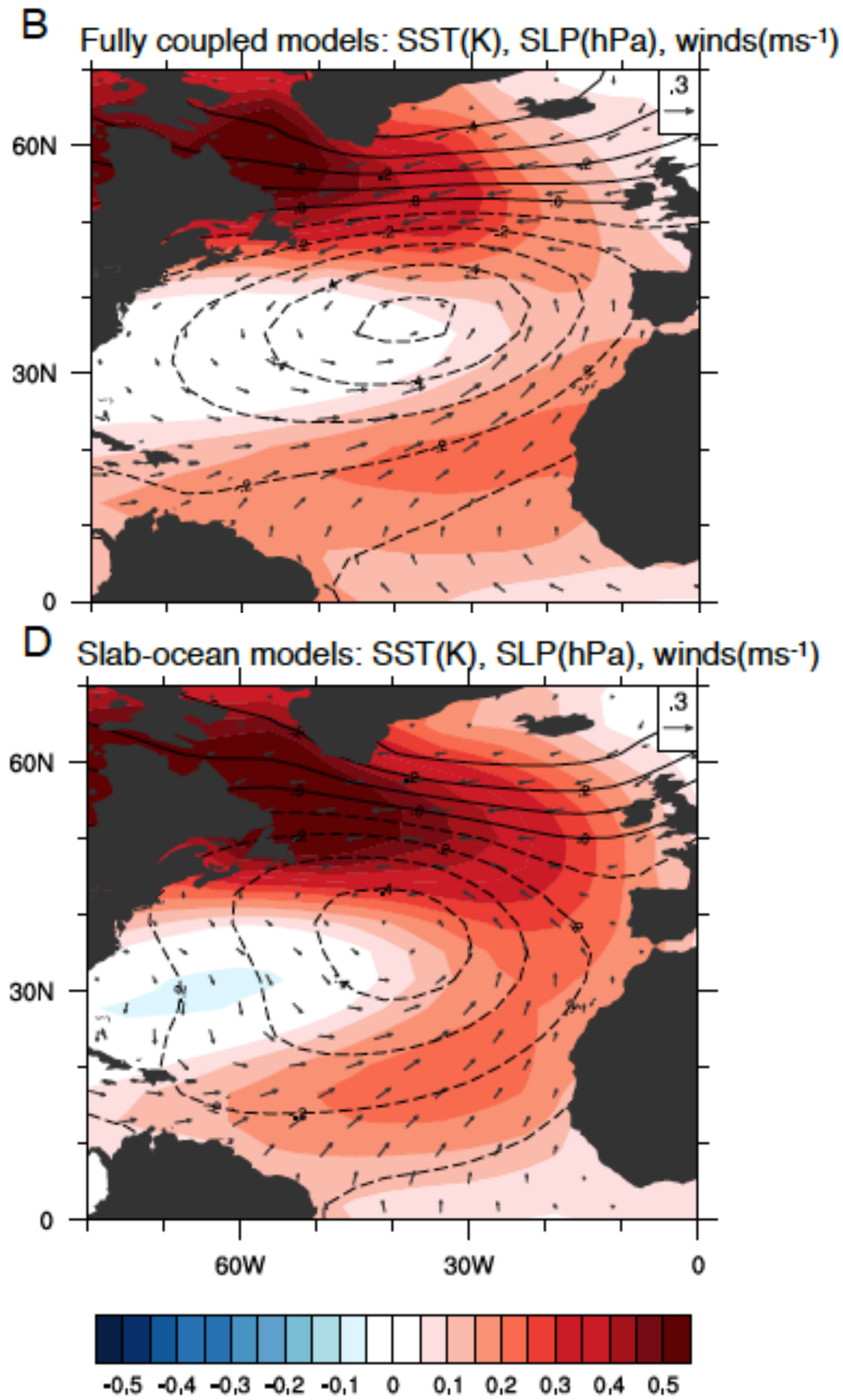
AMO

The **AMO** is associated with societally important climate variations.

The **AMO Index** is the average SST over the entire North Atlantic. Usually it is detrended and low-passed.

Upper figure shows the regression of SST, SLP and winds on the AMO Index. Lower figure is the time series.





Coupled models (CMIP pre-industrial multimodel mean) reproduce this pattern!

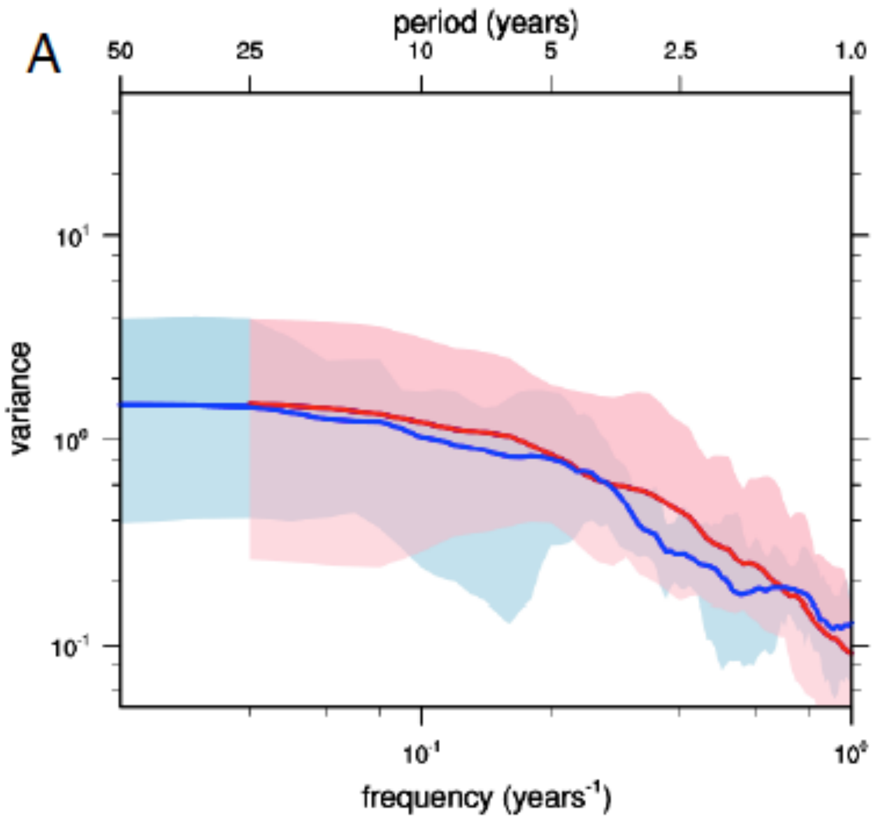
So do the same atmosphere models coupled to a **slab** ocean.

From Clement et al 2015 *Science*

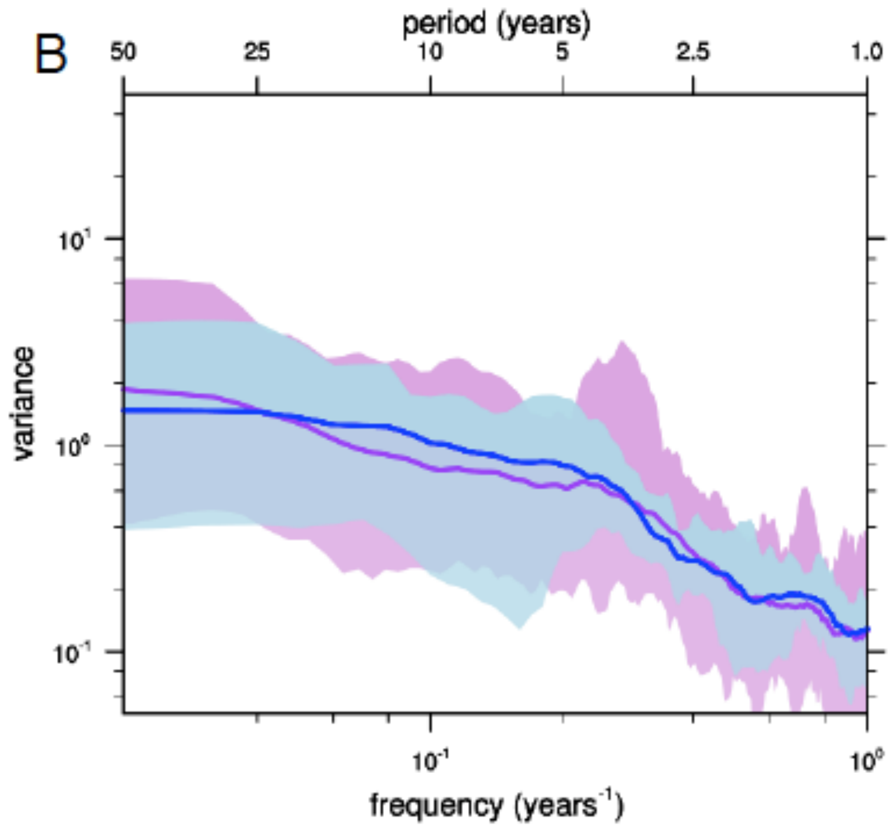
How do the temporal characteristics compare with and without interactive ocean dynamics?

- Slab and coupled, CMIP3,5 have the same variance
- All look like red noise, without a multidecadal peak

AMO in CMIP3 slab models (red) and CMIP3 coupled models (blue)



AMO in CMIP3 coupled models (blue) and CMIP5 coupled models (purple)



The clear implication is that the ocean circulation is not necessary for the AMO.

The AMOC Empire strikes back:

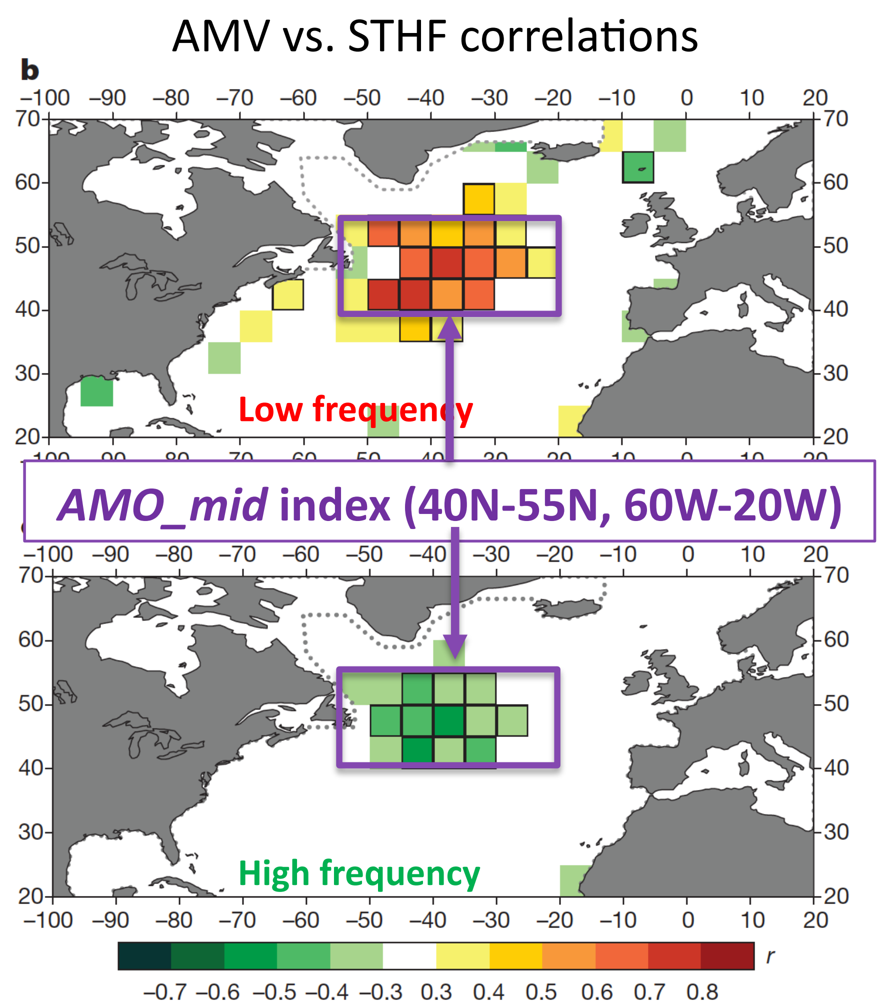
Zhang et al 2016
O’Reilly et al 2016
Drews and Greatbatch 2016

Gulev et al 2013

North Atlantic control on surface turbulent heat flux (STHF) on multidecadal timescales

Gulev et al. (2013, *Nature*)

AMV vs. STHF correlations



Based on VOS reports from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS, version 2.5) for 1880-2007

The Bjerknes hypothesis:

Low Frequency

The ocean heats the atmosphere

High Frequency

The atmosphere heats the ocean

To interpret this correctly, consider the heat equation for the mixed layer:

$$rC_p d[hT]/dt = Q_a + Q_o;$$

Take h = constant:

$$\boxed{dT/dt = \underbrace{-\alpha T + q_a}_{Q_s} + q_o}$$

$-\alpha T$ is the turbulent flux (latent + sensible) damping

q_a are the other atmospheric fluxes – radiative, non-feedback turbulent fluxes

$Q_s = -\alpha T + q_a$ is the total surface flux– the total heat exchange with the atmosphere

q_o is the ocean heat flux convergence

At Low Frequency – e.g. if low pass filtered – **dT/dt << αT :**

$$\boxed{\cancel{dT/dt} = -\alpha T + \underbrace{q_a + q_o}_{Q_s}}$$

1) $Q_s \approx -q_o$ Atmosphere and Ocean Fluxes **balance**.
2) $\alpha T \approx (q_a + q_o)$ Damping **balances** all other forcing.

Implications

- These are **balances** and so not indicative of causality.
- $\boldsymbol{\rho(Q_s,T)} \leq \mathbf{0}$ and = 0 iff there is no ocean forcing (q_o=0):
  - $\mathcal{E}\{Q_s,T\} \approx -\ \mathcal{E}\{q_o,T\}$ because 1) $Q_s \approx -\ q_o$,
  - $\approx -\alpha^{-1}\mathcal{E}\{q_o, (q_a + q_o)\}$ 2) $T \approx (q_a + q_o)/\alpha$
  - $\approx -\alpha^{-1}\mathcal{E}\{q_o, q_o\} \leq 0$ $\mathcal{E}\{q_o, q_a\} \approx 0$

In response to GCMs, we go very simple:

Noise Forced Model (NFM)

$$dT/dt = \underbrace{-\alpha T + q_a}_{Q_s} + q_o$$

$-\alpha T$ is the turbulent flux (latent + sensible) damping

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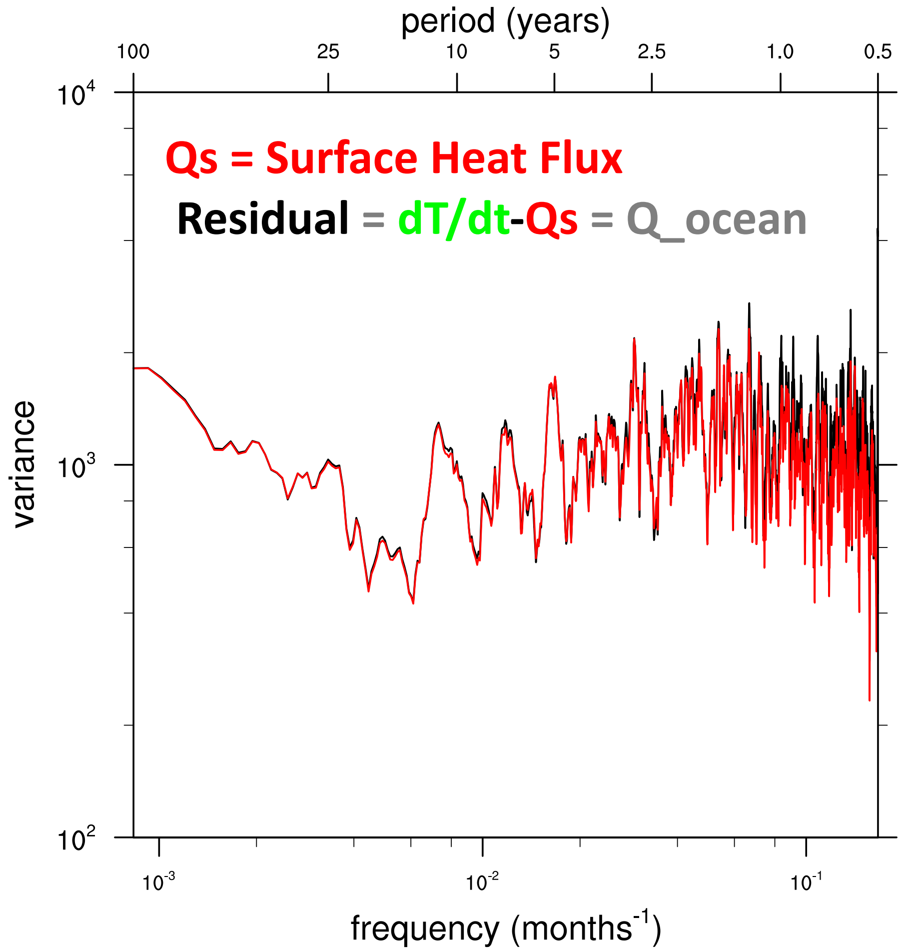
We now take q_a and q_o to be uncorrelated **white noise** forcing:

Is the NFM *relevant* for GCMs and reality?

But are the ocean and atmosphere fluxes white?

Spectra of Fluxes in the Coupled Model (CESM-CAM5)



All quantities are averages over the **AMO_mid** region (60-20W, 40-55N) the ACF of LP noise and the cross-correlation of LP dT/dt and dT/dt for AMO-mid

Comparison of AMO_mid from Pre-industrial runs of two Coupled Models (GFDL CM2.1, CCSM) with functions of the Filter Autocorrelation R(t) from **white noise forced theory**

$R(t)/R(0)$

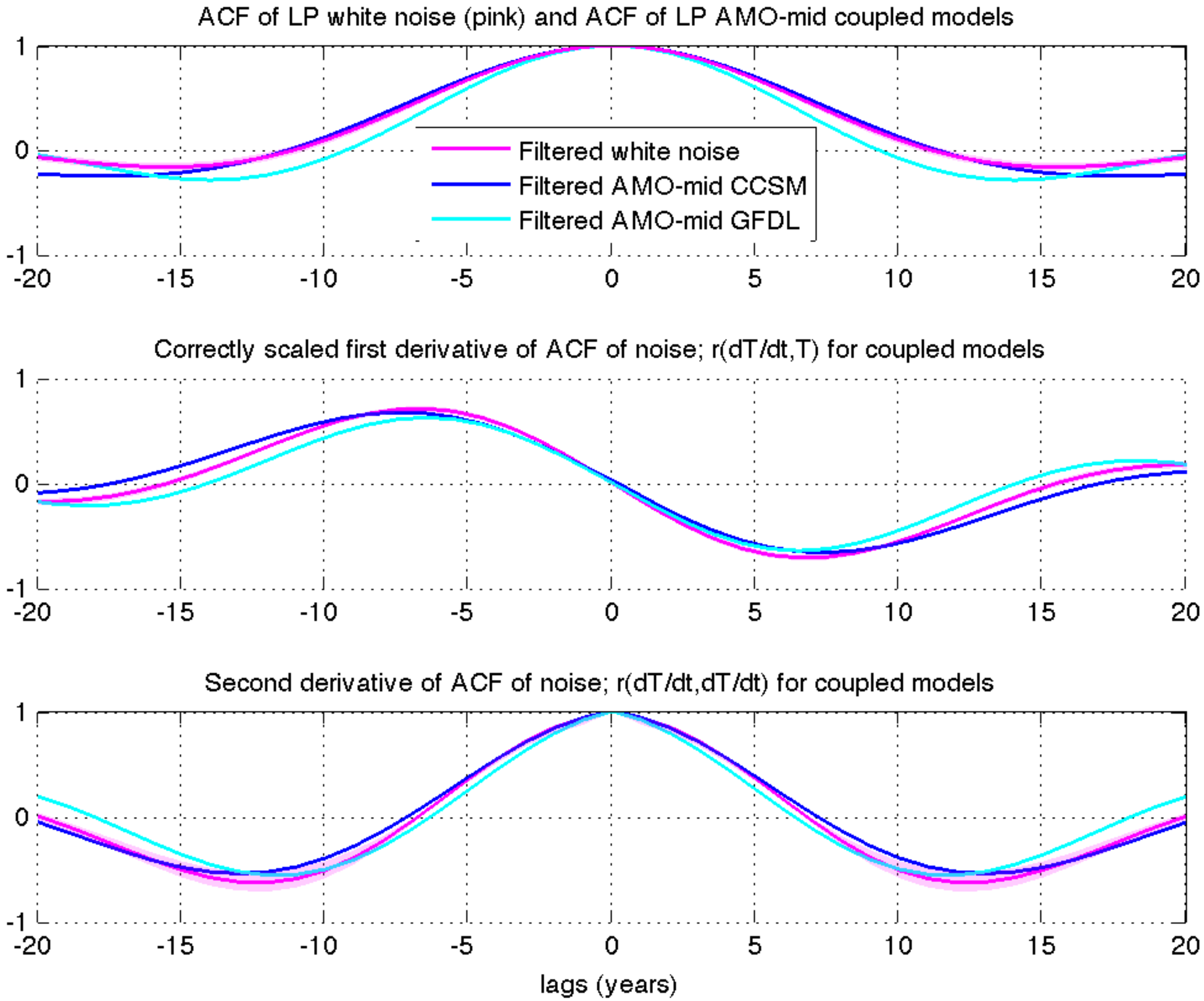
$r(T,T)$

$R_t(t)/[-R_{tt}(0)R(0)]^{1/2}$

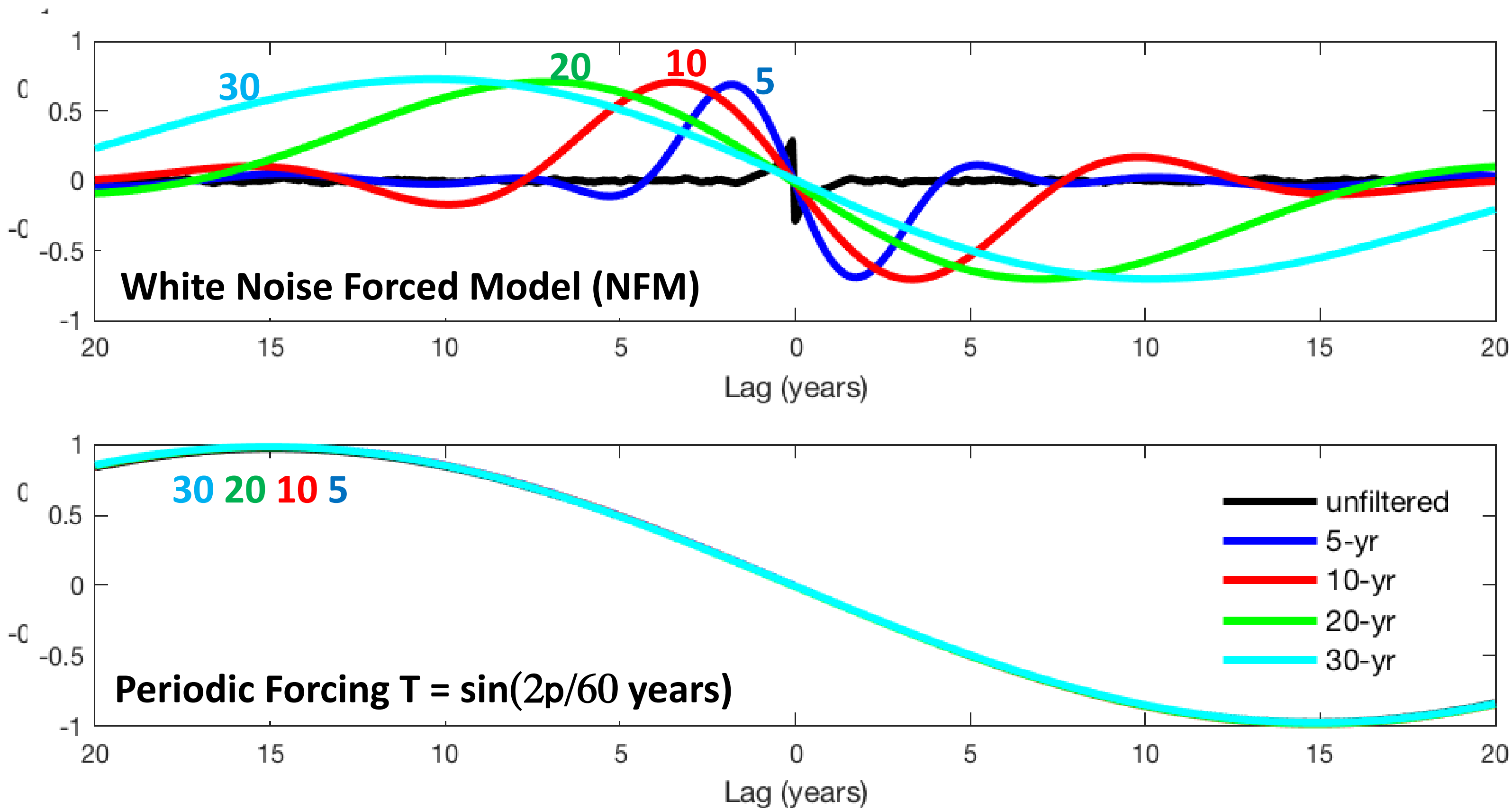
$r(dT/dt,T)$

$-R_{tt}(t)/[-R_{tt}(0)]$

$r(dT/dt, dT/dt)$



Correlation r(dT/dt,T) with varying filter cutoff periods of 5, 10, 20, 30 years



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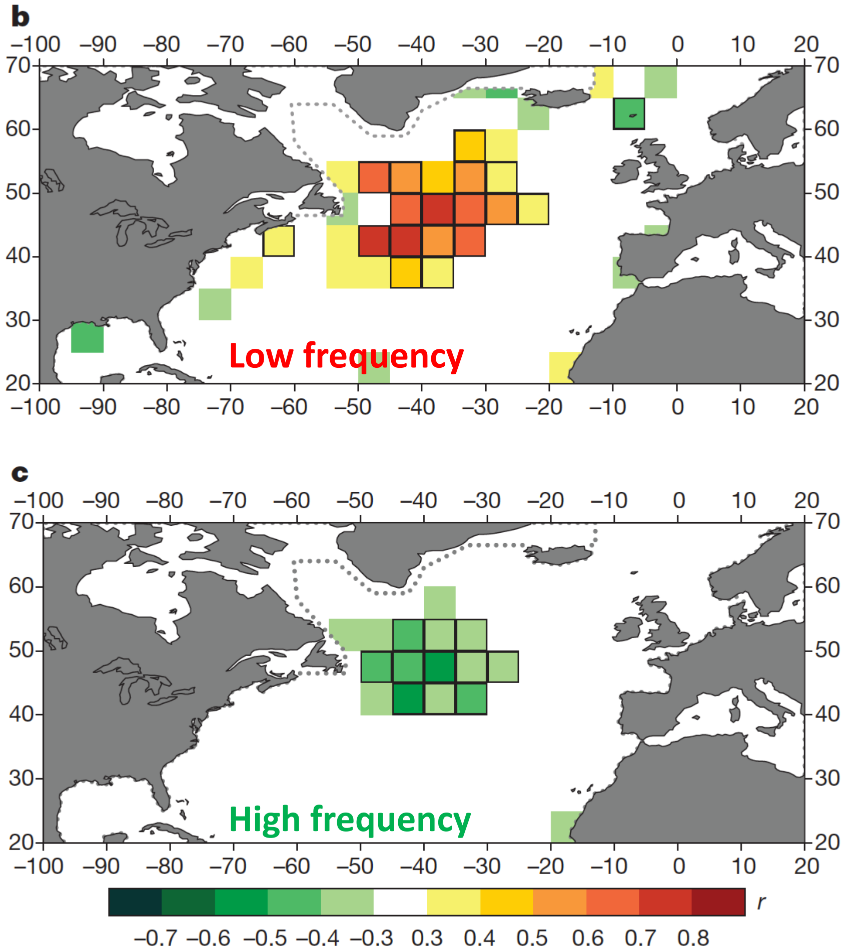
Gulev et al. (2013, *Nature*)

AMV vs. STHF correlations



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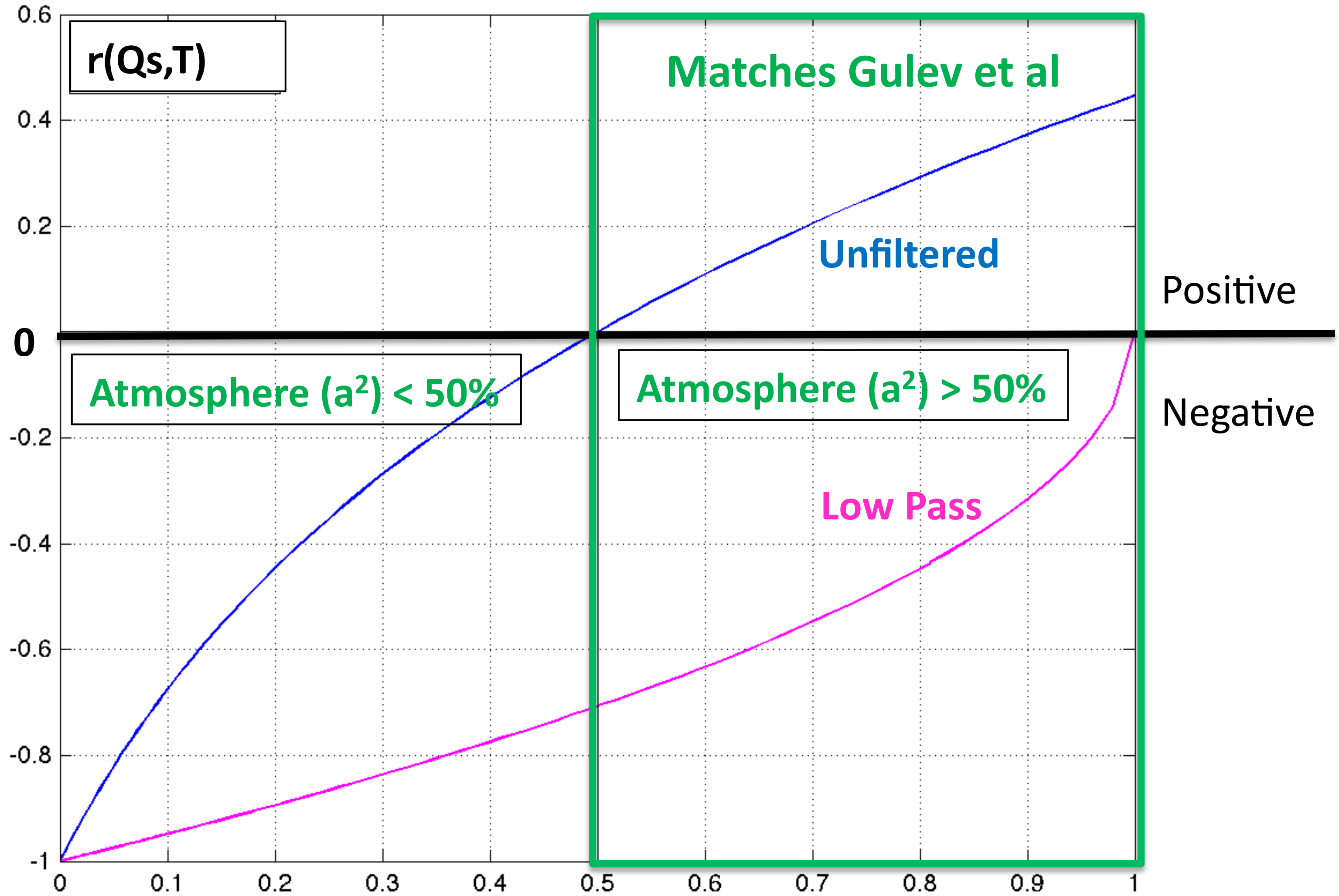
Correlation of Qs and T at lead/lag=0

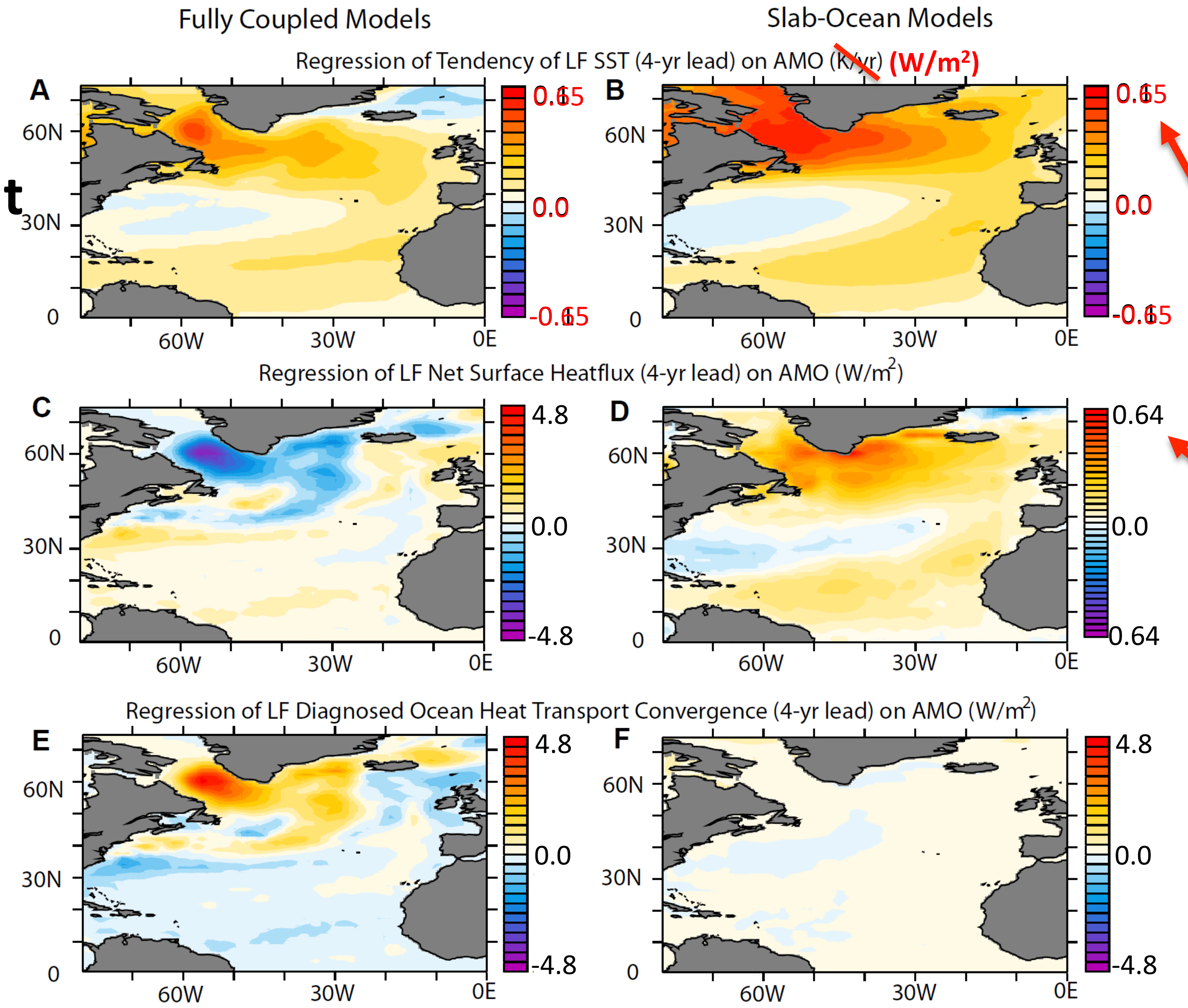
as a function of % of forcing from the atmosphere according to noise model analysis



a^2 = Fraction of the total forcing from the Atmosphere

Zhang et al 2016:

Low Pass Regressions on the (4 year lagged) **AMO index**



d(SST)/dt

Q_s

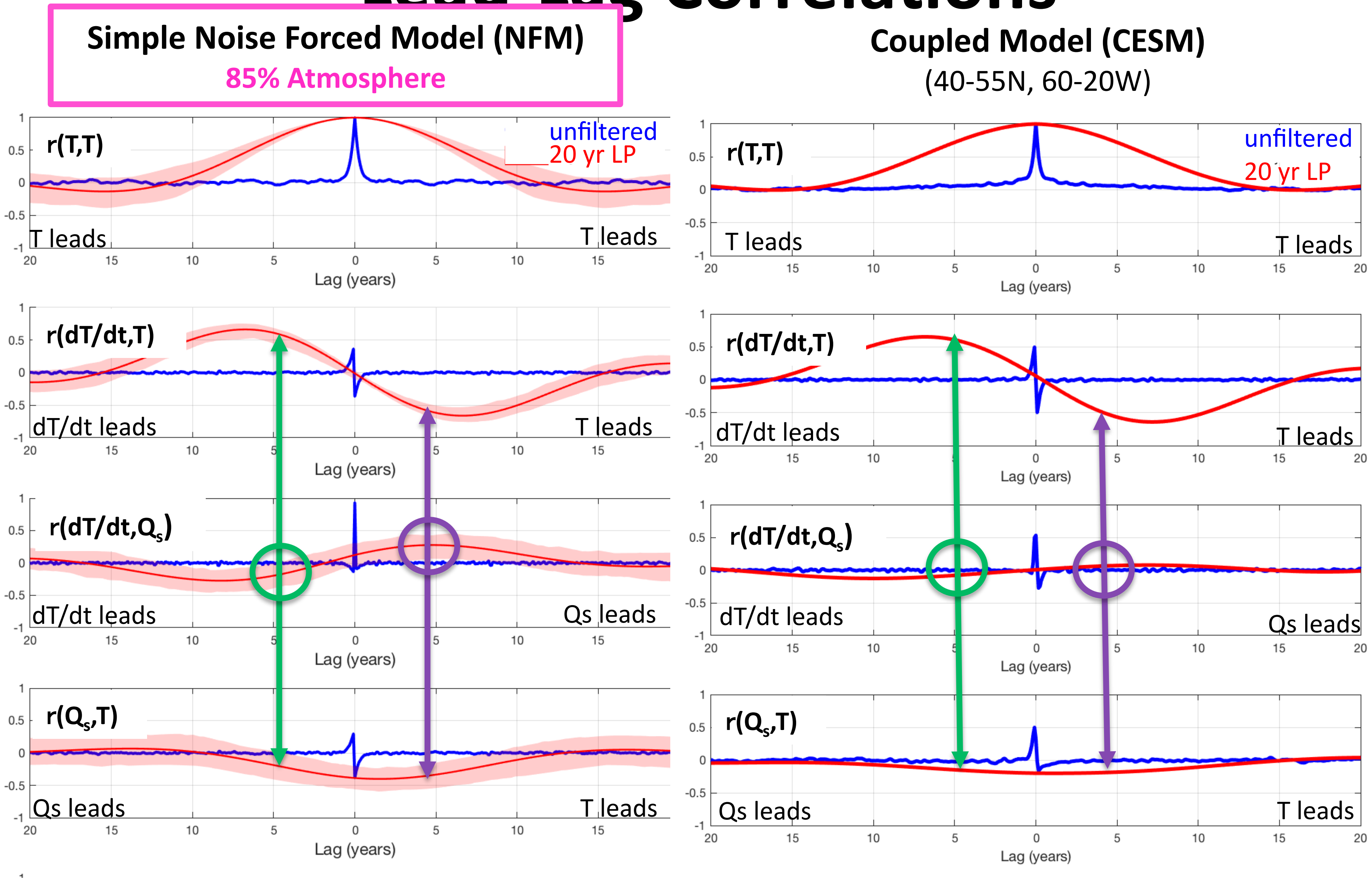
Surface Heat Flux

Residual

aka Ocean Heat Flux

Note Change of Scale

Lead-Lag Correlations



Conclusions

Low frequency balances are not indicative of causality.

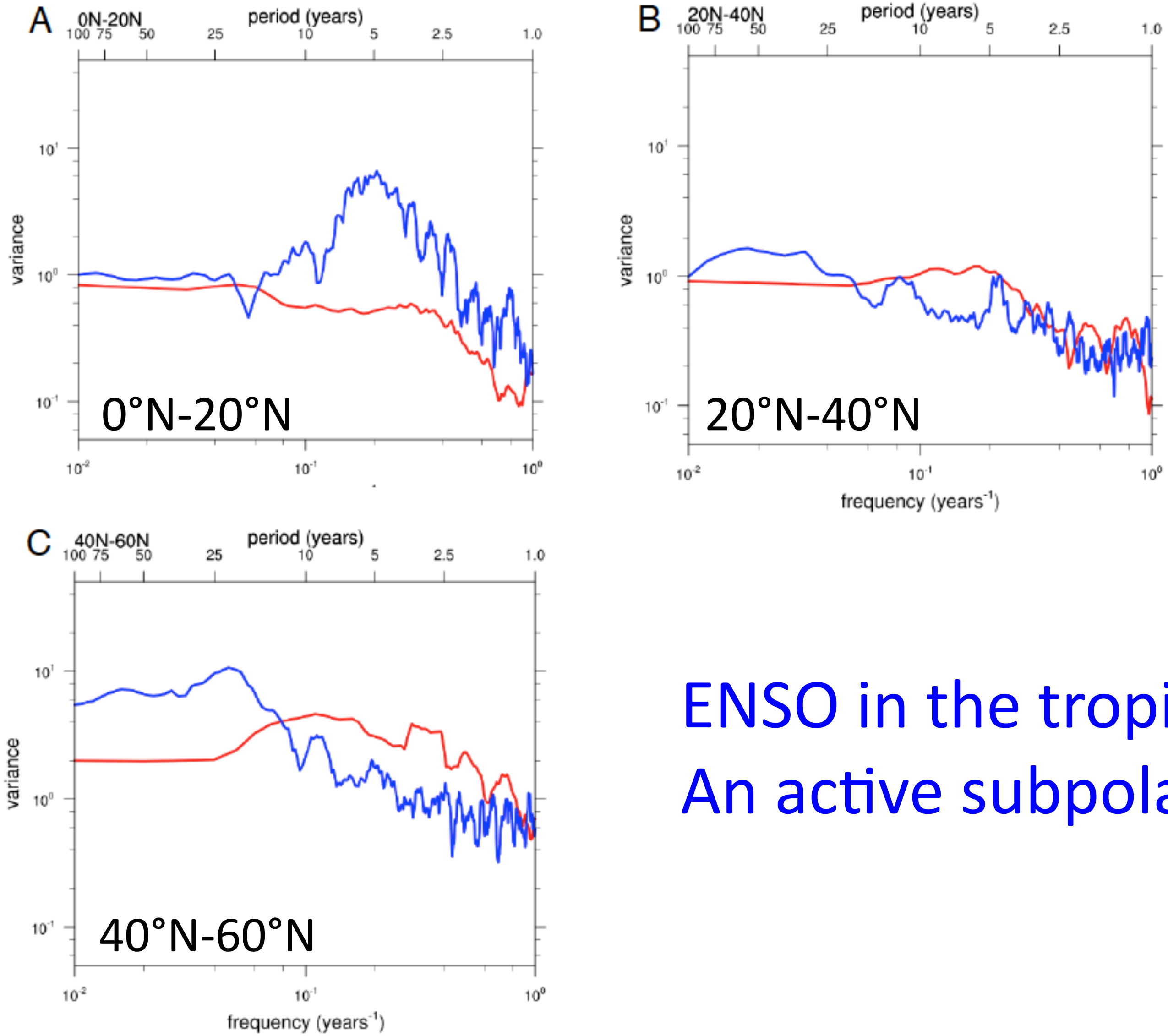
Most Atlantic Multidecadal Variability is most probably forced by noise, mostly from the atmosphere

- So say the models. Unequivocally. But they could be wrong.
- The real AMV is probably forced externally by GHGs, aerosols, volcanos, solar.

If you are going to use a low pass filter, it's a good idea to check first and see if there is a real low frequency signal.

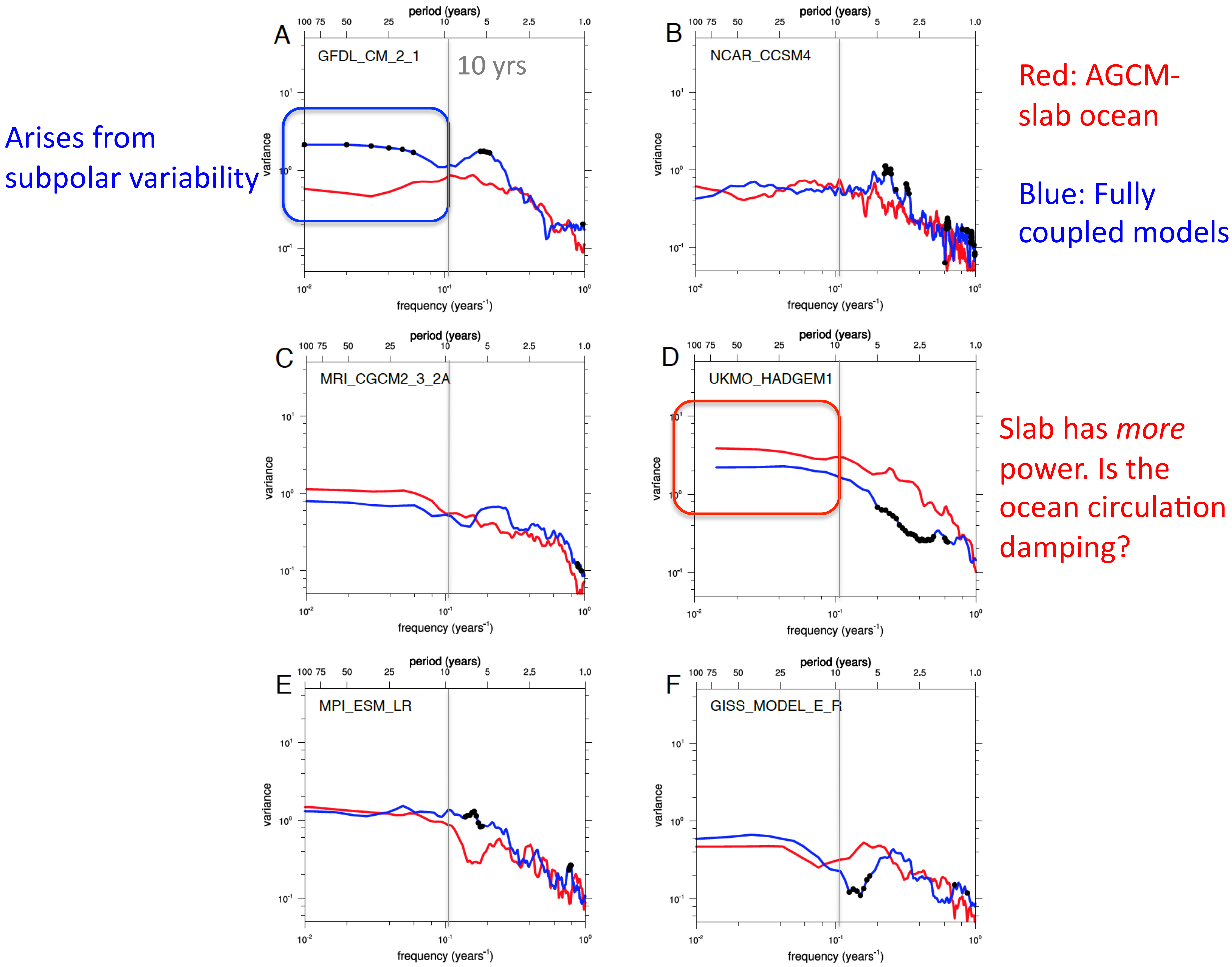
Jacob Riis Park, New York City

GFDL slab model (red) and coupled model (blue)



ENSO in the tropics

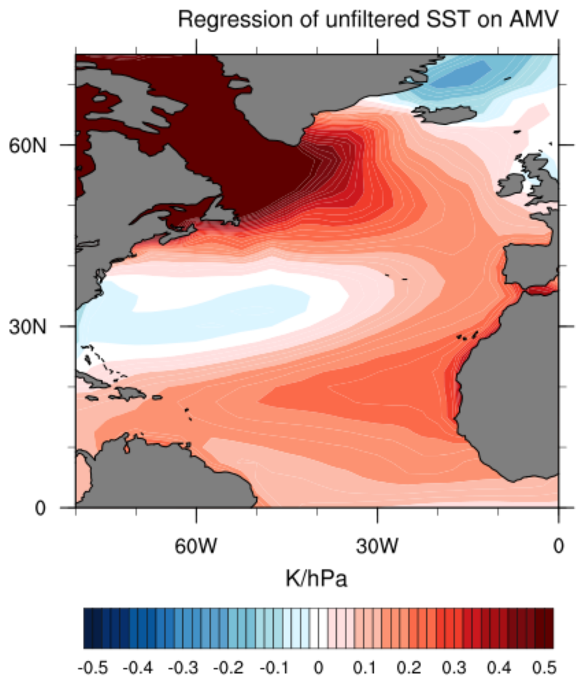
An active subpolar gyre

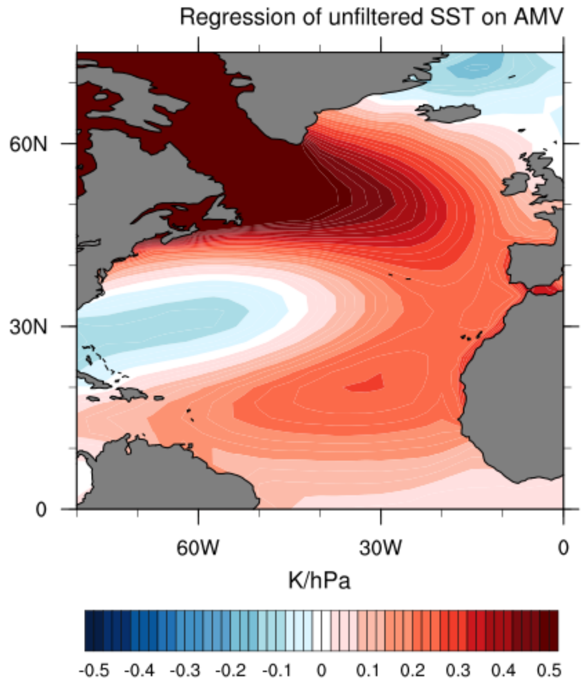


Arises from subpolar variability
Red: AGCM-slab ocean
Blue: Fully coupled models
Slab has *more* power. Is the ocean circulation damping?
10 yrs
A
GFDL_CM_2_1
B
NCAR_CCSM4
C
MRI_CGCM2_3_2A
D
UKMO_HADGEM1
E
MPI_ESM_LR
F
GISS_MODEL_E_R
period (years)
100 75 50 25 10 5 2.5 1.0
variance
frequency (years^{-1})

Is the impact of the ocean **circulation** apparent only at low frequencies?

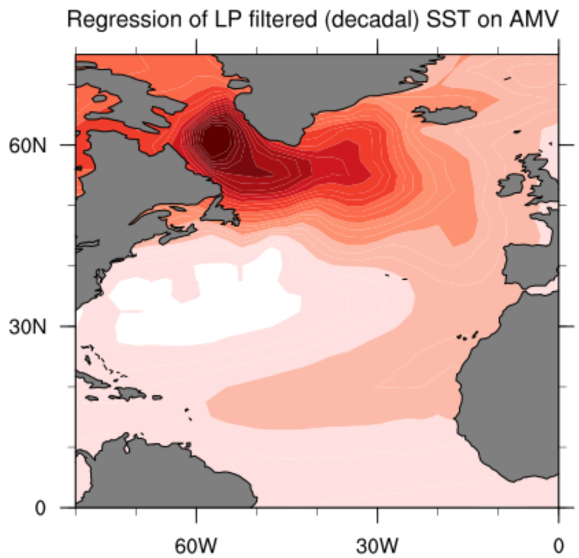
Coupled **unfiltered**

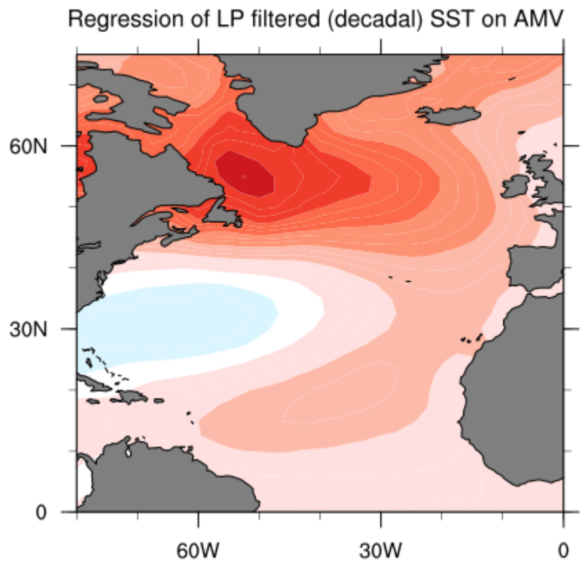




Slab **unfiltered**

Coupled **Low Pass filtered**





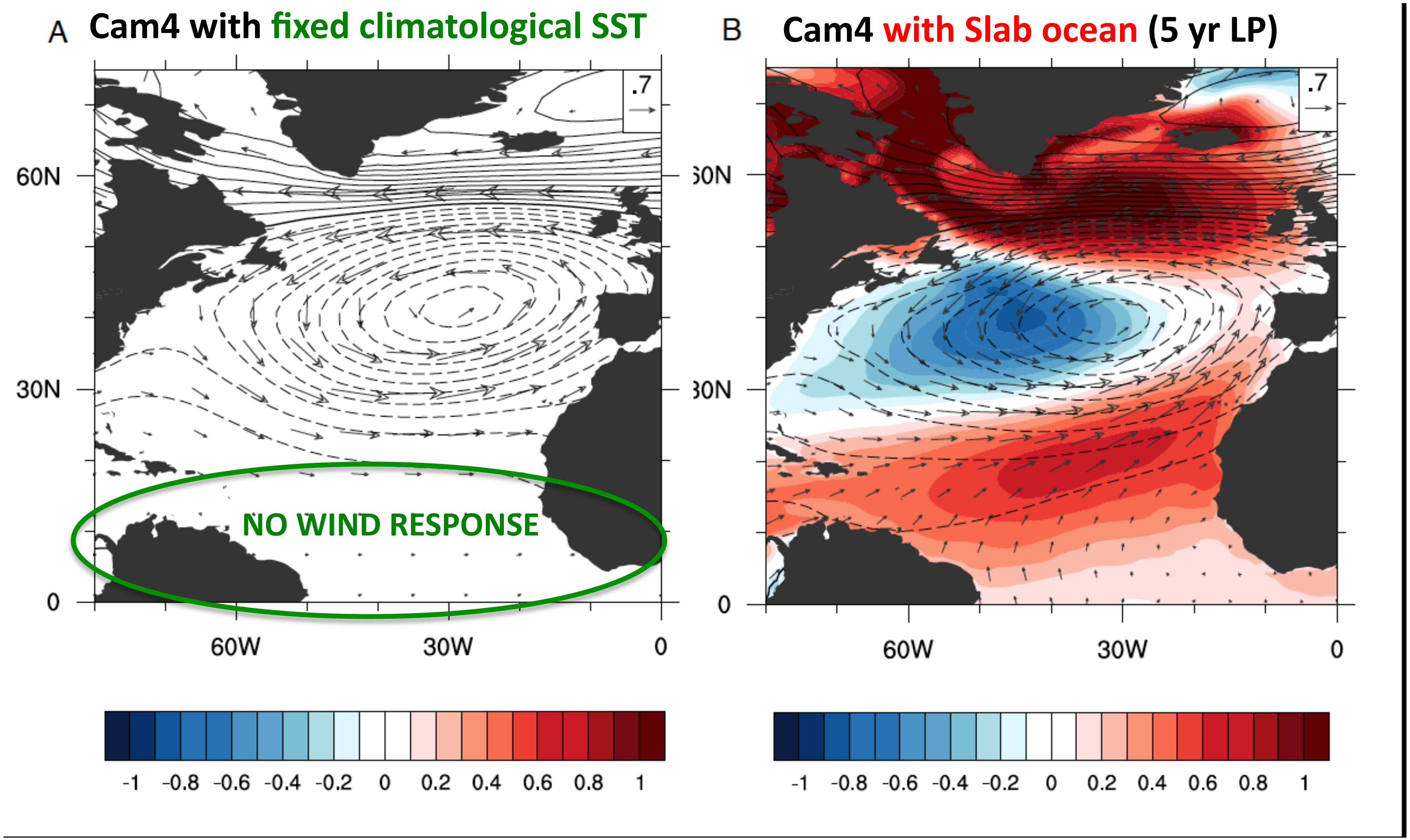
Slab **Low Pass filtered**

All are CMIP multi-model means

Conclusion:

The AMO is a response to stochastic atmospheric forcing.

But thermal coupling (WES) is active in the tropics, generating a wind (and SST) signal there



No spectral peak in long model simulations (Ba et al. 2014)

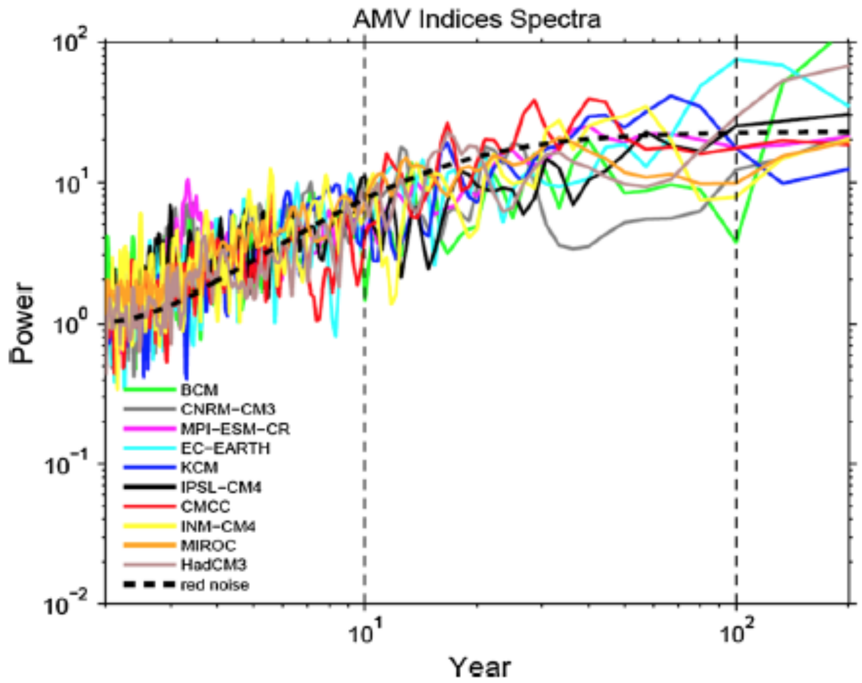
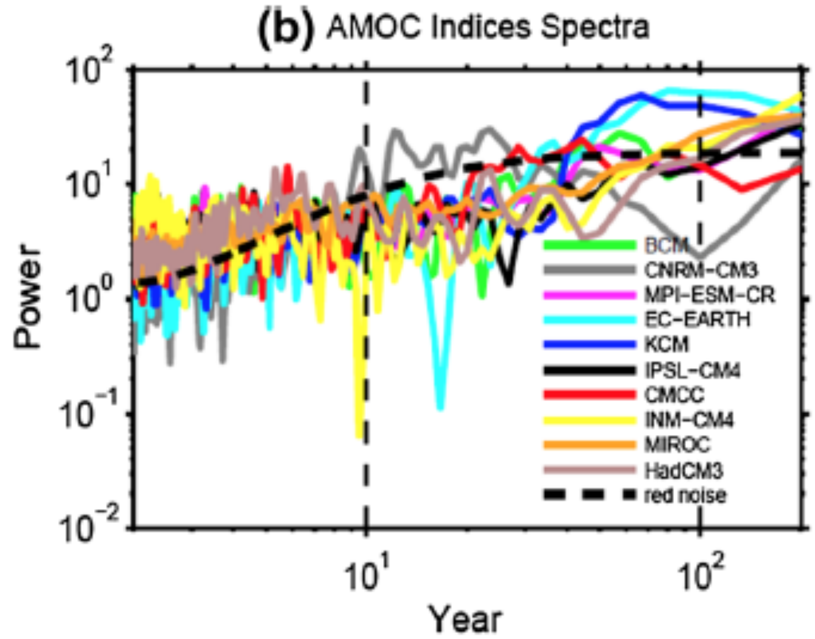


Fig. 2 The spectra of detrended AMV Indices in ten coupled general circulation models (CGCMs). The AR1 red noise fit is the mean of the AR1 red noise fits from ten models. Due to the varying autocorrelation for the models, the individual red-noise spectra are not shown



The **fact** that the coupled and slab results are so similar is a surprise, and creates a puzzle:

How can the Atmosphere + (constant depth) Ocean Mixed Layer generate the same AMO patterns as a model with fully active ocean dynamics?

- There is an ocean circulation and it surely transports heat and salt.
- In the current prevailing paradigm, the ocean circulation (usually the AMOC) is considered essential for Atlantic Multidecadal Variability

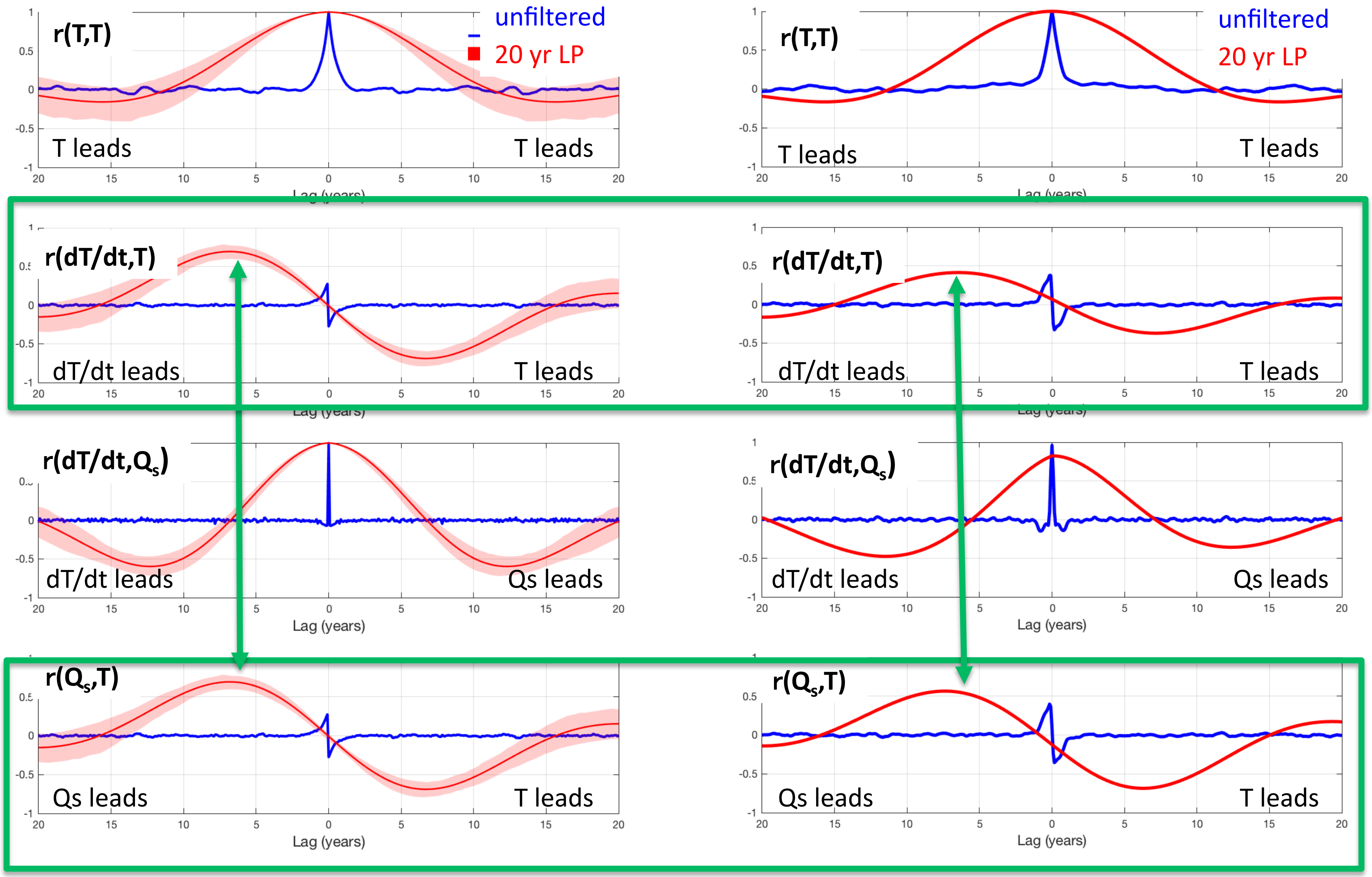
Lead-Lag Correlations

Simple Noise Forced Model (NFM)

a^2= 1.0, b^2= 0, a = 13W/m²/K

Slab Ocean Model (SOM)

(40-55N, 60-20W)



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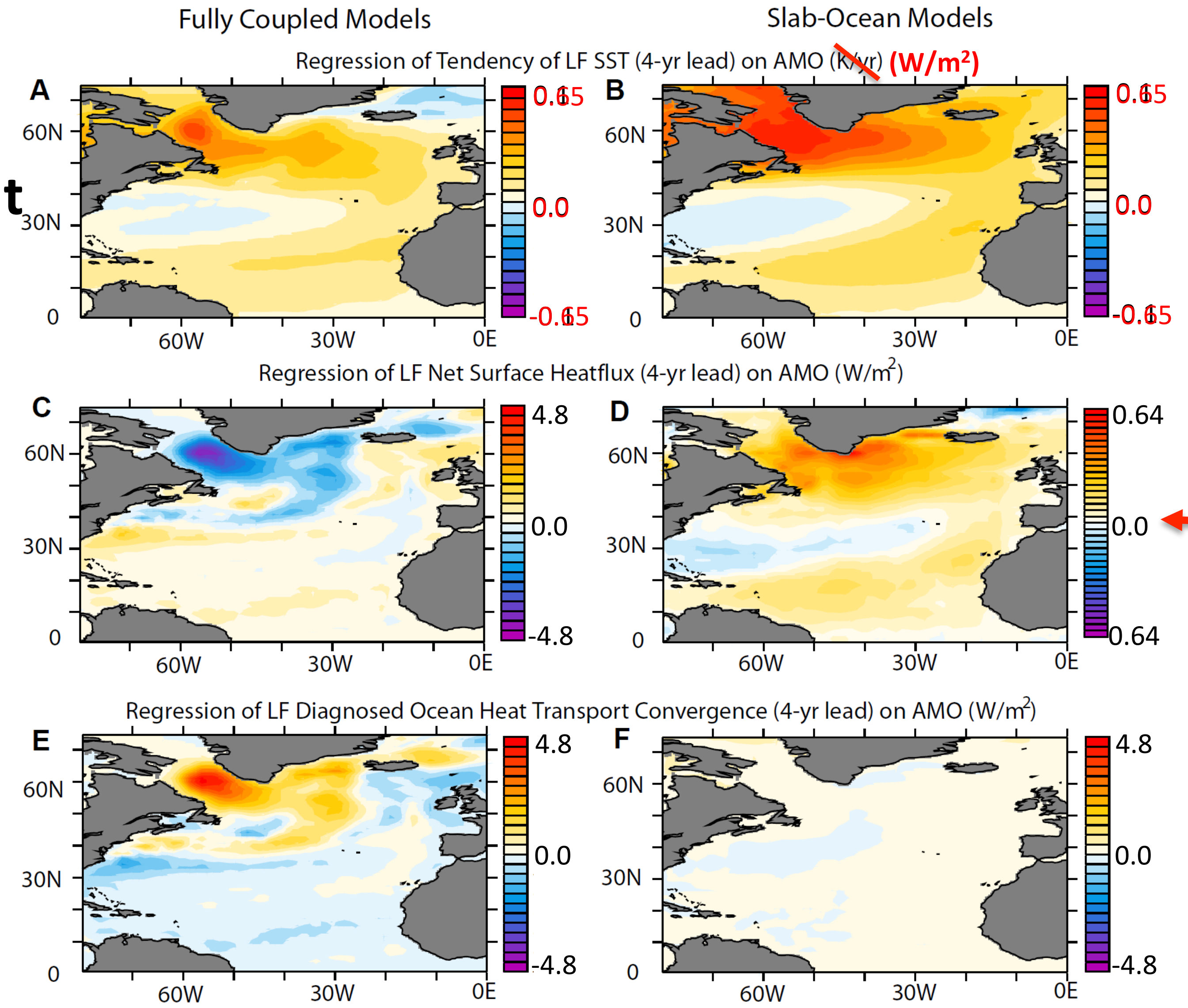

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Heat Flux

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$$\mathcal{E}\{q_a, q_a\} = a^2, \ \mathcal{E}\{q_o, q_o\} = b^2, \quad a^2+b^2 = 1:$$

a^2 is the fraction of forcing variance from the **atmosphere**

b^2 is the fraction of forcing variance from the **ocean**

$\boxed{\text{We now take } q_a \text{ and } q_o \text{ to be } \textbf{white noise} \text{ forcing.}}$

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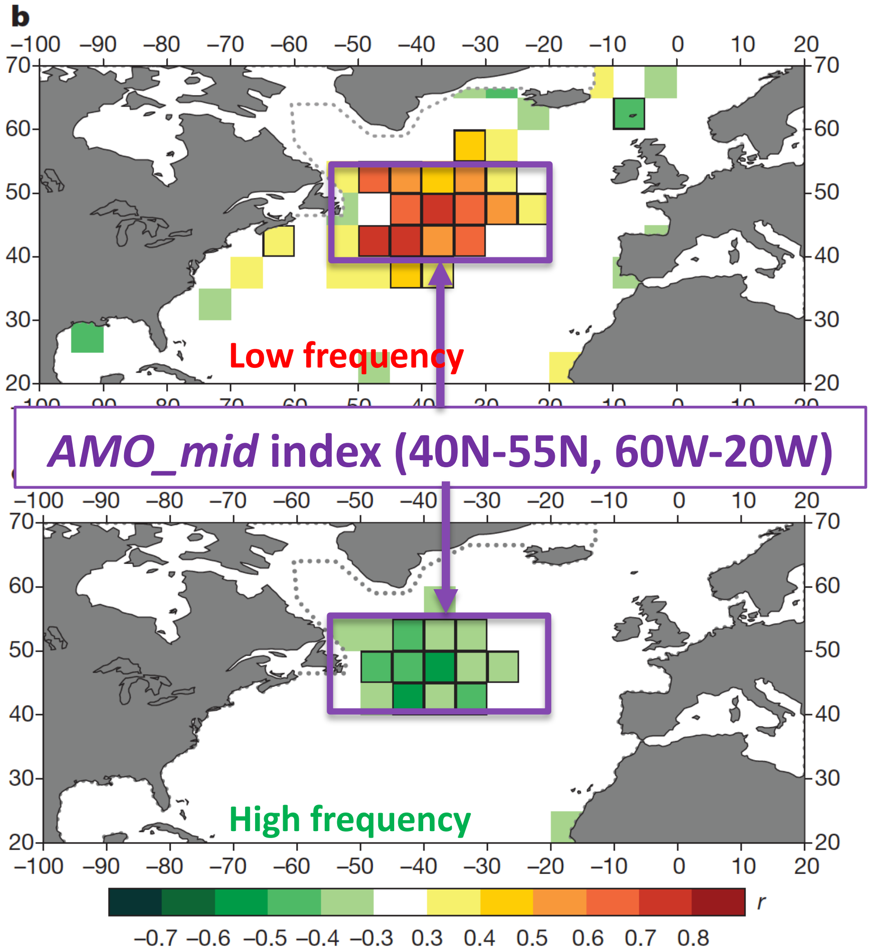

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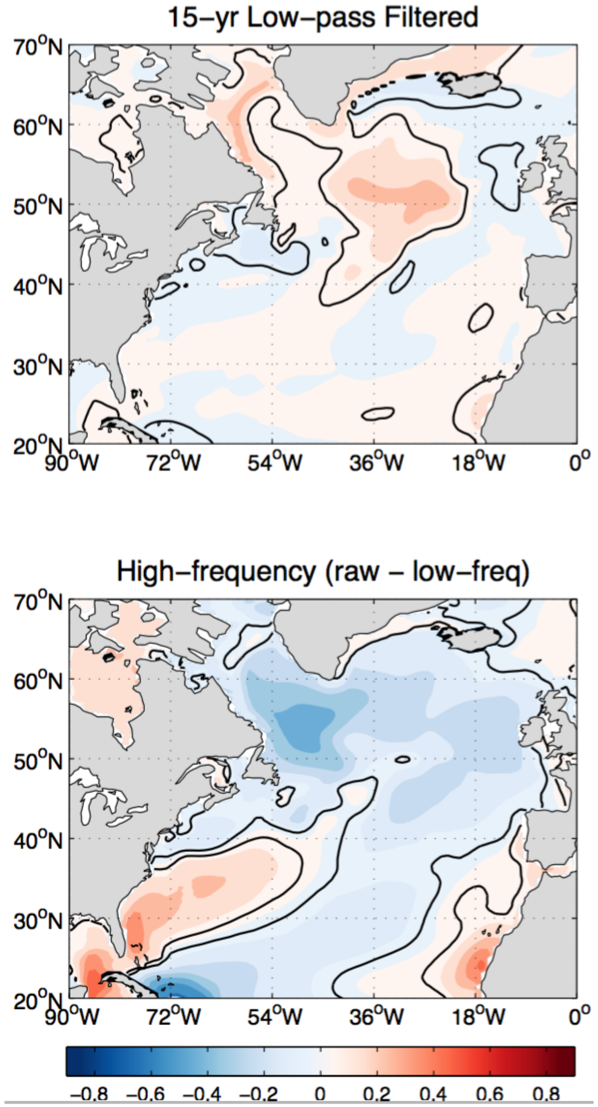
CESM1



Courtesy of Gokhan Danabasoglu