Atlantic Multidecadal Variability is Radiatively Forced. Mostly.

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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

NYC: Rockaway Jacob Riis Park and
Marine Parkway Bridge Brooklyn

This talk is based on:

- **Bellomo,** K. N. Murphy, M. A. Cane, 2017, A. C. Clement, L.M. Polvani, L: Historical Forcings as Main Drivers of the Atlantic Multidecadal Oscillation in the CESM Large Ensemble, *Clim. Dyn.*. DOI 10.1007/s00382-017-3834-3

- **Murphy**, L.N., K. Bellomo, M. A. Cane, A. C. Clement, 2017: The Role of Historical Forcings in Simulating the Observed Atlantic Multidecadal Oscillation, *Geophys. Res. Lett.* **44**(5), 2472-2480 10.1002/2016GL071337

- **Cane**, M.A., A. C. Clement, L.N. Murphy, L.N., K. Bellomo, 2017: Low Pass Filtering, Heat Flux and Atlantic Multidecadal Variability, *J. Climate.* **30** (18) 7529-7553 10.1175/JCLI-D-16-0810.1

- **Clement,** A.C., M. A. Cane, L.N. Murphy, K. Bellomo, T. Mauritsen, B. Stevens, 2016: Response to Comment on "The Atlantic Multidecadal Oscillation without a role for ocean circulation" *Science* **352**, (6293) 1527. [doi: 10.1126/science.aaf2575]

- **Clement**, A., K. Bellomo, L.N. Murphy, M.A. Cane, G. Rädel, B. Stevens, T. Mauritsen, 2015: The Atlantic Multidecadal Oscillation Without a Role for Ocean Circulation. *Science* **350**, no. 6258, 320-324.

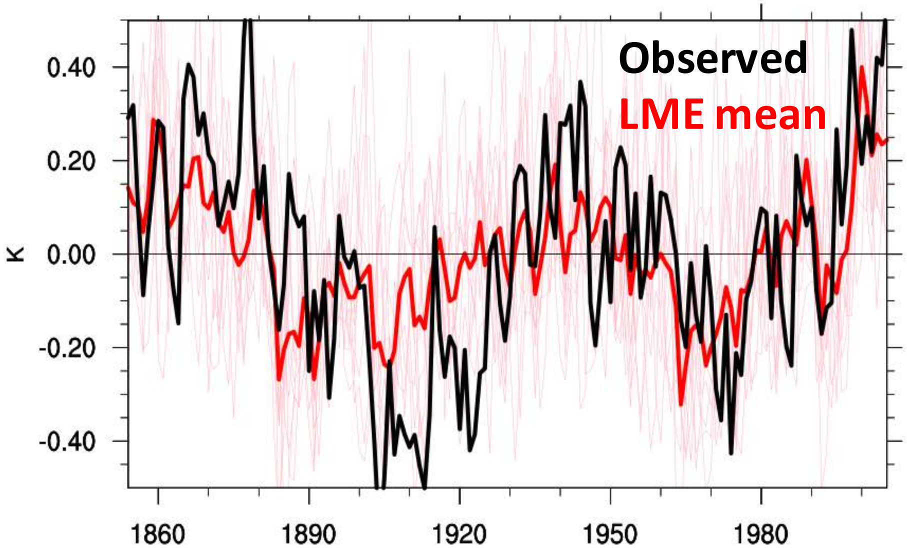
OUTLINE

- Radiative Forcing of AMV ("Signal")
  - Murphy et al. 2017, Bellomo et al. 2017
  - Hardly a new idea with us:
  - Mann and Emanuel 2006, Otterå et al. 2010, Terray 2012, Booth et al. 2012, Dunstone, et al. 2013, Cheng et al. 2013, Martin et al. 2014, Allen et al. 2015, Steinman et al. 2015, Bellucci et al. 2017, Booth, 2017 Nature
- Internal variability and the AMV ("Noise")
  - But not quite all is noise – not in the subpolar gyre
- Conclusions

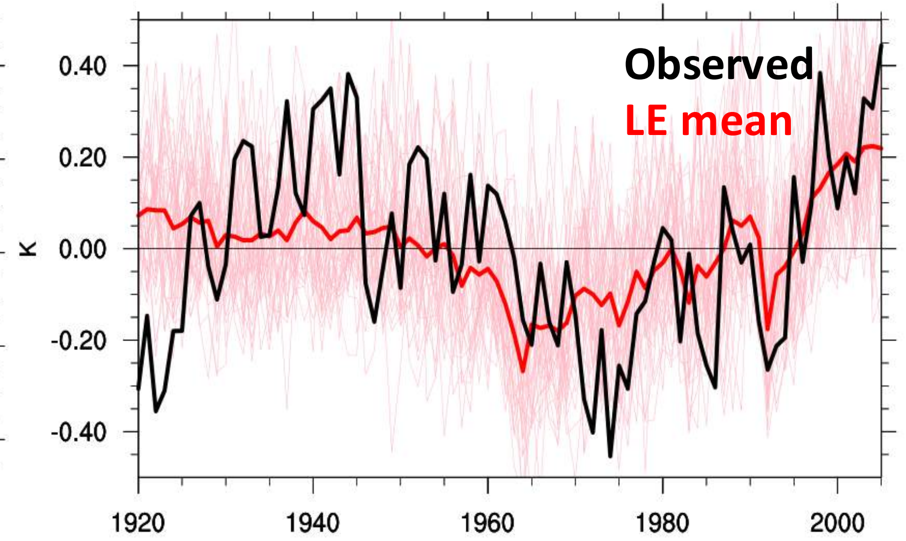
Jacob Riis Park, New York City

NASST in Observations and CESM Large Ensembles

NASST index 1854-2005



NASST index 1920-2005



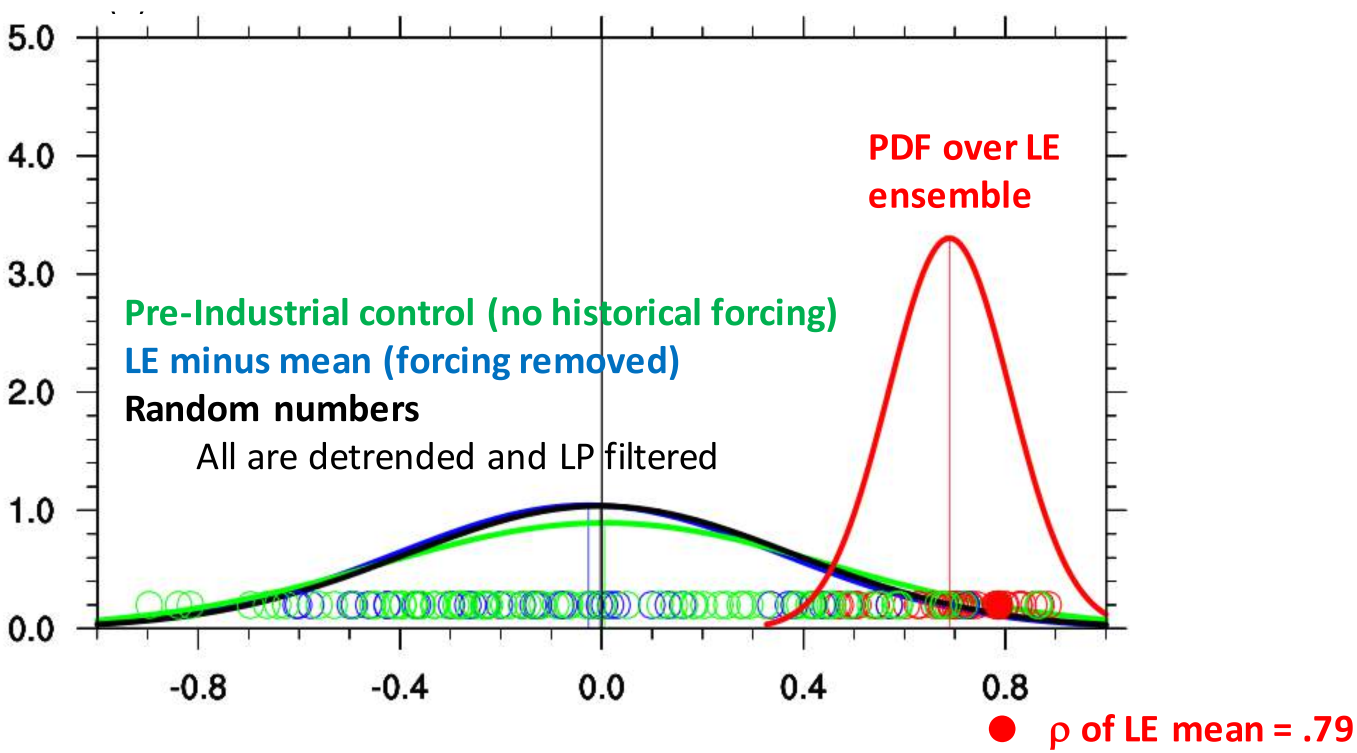
NASST index = SST averaged over the North Atlantic (0-60N,80W-0)
LME = Last Millennium Ensemble (10 members, CESM)
LE = Large Ensemble (42 members, CESM)
Light red = individual ensemble members

Mean: the internal variations are averaged out;
≈ Forced Component only

Bellomo et al. 2017

AMO: LE correlation with Observed 1920-2005

AMO index = NASST linearly detrended and LP filtered (20-year Lanczos filter)



From Bellomo et al. 2017

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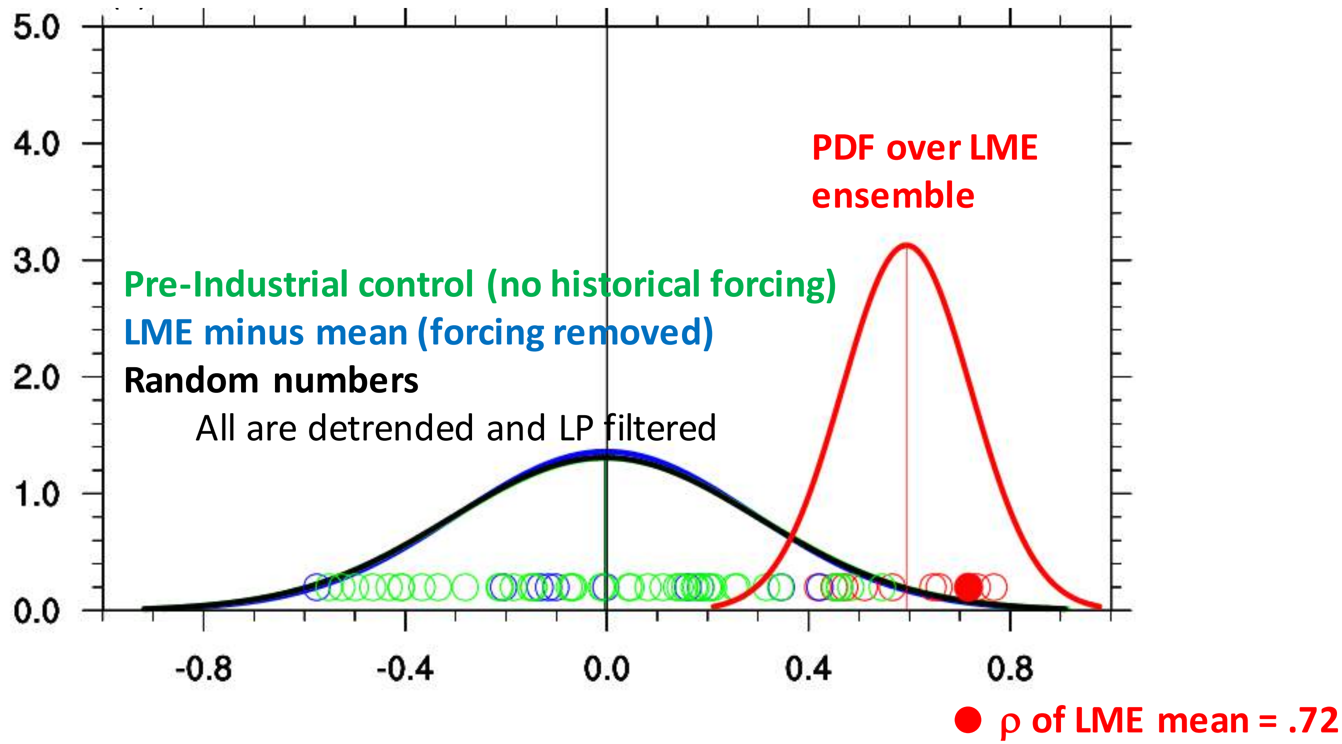
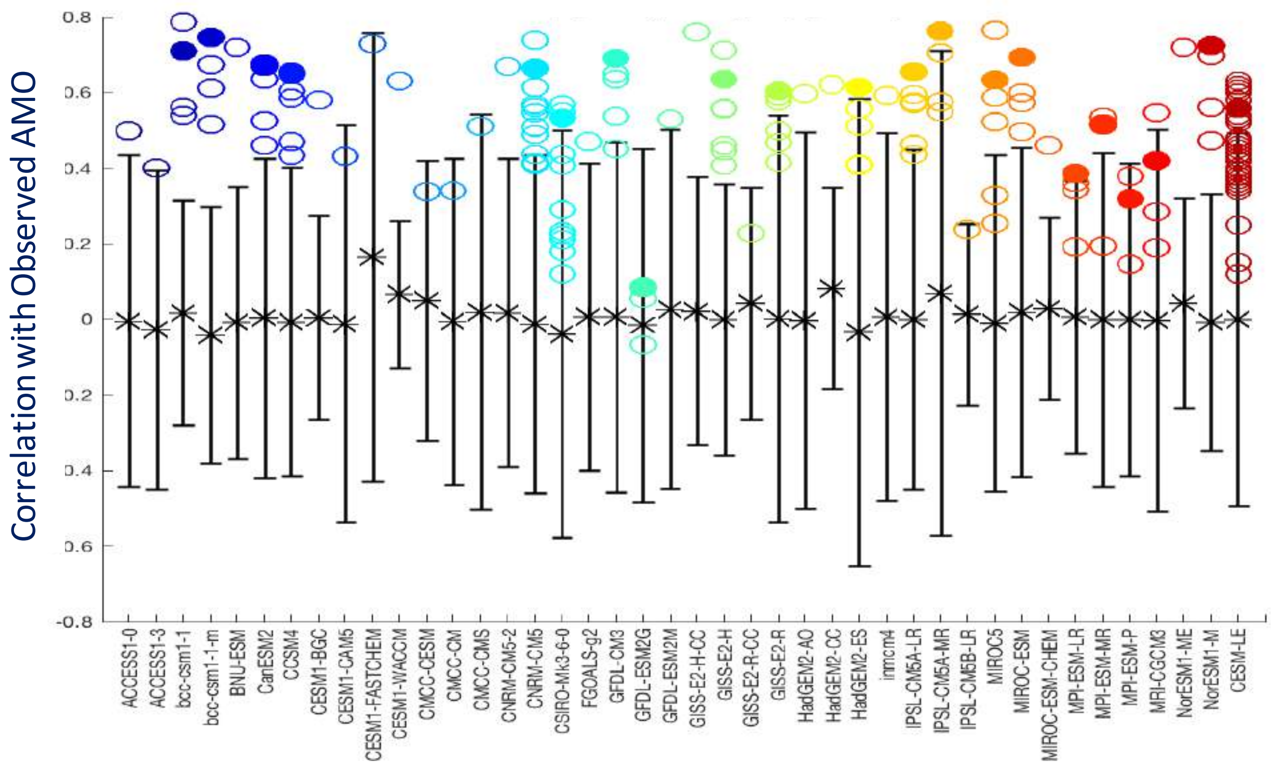


From Bellomo et al. 2017

CMIP5 models *without* historical forcing do not produce agreement with observations

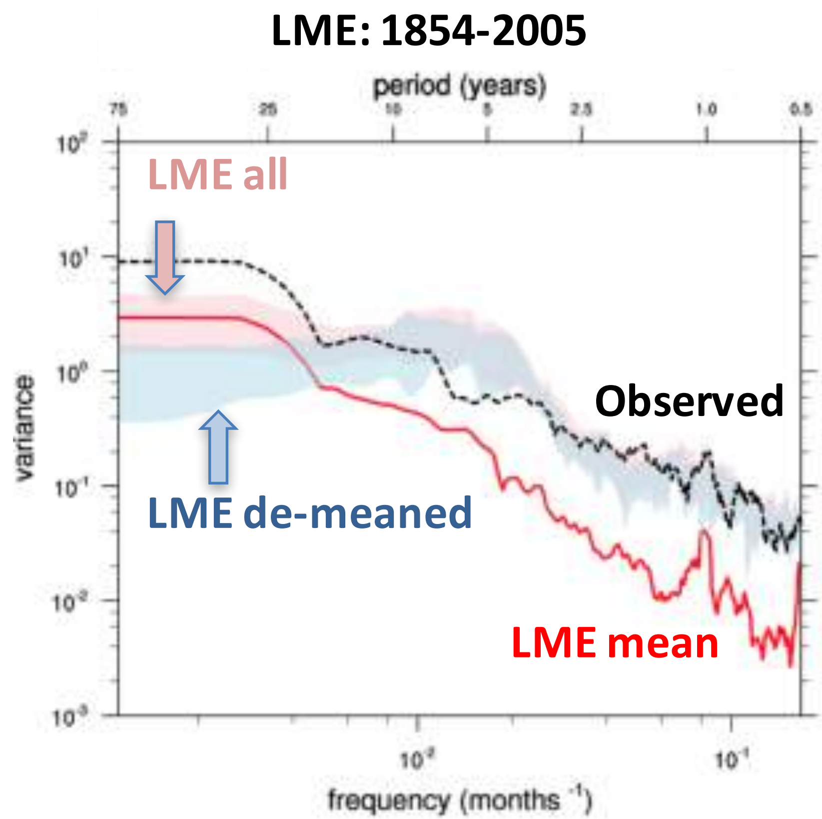


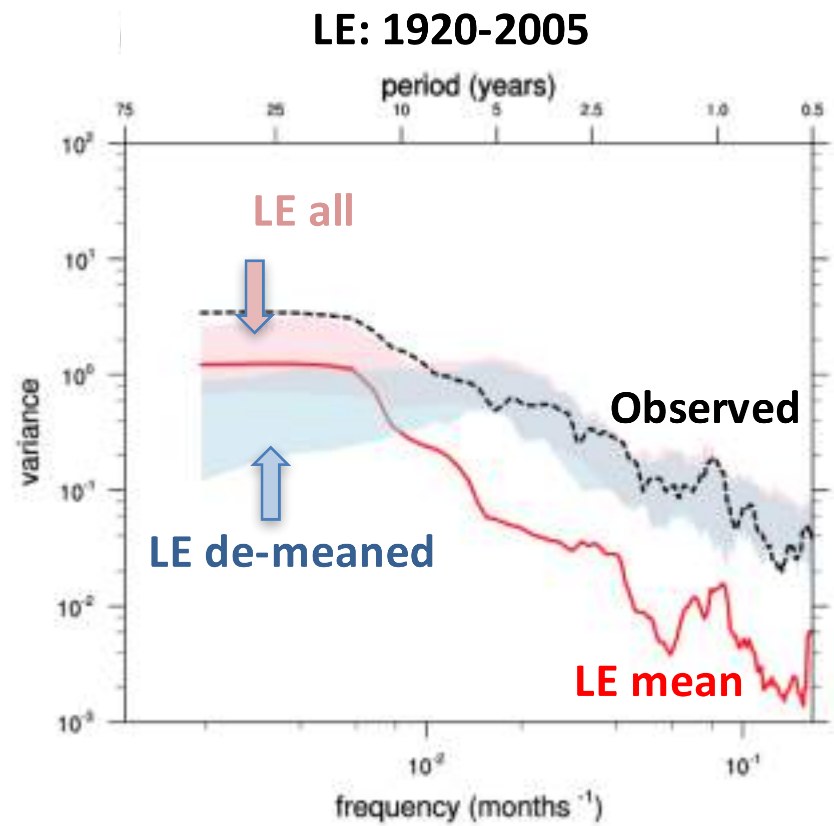
COLORS:
External forcing
(HIST)

BLACK:
No external forcing
(Pre-industrial)

Murphy et al. 2017

NASST Index Power Spectra





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LME = Last Millennium Ensemble (10 members, CESM)

LE = Large Ensemble (42 members, CESM)

Light red = envelope of individual ensemble members

Light blue= envelope of individual ensemble members, mean (forced part) removed

From Bellomo et al. 2017

These correlations imply **Bounds** on **INTERNAL/TOTAL variance in Observed AMO index**

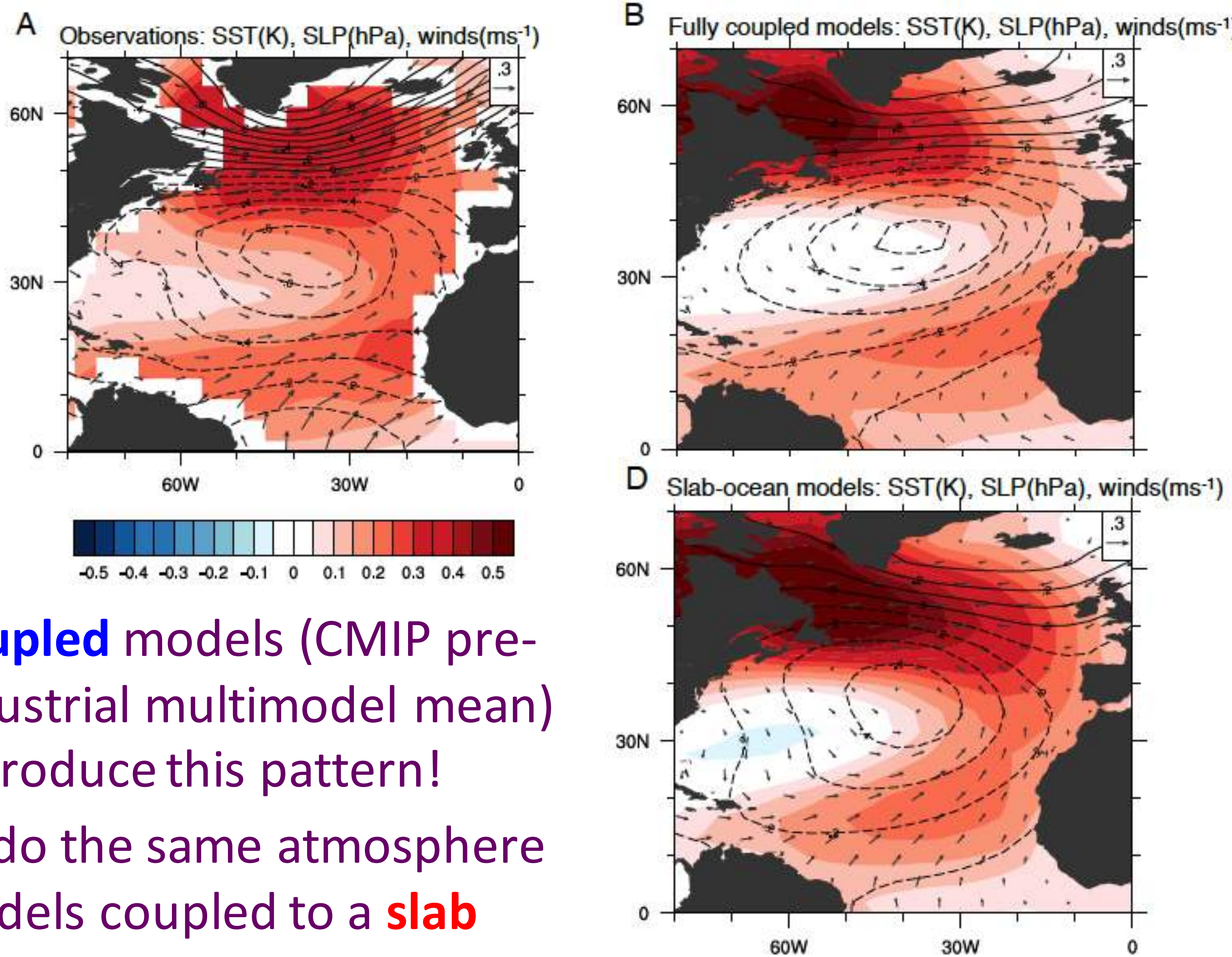
	MAX	MIN
LME 1854-2005:	0.48	0.0
LE 1920-2005:	0.39	0.0
LME 1920-2005:	0.28	0.0

- **Maximum** is reached only if the model **perfectly** captures the forced response. (any takers?)
- **Minimum** (0.0) means **no** internal variability at all. (Not credible.)

A reasonable estimate for the observed is 20-40%;
FORCED:INTERNAL ≈ 2:1.

Model is ≈ 0.4 (too high) but model variance is too low

What is the nature of the internal variability?



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

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

Clement et al. 2015

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

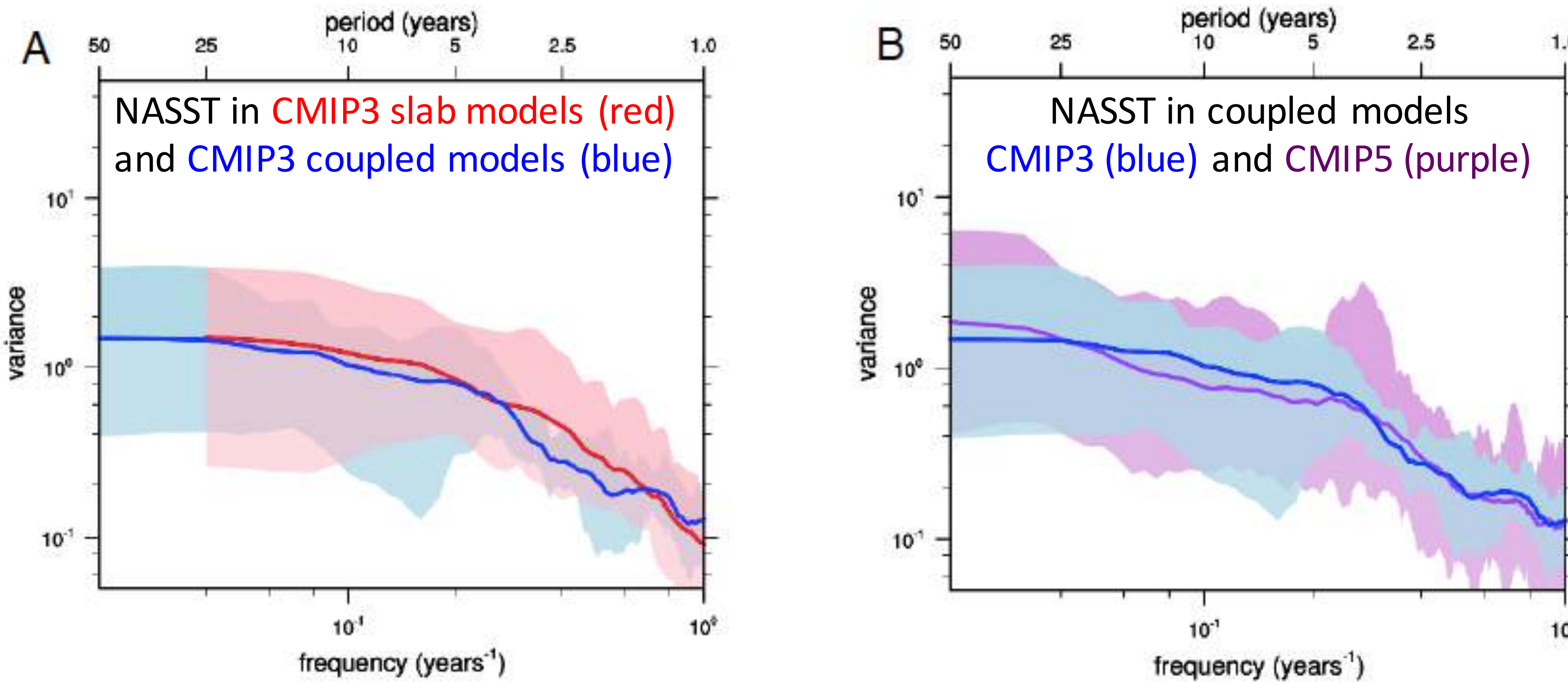
How can the Atmosphere + (constant depth) Ocean Mixed Layer generate the same AMO patterns as a model with fully active ocean dynamics?

- 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

Lets look at the time/frequency behavior:

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

NB: All are PI runs; No External Forcing. All variability is Internal.



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

Clement et al 2015

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

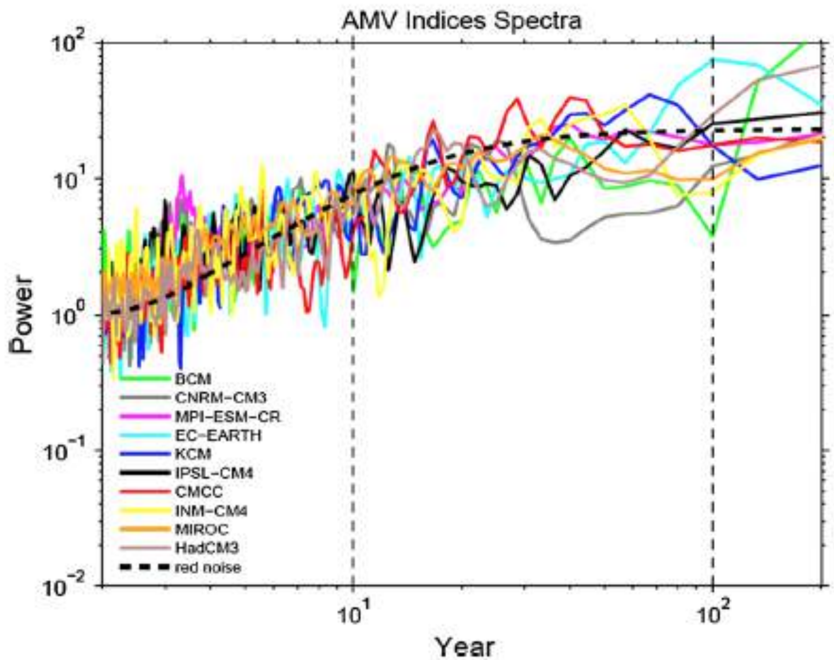
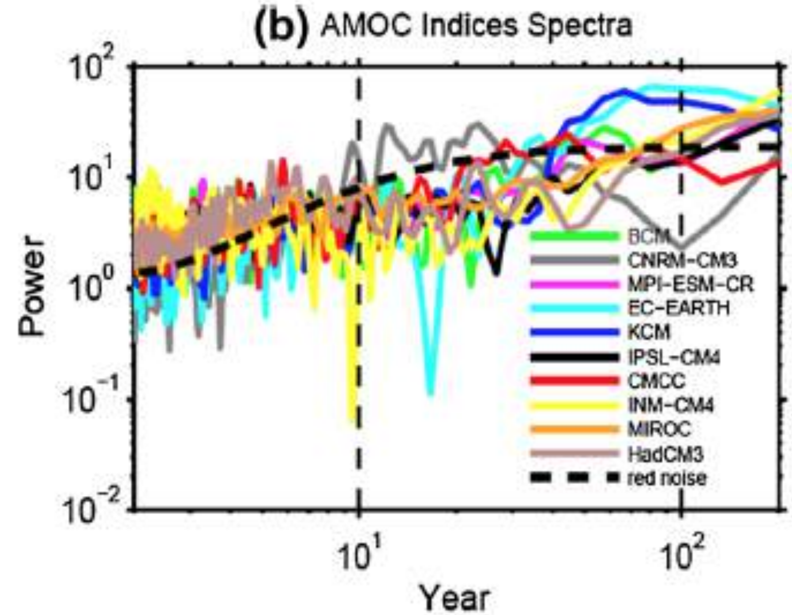


Fig. 2 The spectra of detrended AMV Indices in ten coupled general circulation models (CGCMs). The AR1 red noise fit is the mean of the AR1 red noise fits from ten models. Due to the varying autocorrelation for the models, the individual red-noise spectra are not shown



The SST Equation may be written as

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

v

$-\alpha T$ 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 + ocean mixed layer effects

To enlighten us about **Internal Variability in Pre-Industrial (no external forcing) GCMs,** we go very simple:

and take q_a and q_o to be **white noise** forcing.

Cane et al. 2017

But are the ocean and atmosphere fluxes white?

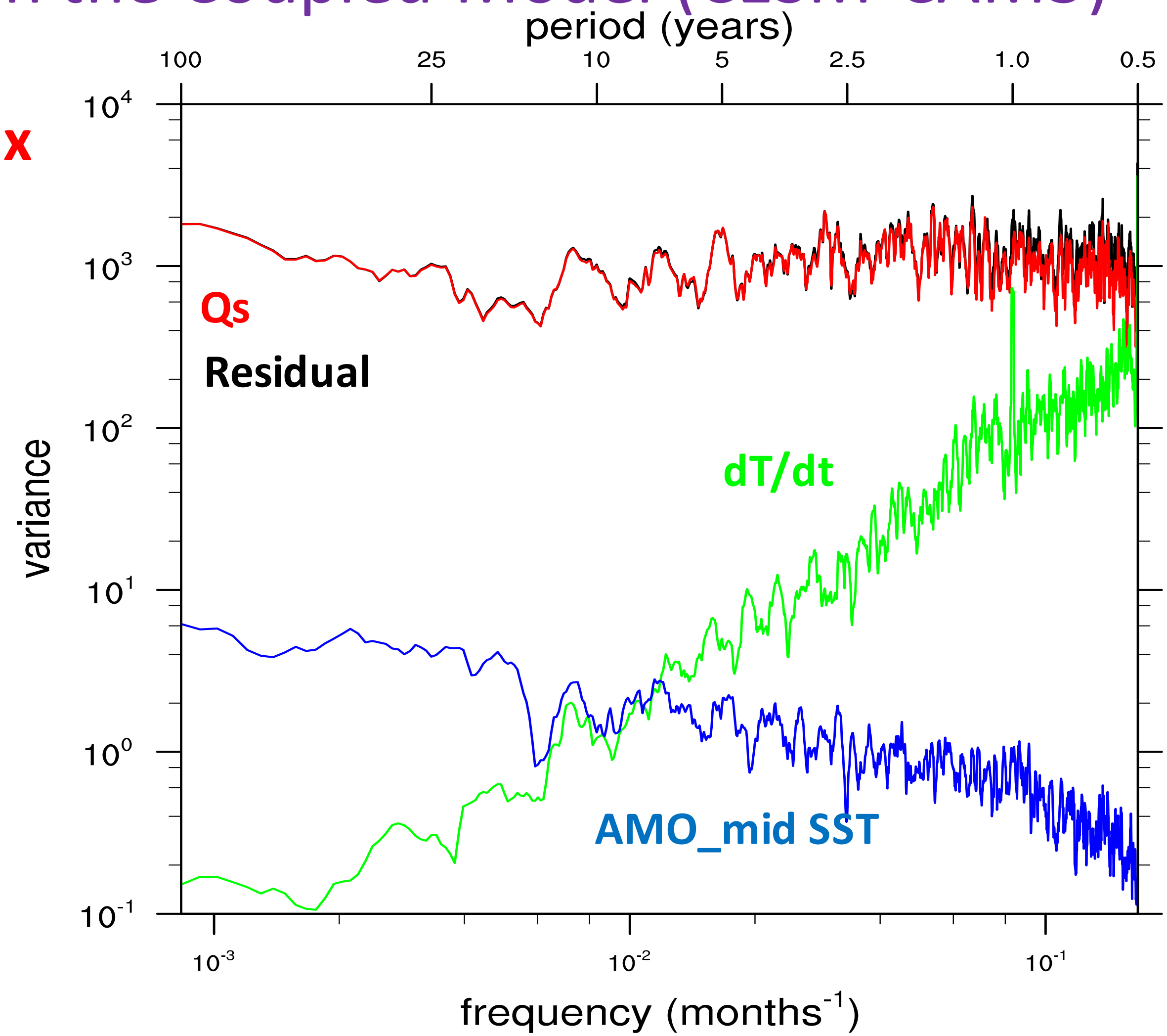
Wunsch, 1999; Stephenson et al 2001 say NAO is white.

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

Qs = Surface Heat Flux

Residual = dT/dt-Qs

= Q_ocean



All quantities are averages over the **AMO_mid** region (60-20W, 40-55N)

Cane et al. 2017

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

$R(t)/R(0)$

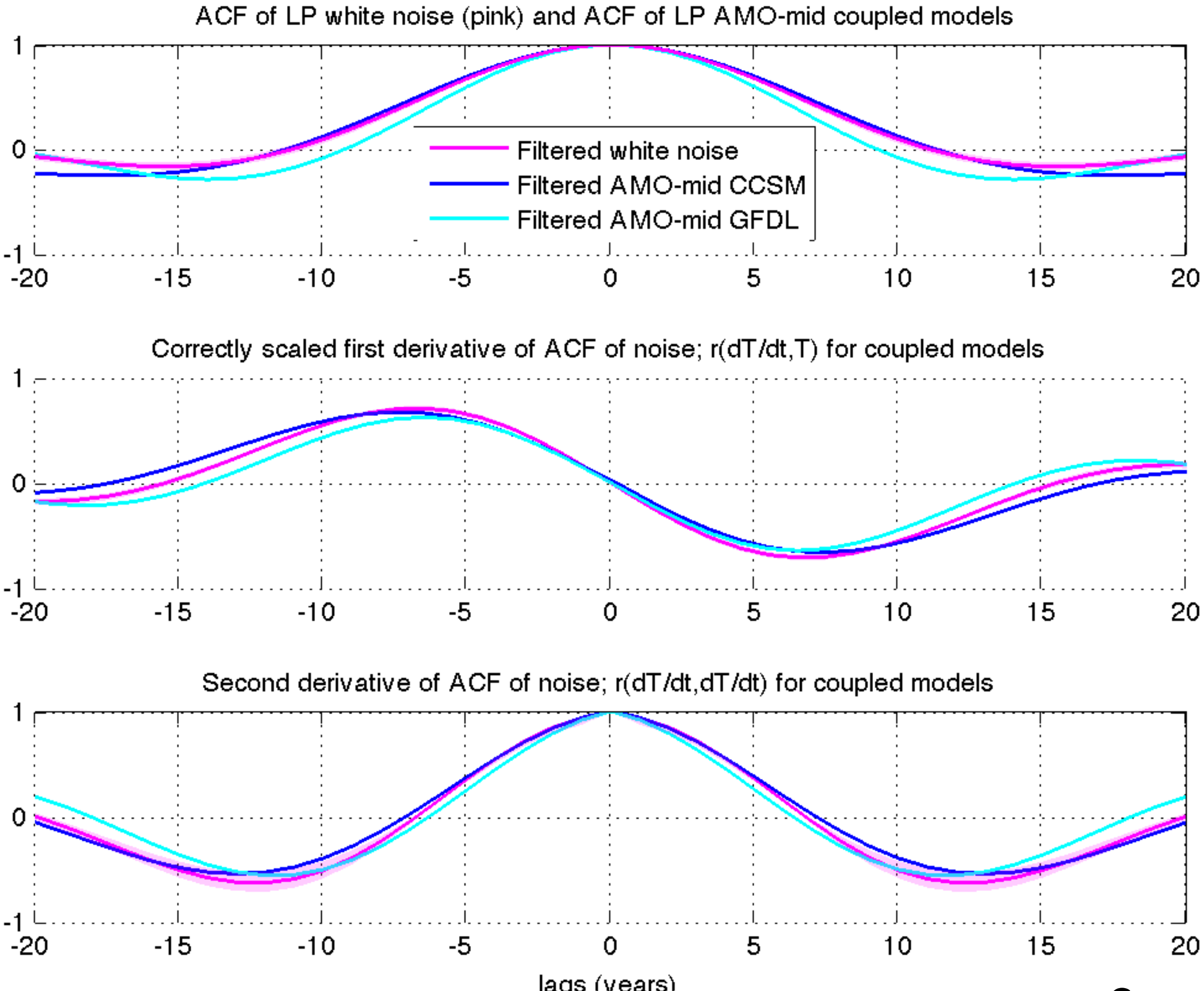
$\rho(T,T)$

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

$\rho(dT/dt,T)$

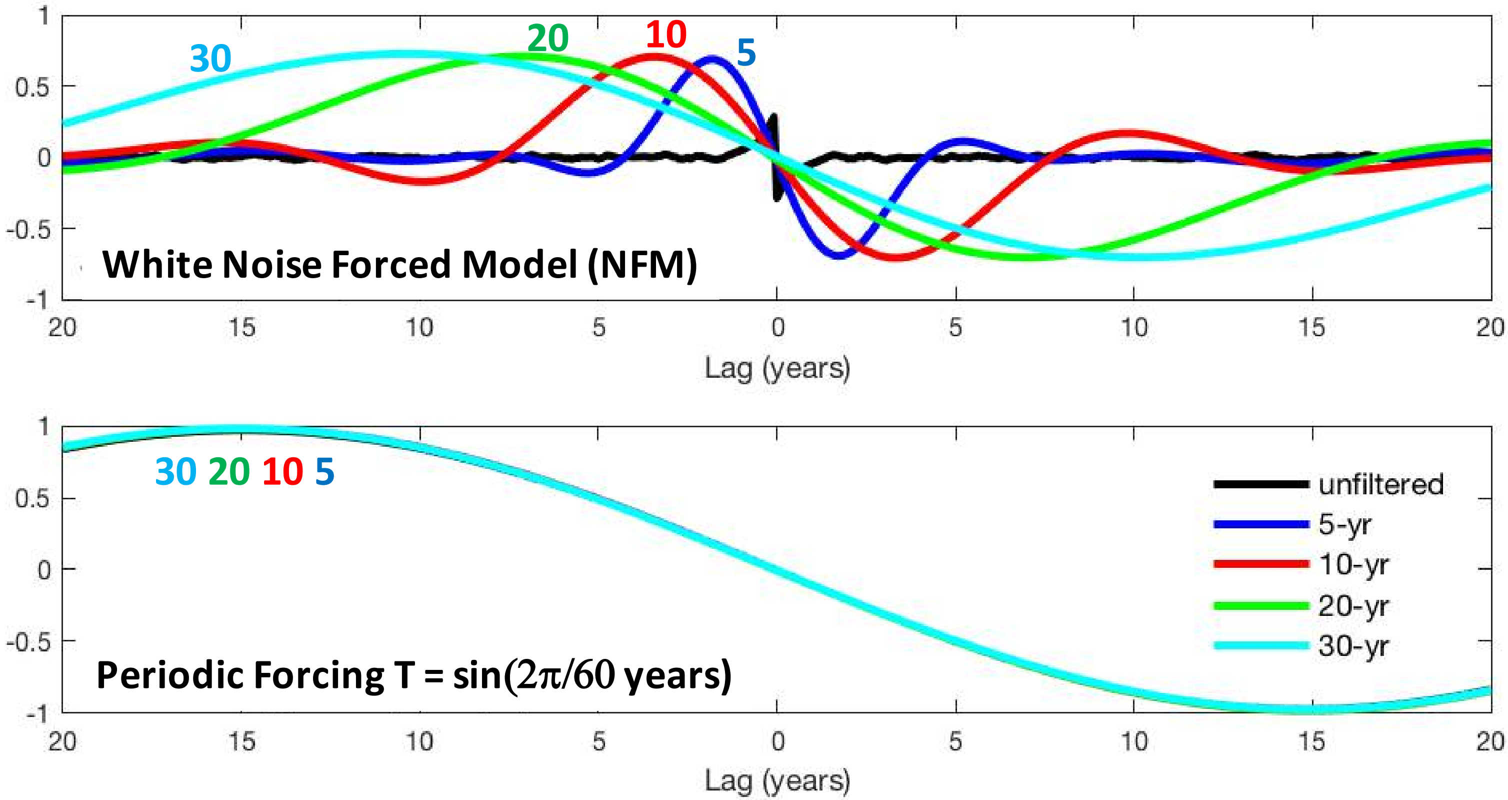
$-R_{tt}(t)/[-R_{tt}(0)]$

$\rho(dT/dt, dT/dt)$



Cane et al. 2017

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



Cane et al. 2017

Low frequency forcing + noise

$$dT/dt = -\alpha T + q_a + q_o + c^2 \sin(2\pi t/60\text{years})$$

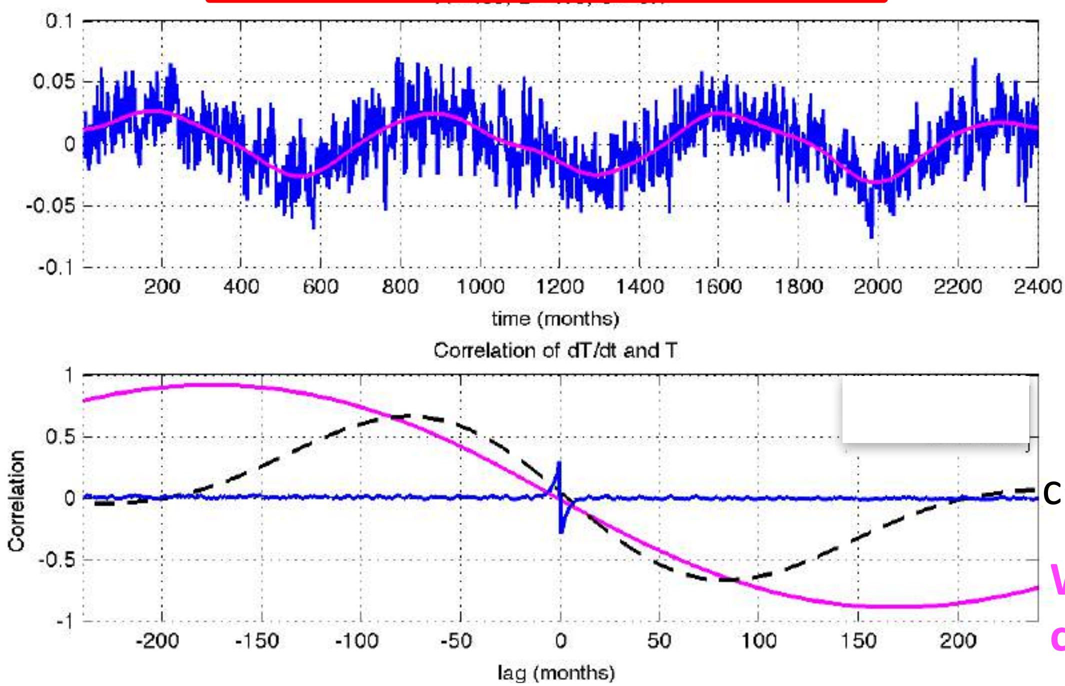
q_a, q_o are white noise with variances $\sigma^2(q_a) = a^2$; $\sigma^2(q_o) = b^2$

Set $a^2 = 0.85$, $b^2 = 0.15$, $c^2 = 0.1$

Signal/Noise = $c^2/2$ = 5%

T(t)

$\rho(dT/dt, T)$



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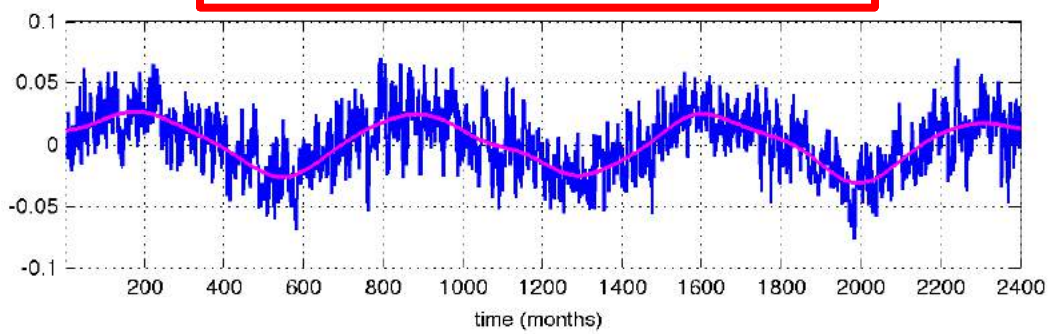
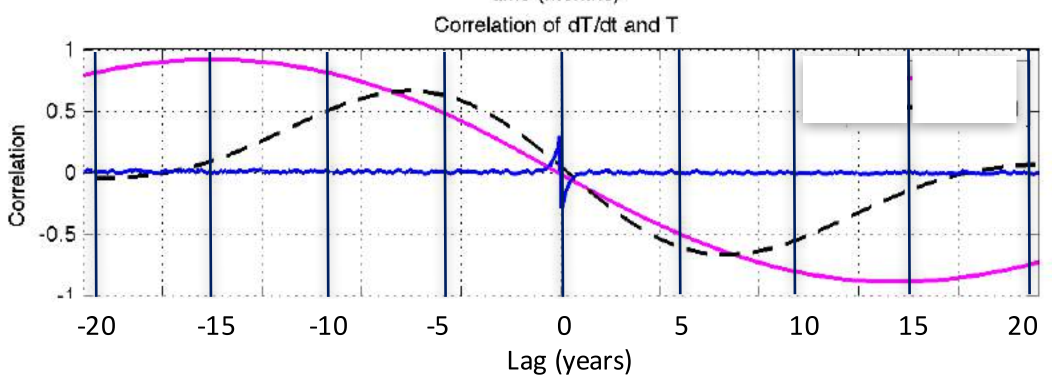


ρ(dT/d



$c^2=0$

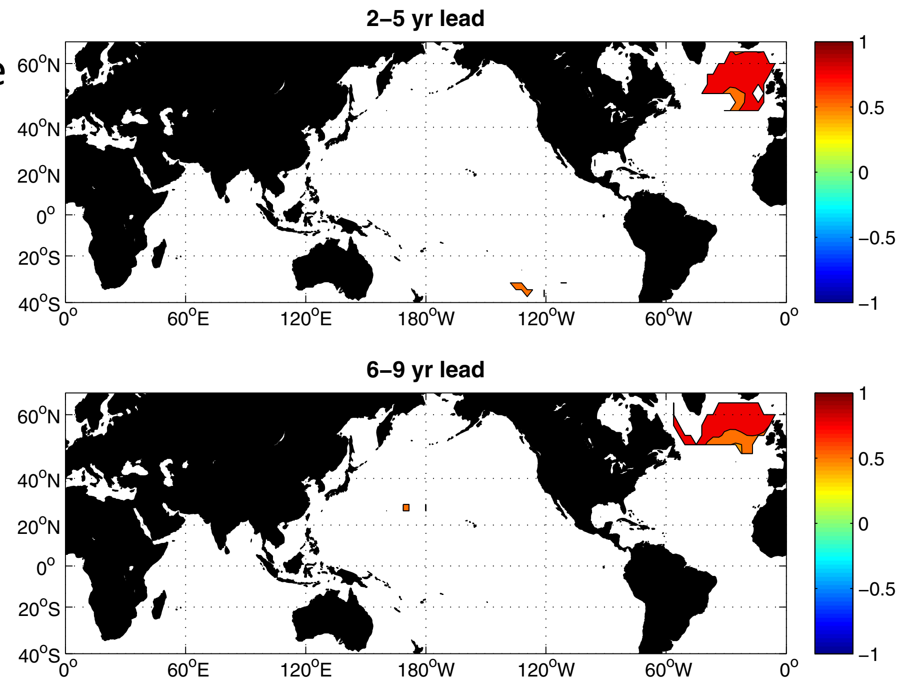
With periodic $c^2 = 0.1$

Cane et al. 2017

But there is some evidence from decadal prediction work that ocean circulation matters in the Subpolar North Atlantic

"Only correlation coefficients that exceed the 'no-skill' statistical reference forecast at the 90% confidence and exceed the NoInit* run at 90% confidence are plotted."

* Noinit = (small) HIST ensemble;
i.e. Externally Forced



But perhaps not the buoyancy driven circulation -- the AMOC:

"…near-term prediction in this region may not rely on skillful AMOC prediction, only on adequate AMOC initialization—or more precisely, adequate initialization of temperature and salinity fields that support the correct geostrophic currents."

Piecuch et al. 2017 show it is wind-driven horizontal circulation (1994–2015)

Karspeck et al. 2015
Figure 10

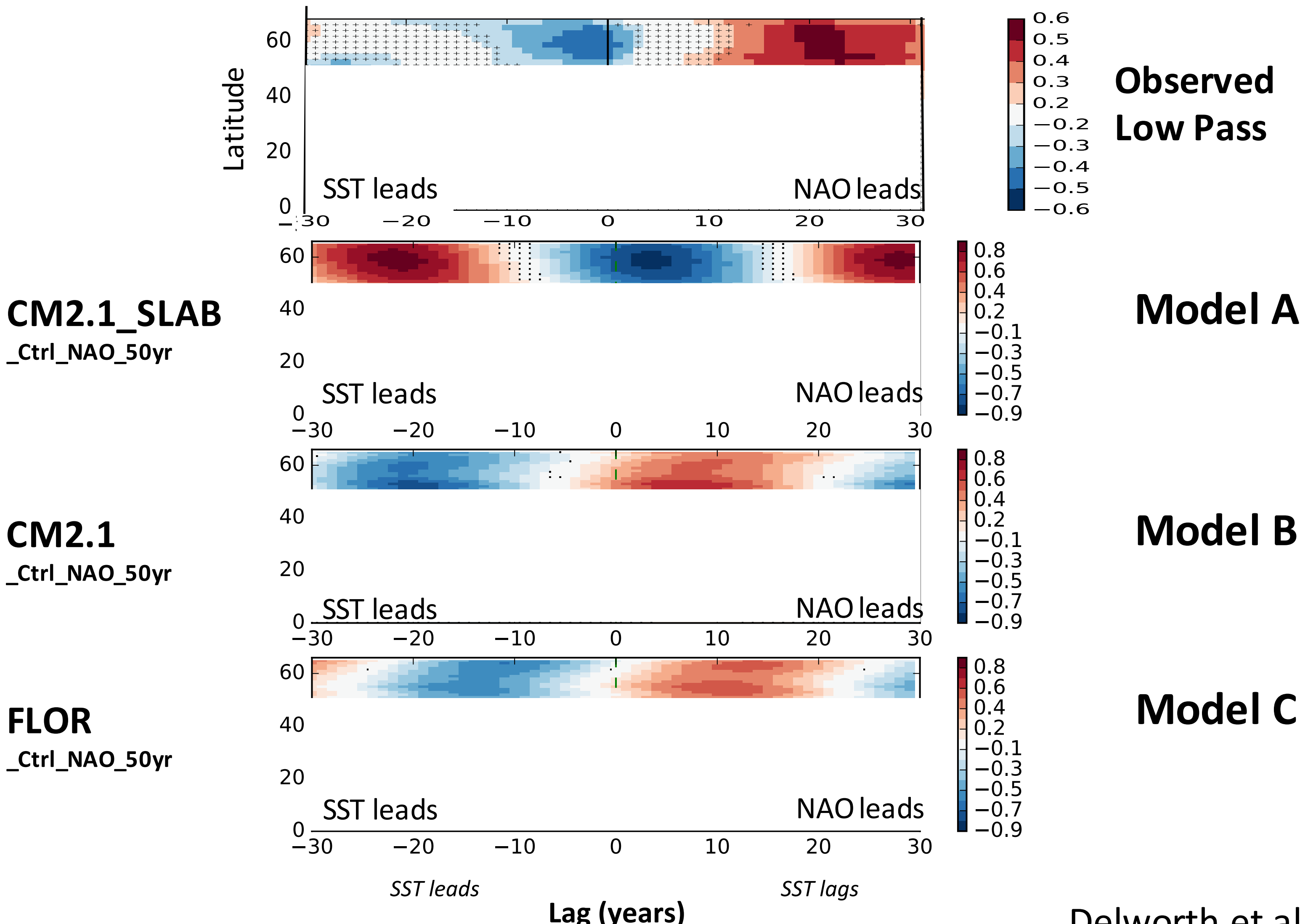
Conclusions

- The *observed* Atlantic Multidecadal Variability is radiatively forced. Mostly.
  - By greenhouse gases, anthropogenic (tropospheric) aerosols, volcanic (stratospheric) aerosols.
- The internal component is short timescale *noise*, largely in the atmosphere but also in the ocean, turned multidecadal by LP filtering. Mostly.
- The North Atlantic Subpolar Gyre is an exceptional place where *horizontal gyre circulation* matters.
- The Indo-Pacific probably matters too, and maybe more (it does for the NAO –Scaife et al., others)

Jacob Riis Park, New York City

SST vs. NAO Lead-Lag Correlations

Models runs are PI Control + NAO_50yr



Delworth et al. 2017
Figures 1, 6

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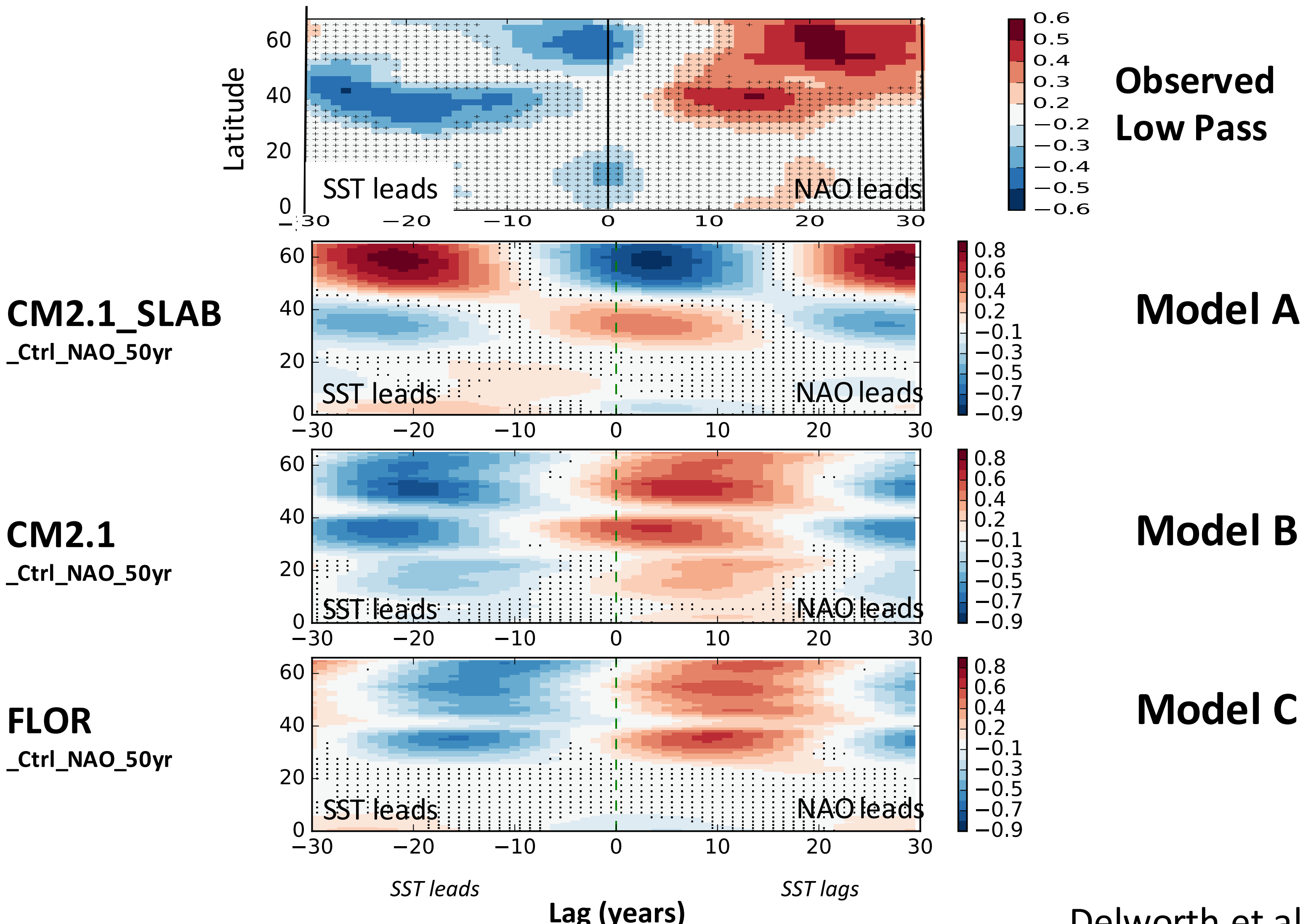
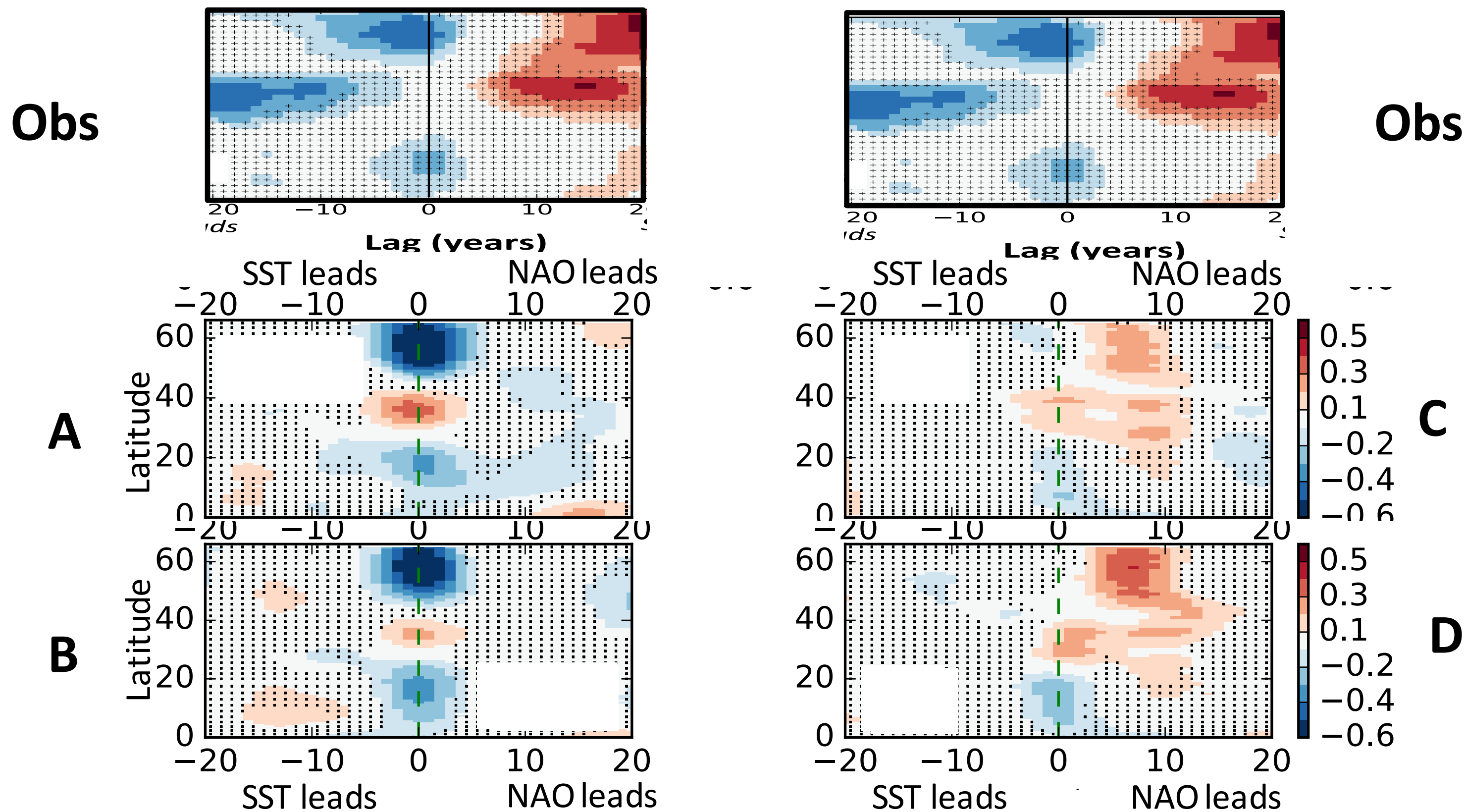


Delworth et al. 2017
Figures 1, 6

Correlation of LP filtered SST with NAO
PI runs; Internal variability only



Delworth et al. 2017
Figures 1, 3

Observed

vs.

CMIP5 control (PI) runs

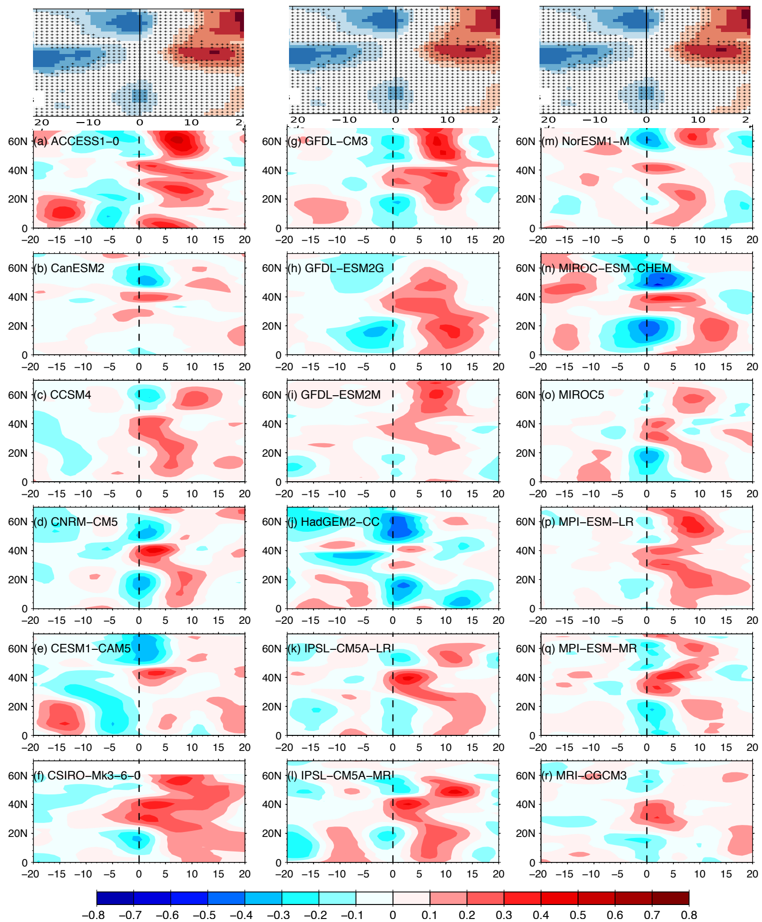
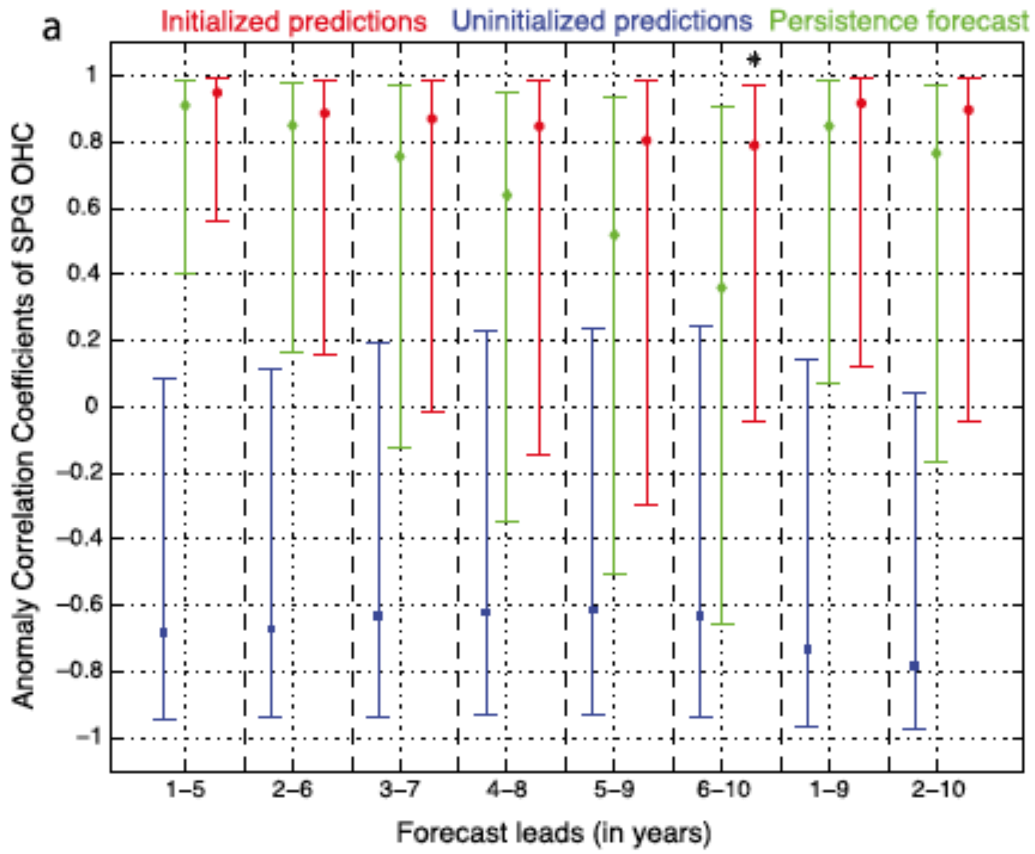


Figure 7 Lead-lag correlation analyses, similar to Figure 3f and 3h, using output from CMIP5 models (models were used that had Control simulations at least 300 years in length).

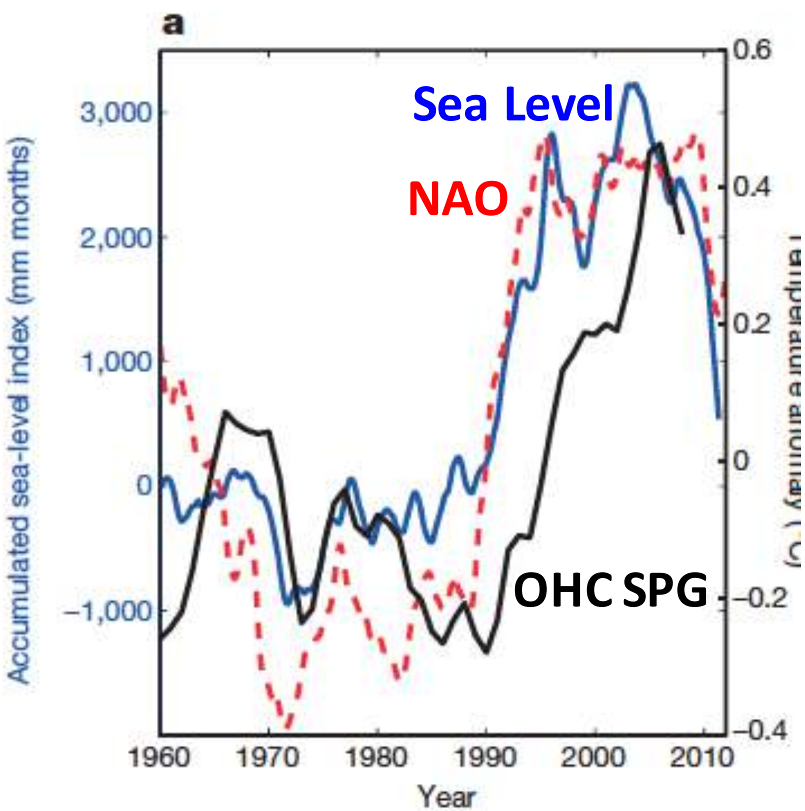
Delworth et al. 2017
Figures 1, 7

Msadek et al. (2014): predicting the 1990's shift

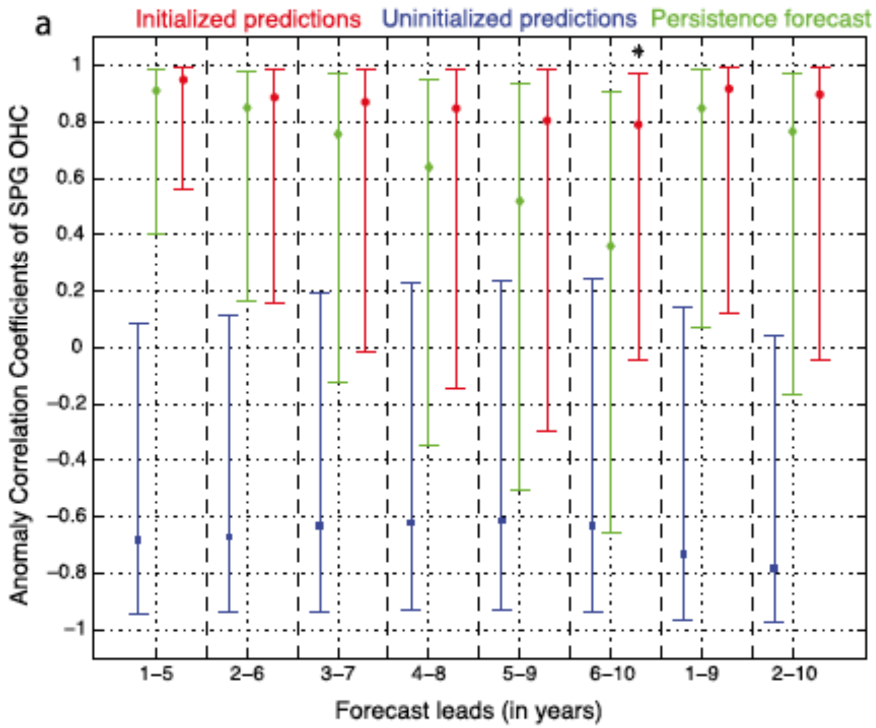


Initialization gives no significant improvement over **Persistence**

Predicting the 1990's shift



McCarthy et al. (2015): observations of NAO (red), sea-level (blue), and OHC SPG (black)



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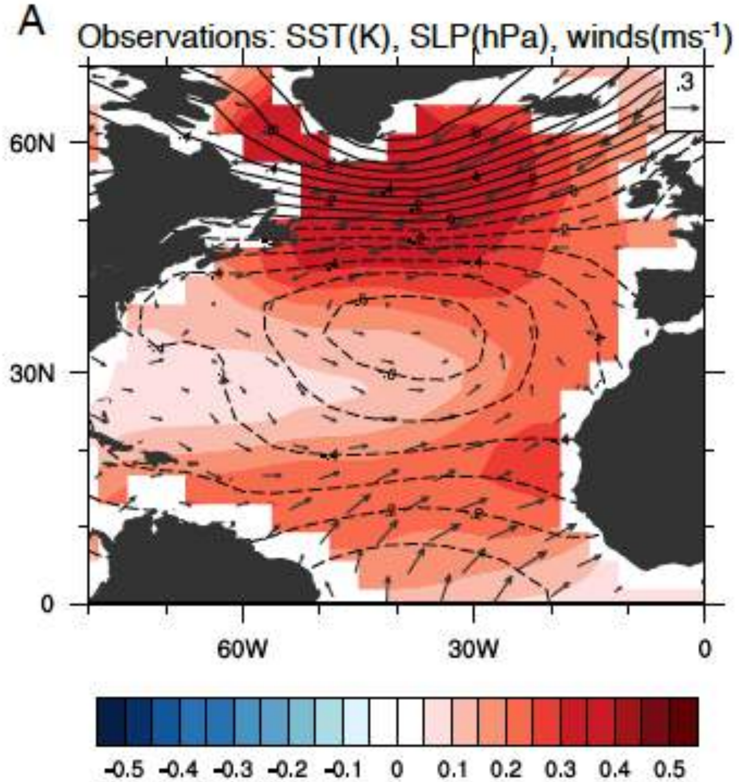

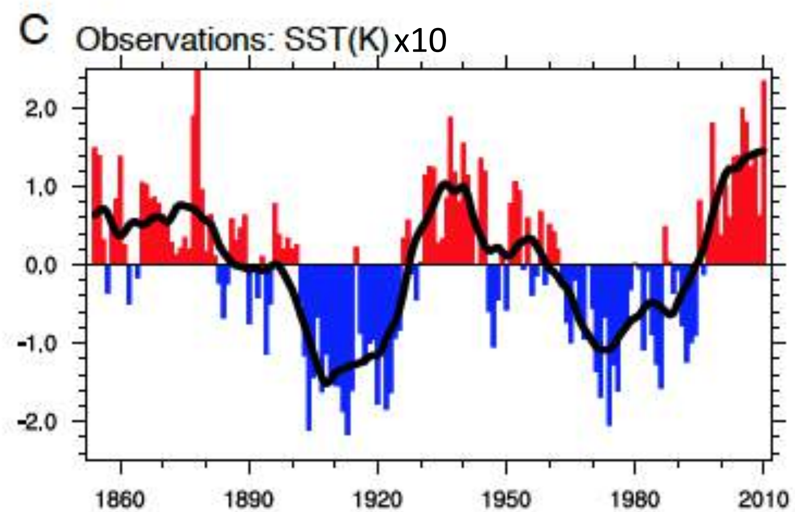

AMO

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.

AMV Impacts (Davini et al 2015, *ERL*)

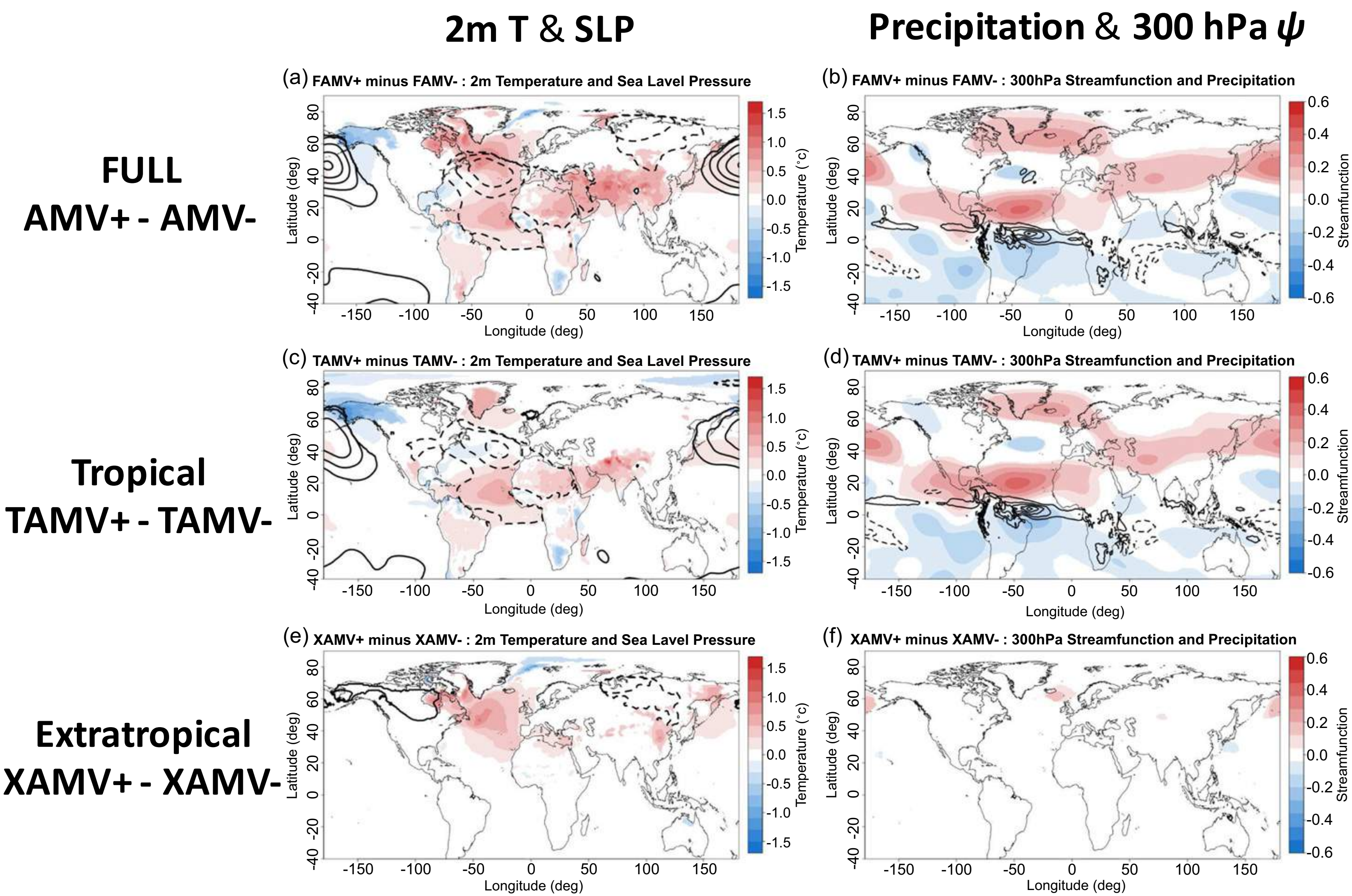

Figure 3. Anomalies of 2 m temperature (color) and sea level pressure (SLP, contours) for (a) FAMV, (c) TAMV and (e) XAMV experiments. Anomalies of 300-hPa streamfunction (colors) and precipitation (contours) for (b) FAMV, (d) TAMV and (f) XAMV experiments. Anomalies are expressed as positive minus negative AMV phase. Solid contours is positive and dashed is negative. For SLP, contours are drawn each 0.5 hPa. For precipitation, contours are drawn each 0.5 mm day^{-1}. Only values where the 2% significant level is reached are drawn.

Summary

- The AMO in pre-industrial runs of both fully coupled and slab ocean models have the same spatial characteristics, and the same red spectrum. They match the observations.
- Interactive ocean heat and salt transport in climate models does not change space-time characteristics of the AMO.
- Low frequency 20th C variability in models is due to radiative forcing by external factors (aerosols, CO_2, solar), not the ocean.

Interpretation (model based)

- The AMO is the ocean mixed layer response to N. Atlantic atmospheric forcing,
- both to white noise and to low frequency external forcing.
- The surface heat exchange is seemingly able to adjust to ocean heat flux divergences and largely maintain the AMO pattern.