# The Atlantic Multidecadal Oscillation Without a Role for Ocean Circulation

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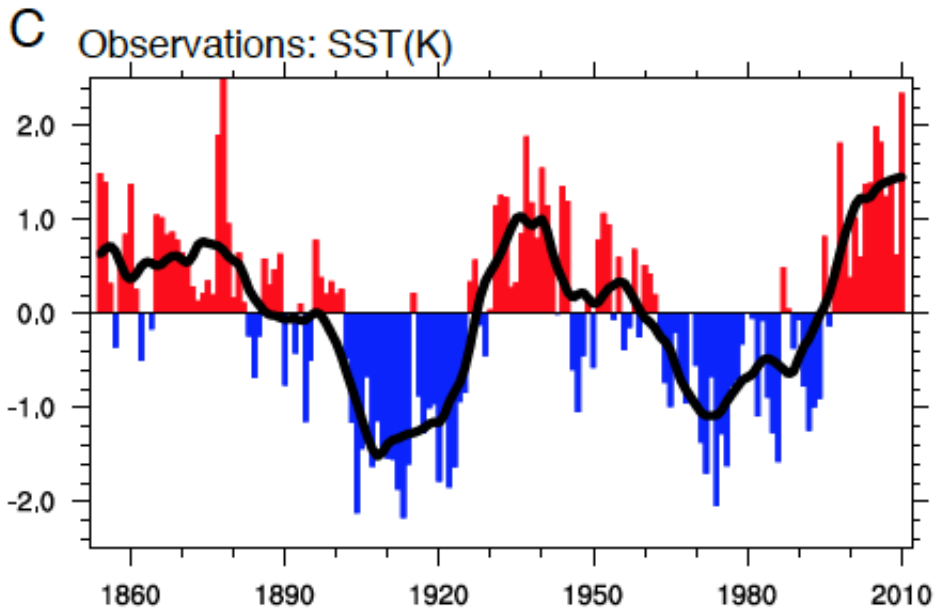
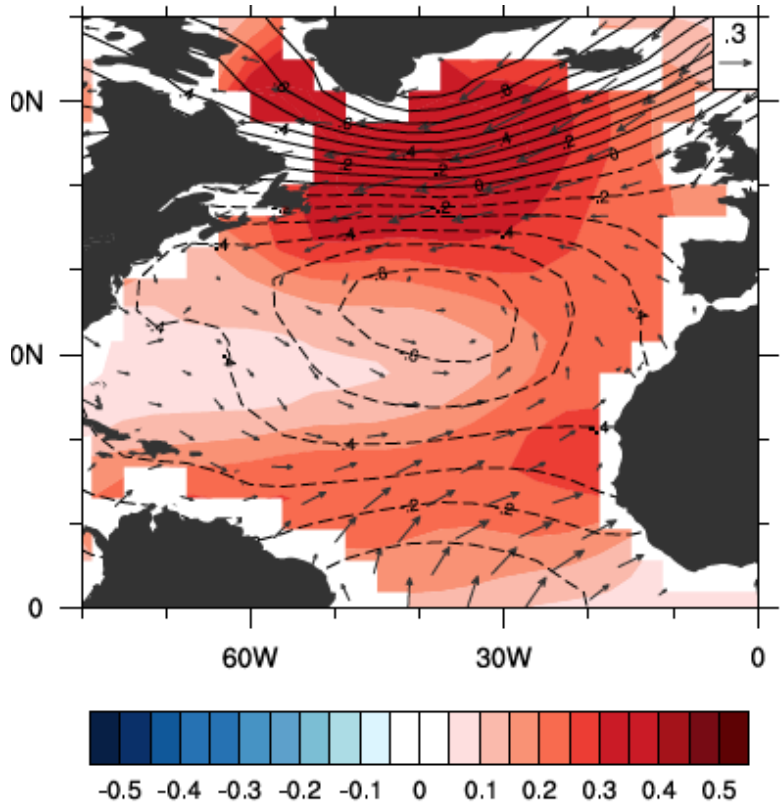
# The Atlantic Multidecadal Oscillation

Average North Atlantic SST (0-60N), ***normalized and detrended*** NOAA ERSST v3b




Regression of SST, SLP, and winds on AMO index (NCEP reanalysis)



# What drives the AMO?

Naturally-occurring changes in the strength of the Atlantic Meridional Overturning Circulation change the amount of heat delivered to the North Atlantic which appears in the SST record…

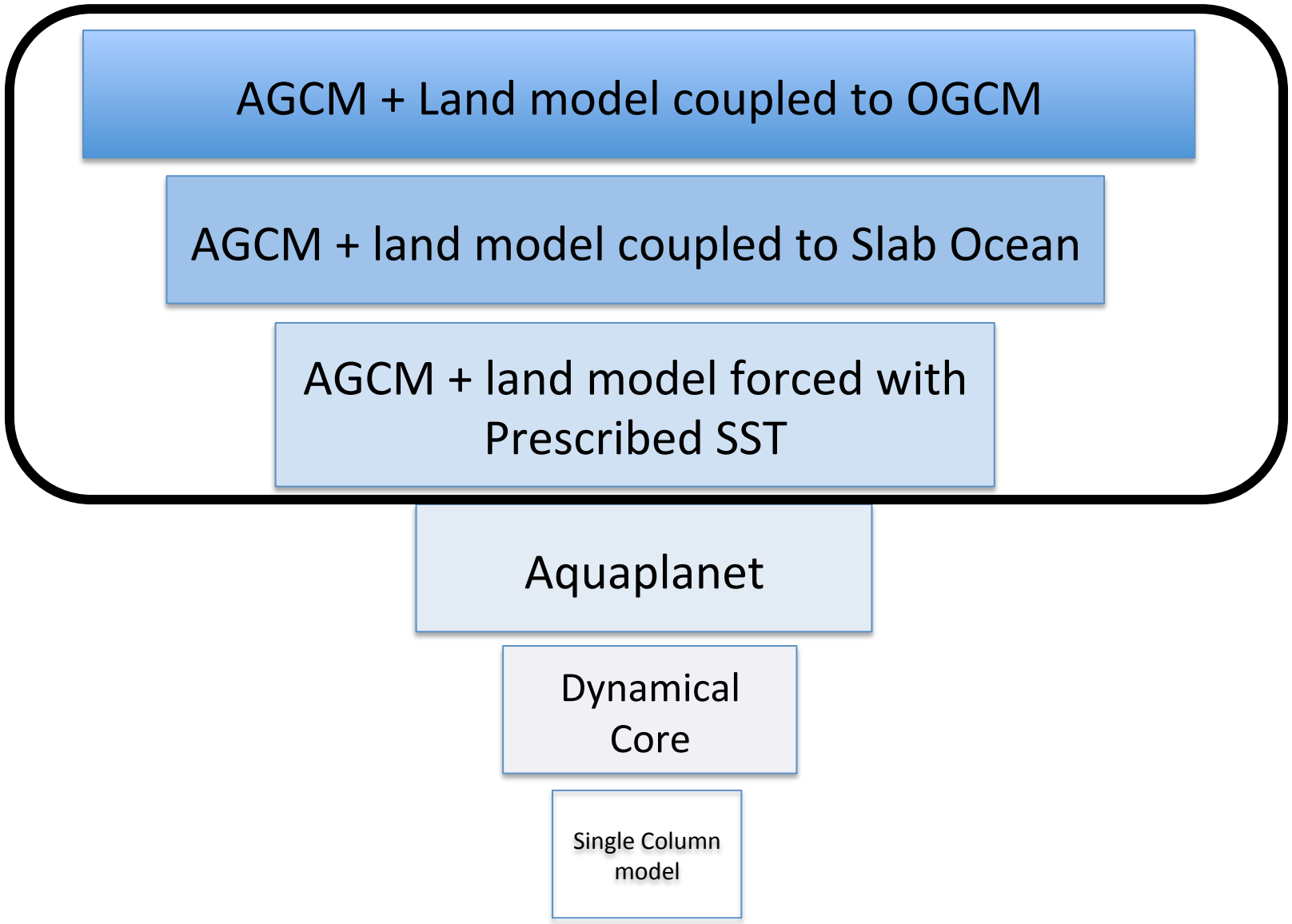
… and can impact the atmosphere.

A different approach:

**Climate Model Hierarchy**

*How do the features of climate simulation change by progressively 'turning off' elements of the climate model?*

# Climate Model Hierarchy



## AGCM + Land model coupled to OGCM

Fully coupled

CMIP3 (12) and CMIP5 (39) pre-industrial runs

## AGCM + land model coupled to 50 m Slab Ocean

| | SOM Coupled | |
|---|---|---|
| CCCMA_CGCM3_1 | 30 | 500 |
| CCCMA_CGCM3_1_T63 | 30 | 350 |
| GFDL_CM2_0 | 50 | 500 |
| GFDL_CM2_1 | 100 | 500 |
| INMCM3 | 60 | 330 |
| MIROC3_2_HIRES | 20 | 500 |
| MIROC3_2_MEDRES | 60 | 100 |
| MPI_ESM_LR | 180 | 1000 |
| MRI_CGCM2_3_2A | 100 | 350 |
| NCAR_CCSM4 ★ | 450 | 500 |
| UKMO_HADGEM1 | 70 | 240 |
| GISS_MODEL_E_R | 120 | 500 |

Thermodynamically coupled;

***no interactive ocean heat transport***

$\rho h C_p \, dT/dt = Q_{net} + Qflux$

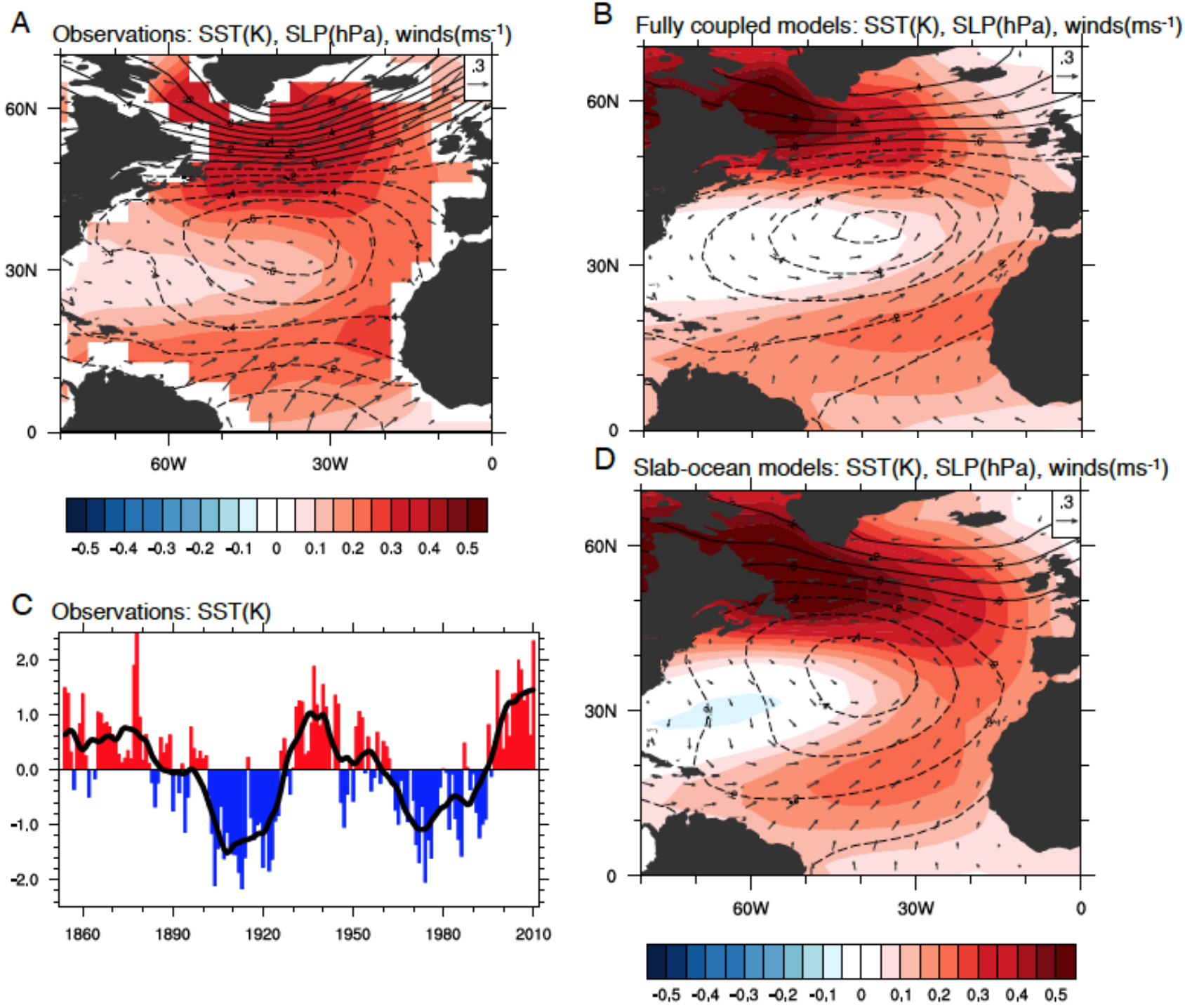
12 CMIP3 models pre-industrial runs

## AGCM + land model forced with Prescribed SST

Uncoupled; CAM4

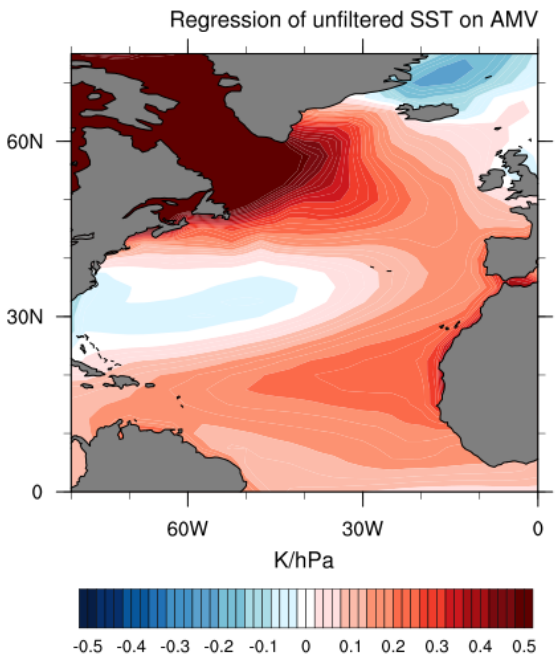
★ CAM4-som has a spatially varying mixed layer depth; does not vary with time

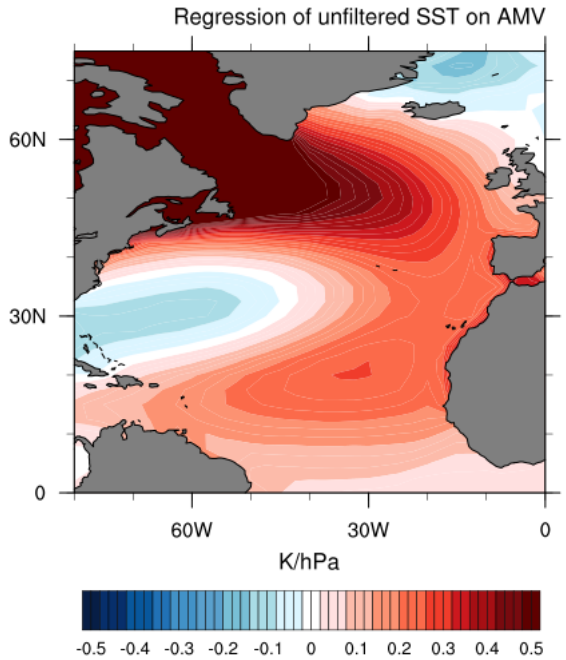
How do the spatial patterns compare with and without interactive ocean dynamics?


A
Observations: SST(K), SLP(hPa), winds(ms-1)
.3
60N
30N
0
60W
30W
0
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
B
Fully coupled models: SST(K), SLP(hPa), winds(ms-1)
.3
60N
30N
0
C
Observations: SST(K)
2.0
1.0
0.0
-1.0
-2.0
1860
1890
1920
1950
1980
2010
D
Slab-ocean models: SST(K), SLP(hPa), winds(ms-1)
.3
60N
30N
0
60W
30W
0
-0,5 -0,4 -0,3 -0,2 -0,1 0 0,1 0,2 0,3 0,4 0,5

# Maybe it's only at low frequencies that the impact of the ocean is apparent?

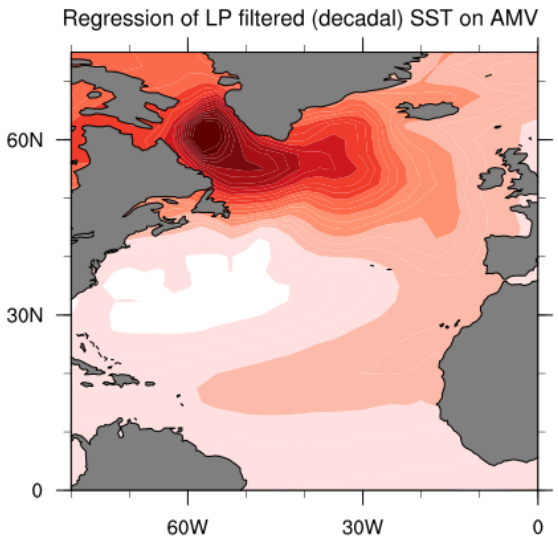
Multi-model mean Coupled unfiltered

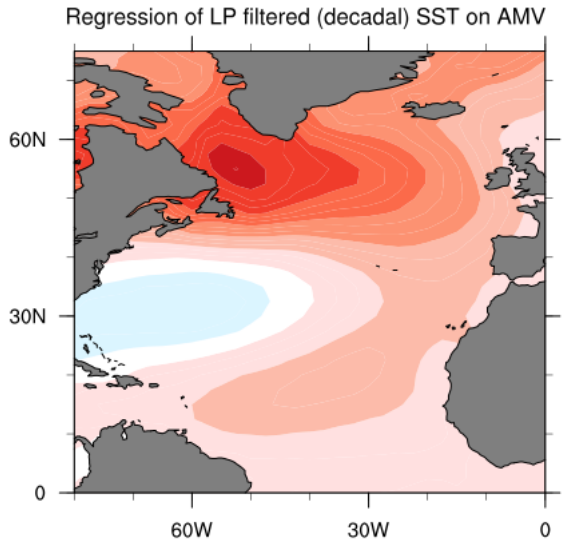



Multi-model mean Slab unfiltered

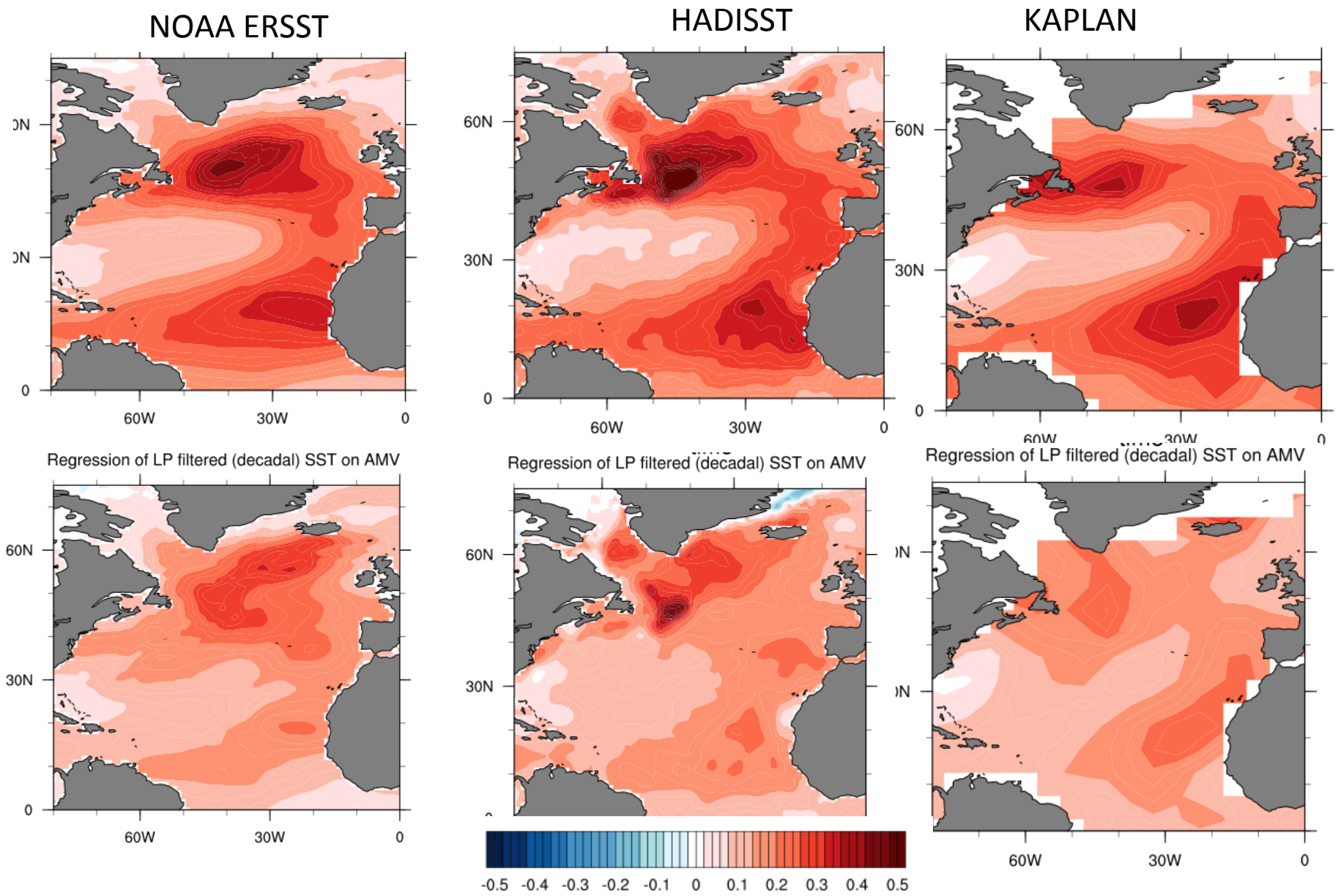
Multi-model mean Coupled LP filtered



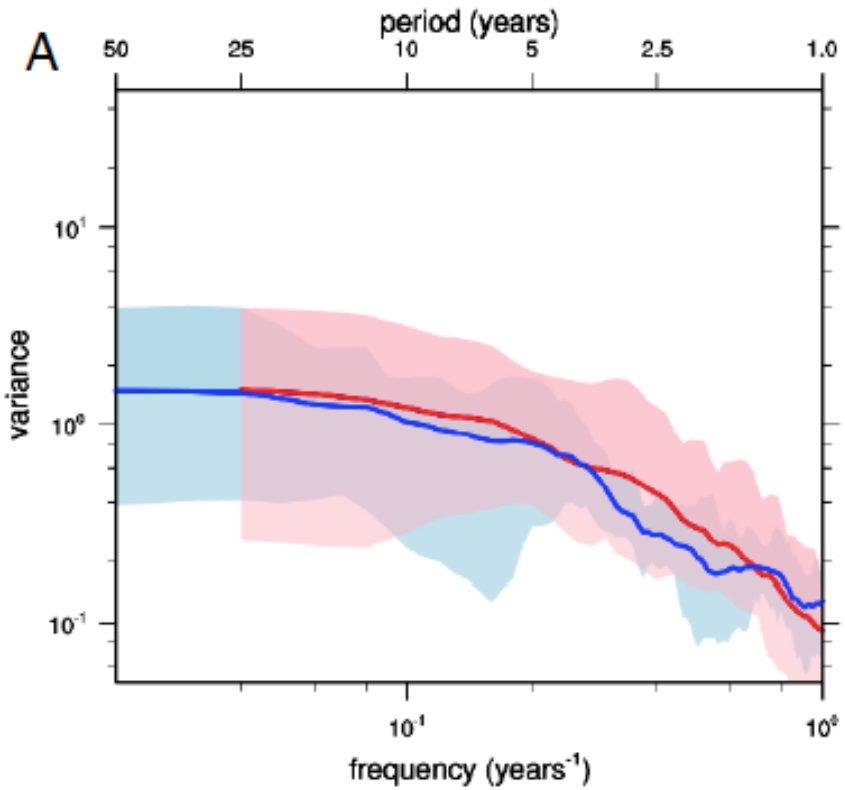

Multi-model mean Slab LP filtered

# But high latitude amplification is less clear in observations

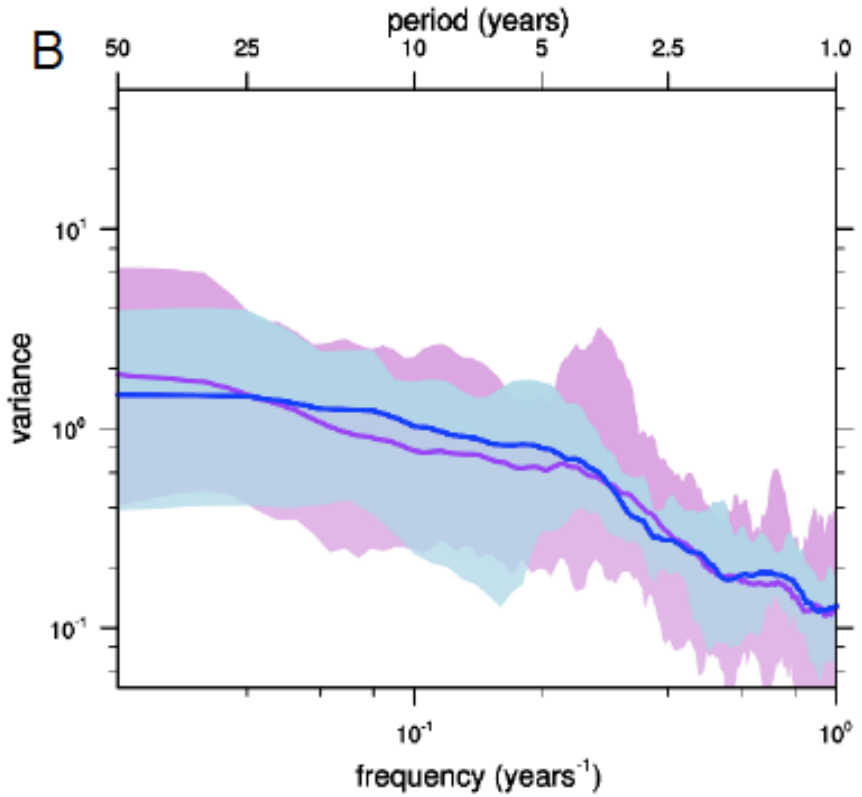


# How do the temporal characteristics compare with and without interactive ocean dynamics?

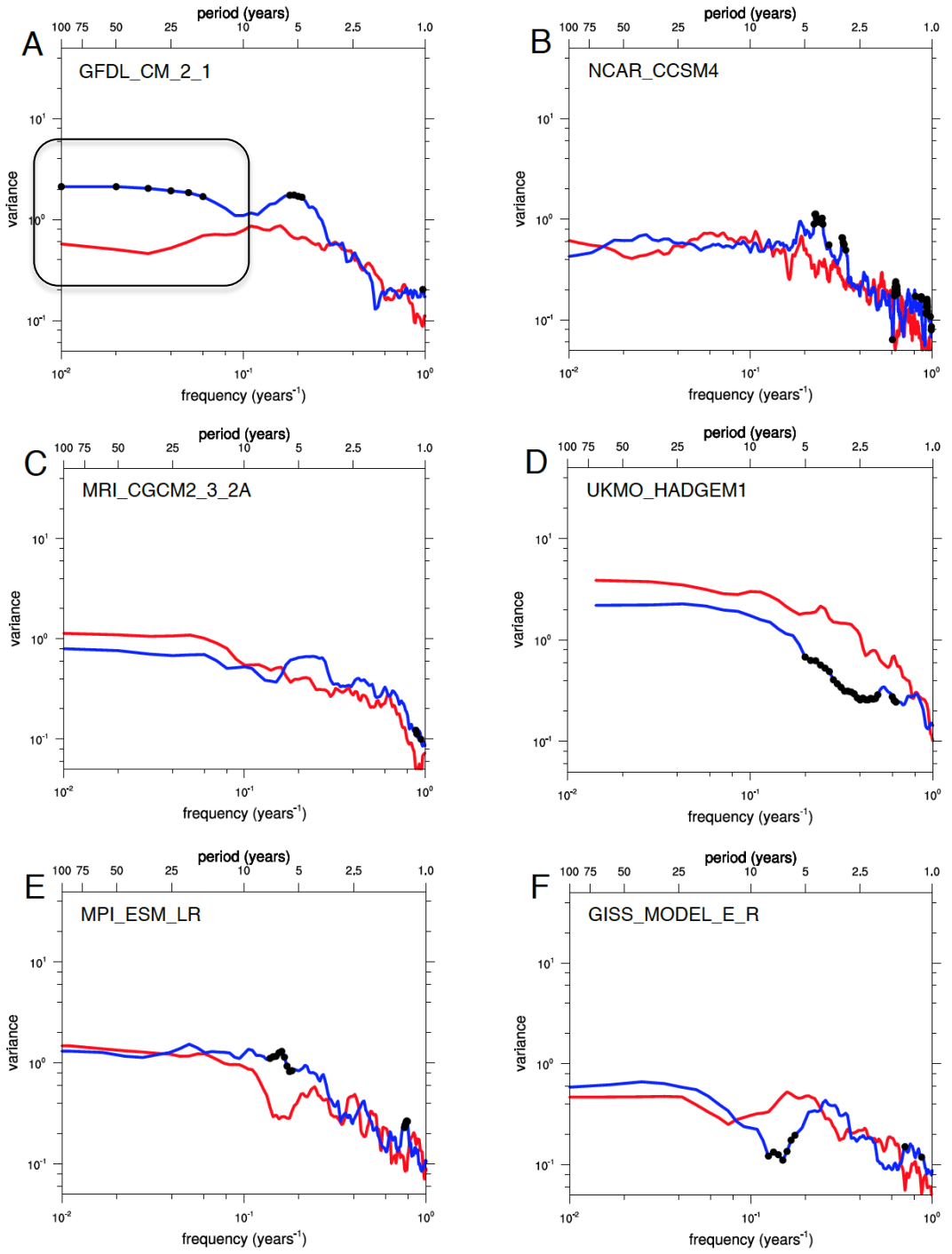
AMO (not normalized) in CMIP3 slab models (red) and CMIP3 coupled models (blue)




AMO (not normalized) in CMIP3 coupled models (blue) and CMIP5 coupled models (purple)



Arises mostly from sub polar variability



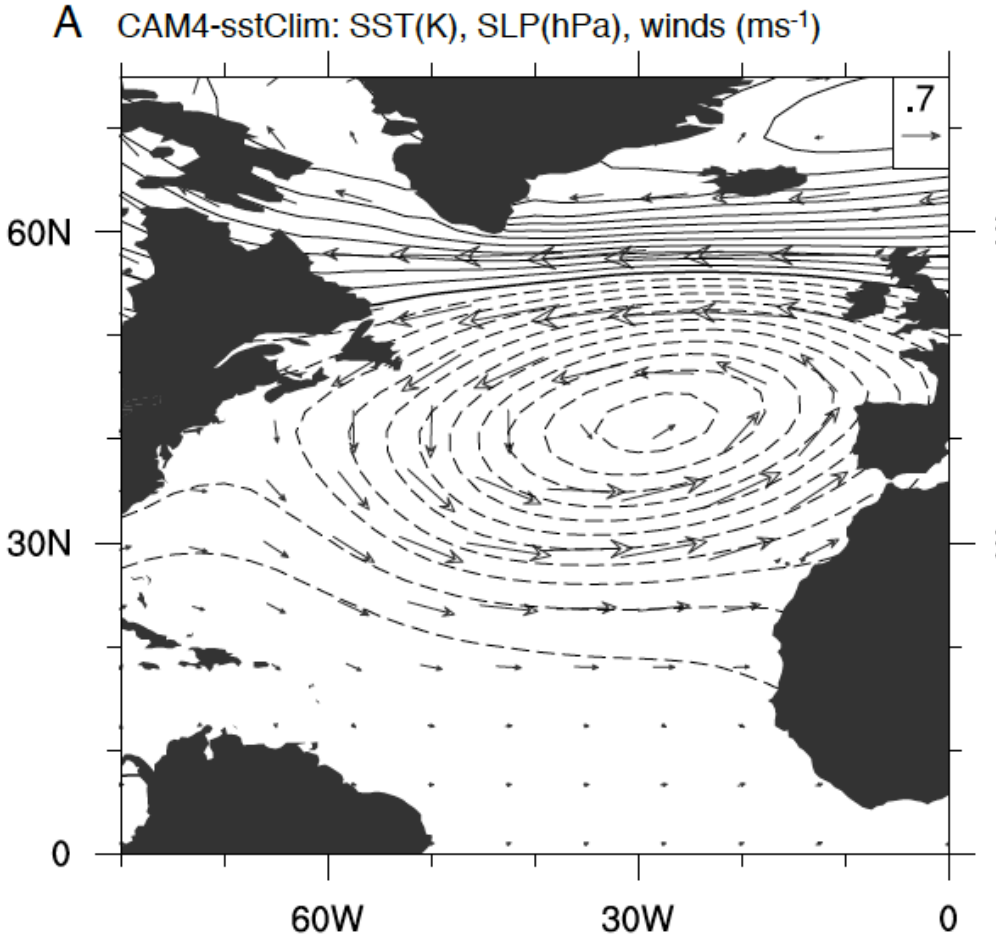

Red: AGCM-slab ocean

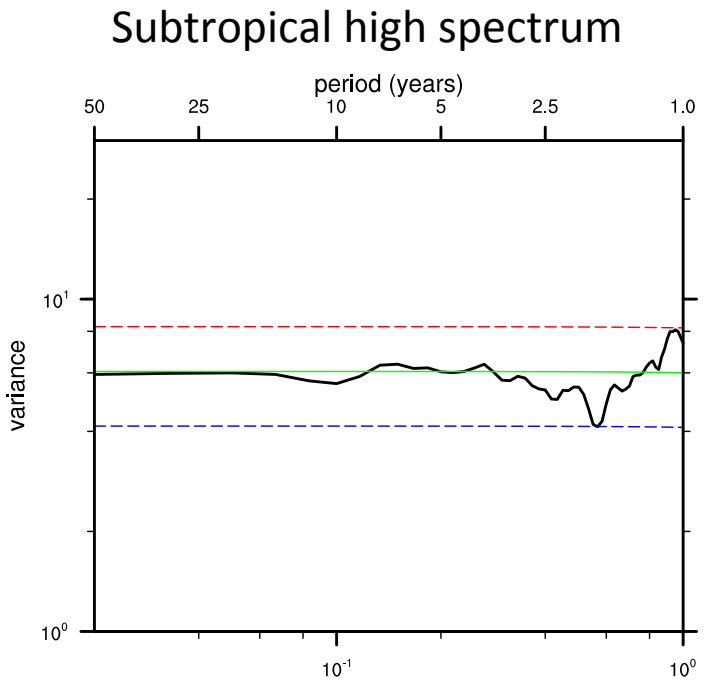
Blue: Fully coupled models

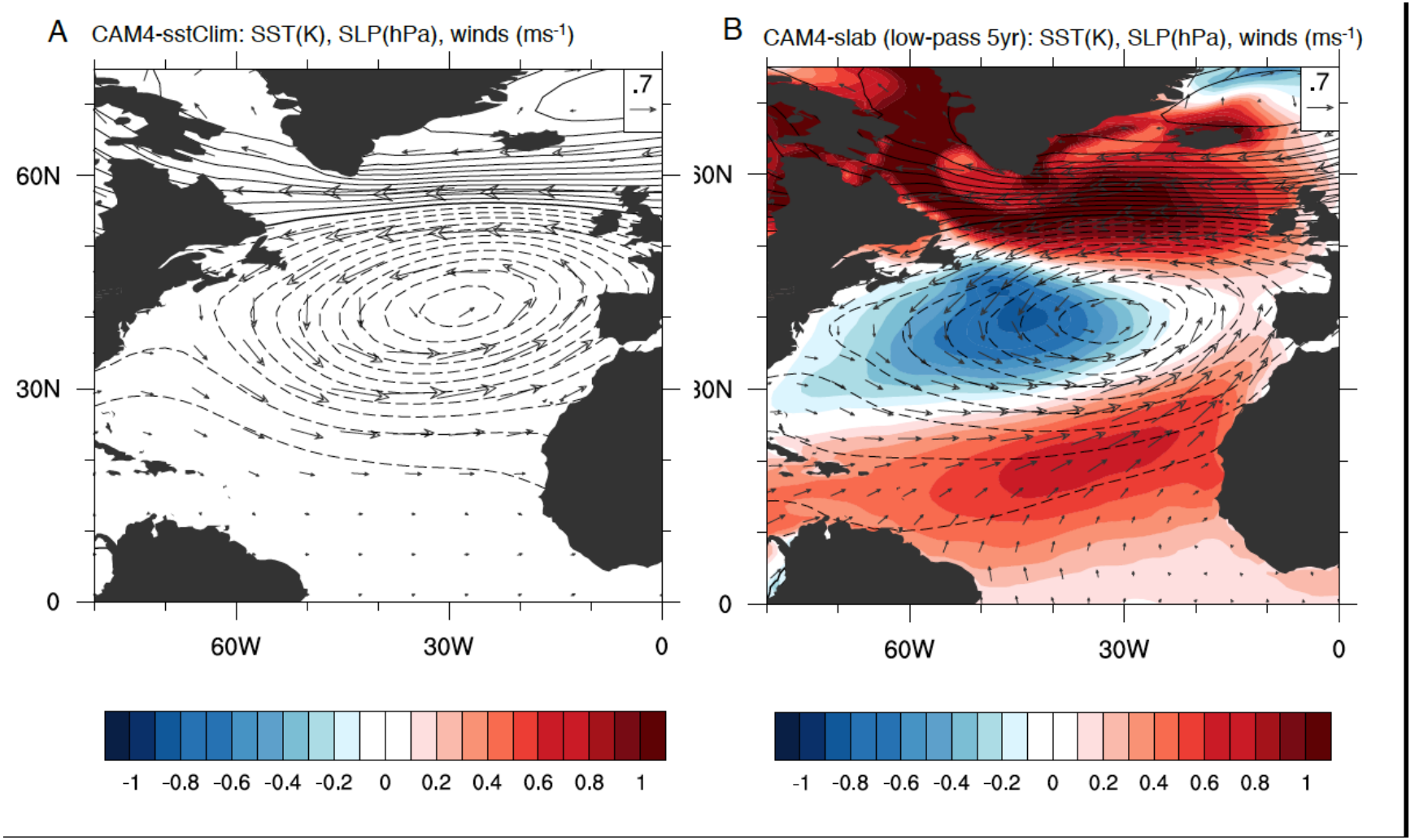
# What is the mechanism in the model that produces the AMO?

The AMO is the response to stochastic forcing from the mid-latitude atmospheric circulation (the NAO), with thermal coupling playing a role in the tropics.

# The NAO in CAM4-prescribed SST (uncoupled)

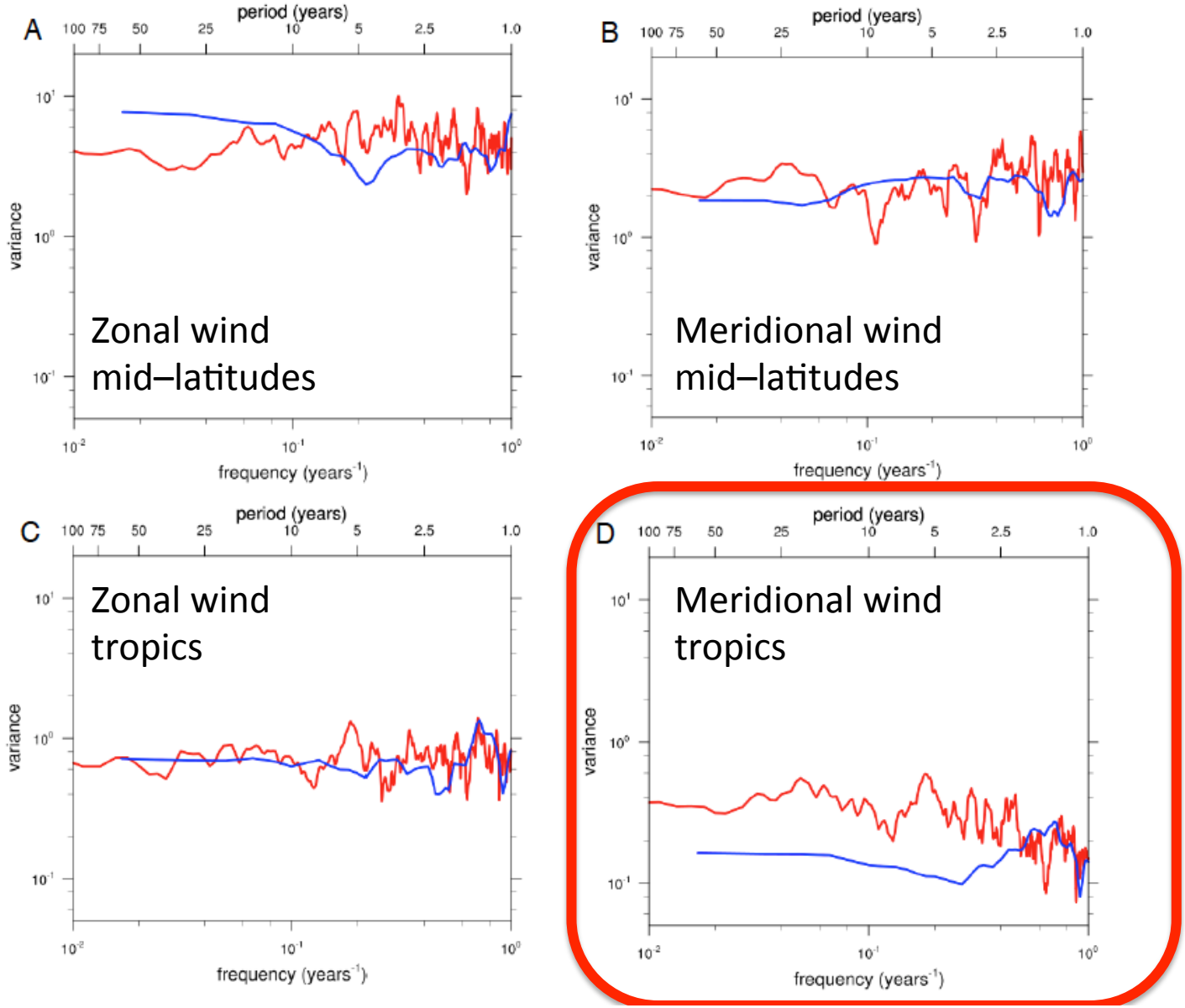




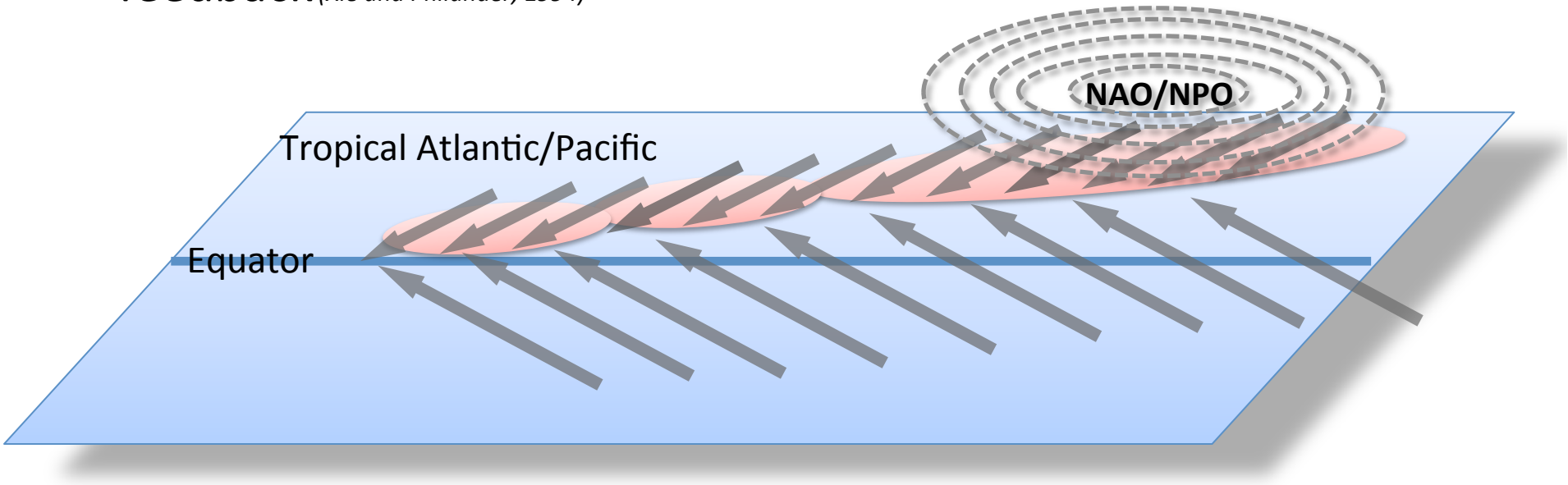

Thermal coupling produces a wind (and SST) signal in the tropics that is absent in the uncoupled model → the tropical part of the AMO signal is 'thermally coupled'

# Wind variability is white noise in uncoupled (blue) and slab (red) models except for meridional winds in the tropics



# Meridional Mode: physics

- Fundamental mechanisms: **W**ind-**E**vaporation-**S**ST (**WES**) feedback *(Xie and Philander, 1994)*




- Characteristic spatial structure: **weakening (strengthening) trade winds** and underlying **warming (cooling) SSTs**
- Time scale: no preferred but on seasonal and longer time scales
  - WES propagation: one to two seasons *(Vimont et al, 2001, 2003; Chiang and Vimont, 2004)*

**Slide courtesy of Honghai Zhang**

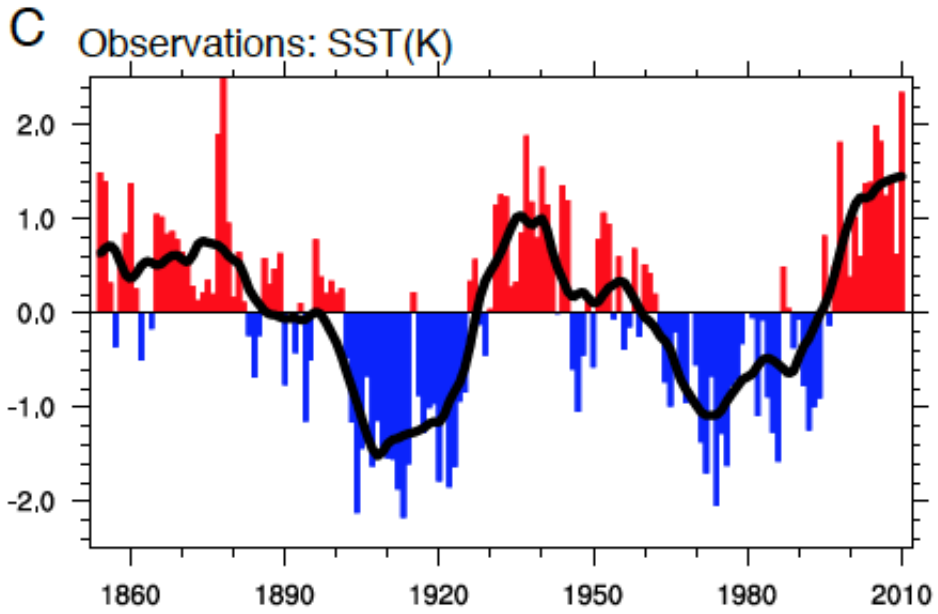
# Summary

- Fully coupled and slab ocean models produce an AMO that has the spatial characteristics of the observations, and a 'red' spectrum
- Interactive ocean heat transport in climate models does not change space-time characteristics of the AMO
- Interpretation: AMO *in models* is the upper ocean thermal response to NAO forcing, and the tropical signal emerges through thermal coupling (i.e. AMO is a hybrid forced-thermally coupled mode)

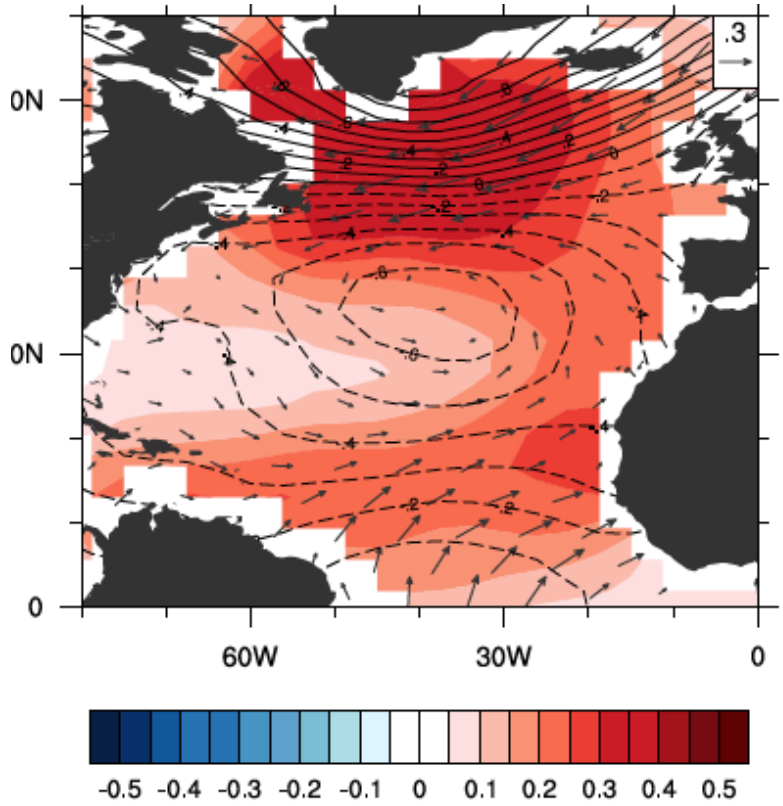
# Extra slides

# Now back to the real world…

Average North Atlantic SST (0-60N), ***normalized and detrended*** NOAA ERSST v3b

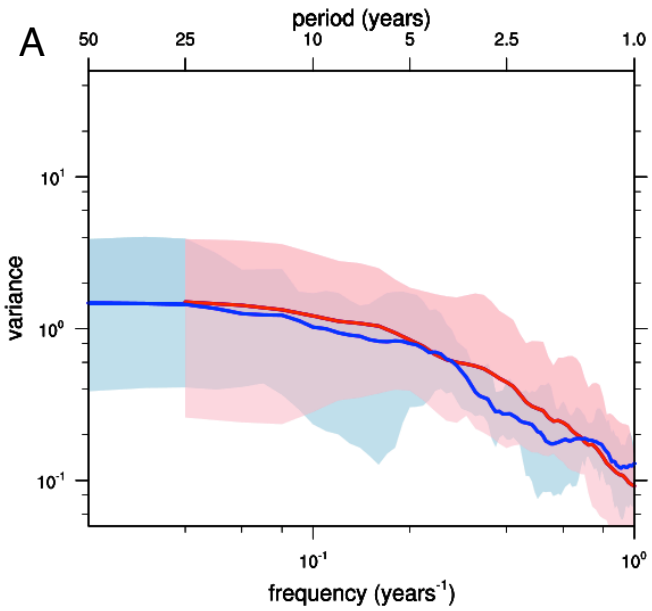


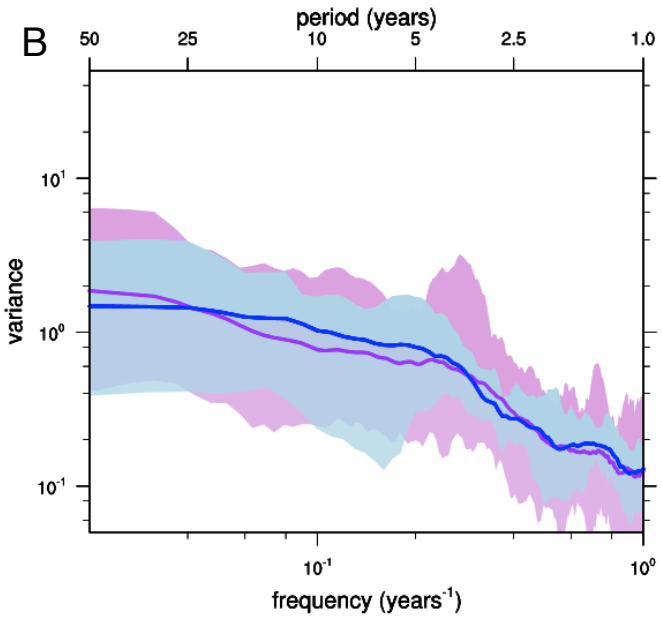

Regression of SST, SLP, and winds on AMO index (NCEP reanalysis)

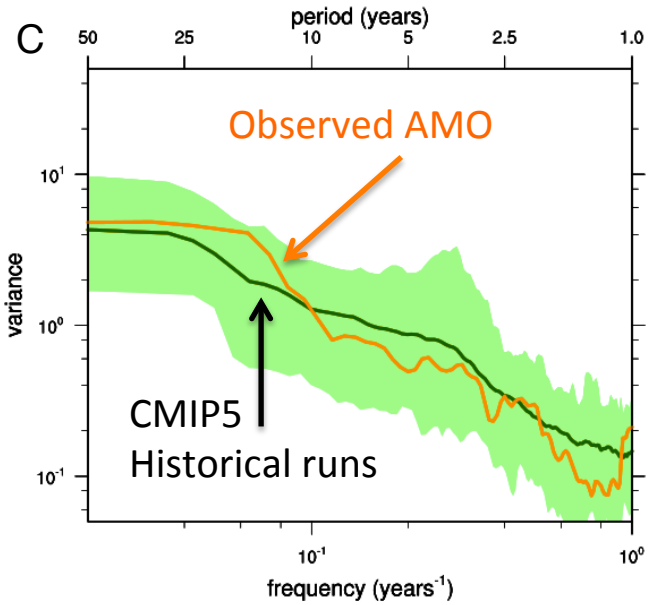



Pattern of SST can be explained as thermal response to winds, but what about the multi-decadal power?

# What about external forcing?

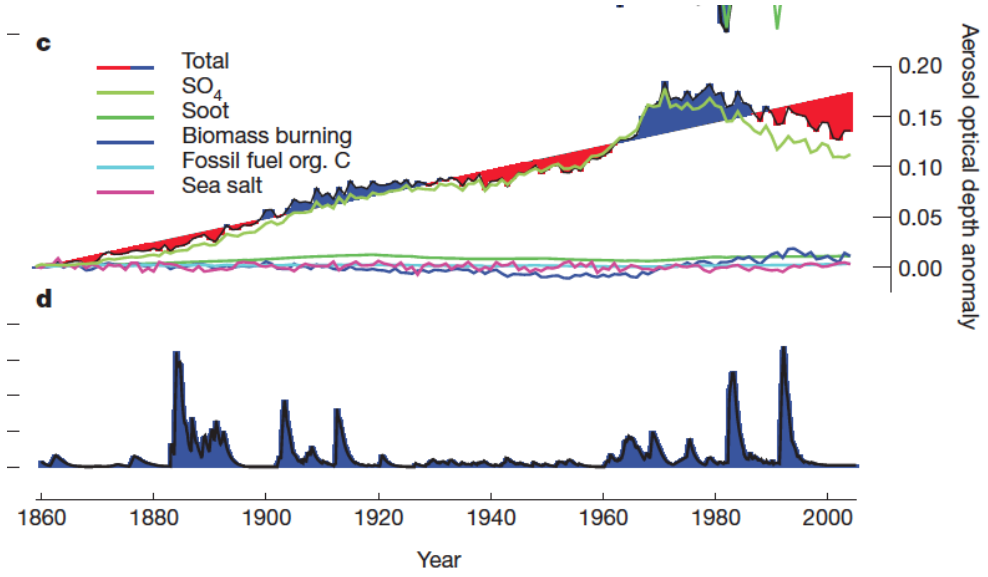


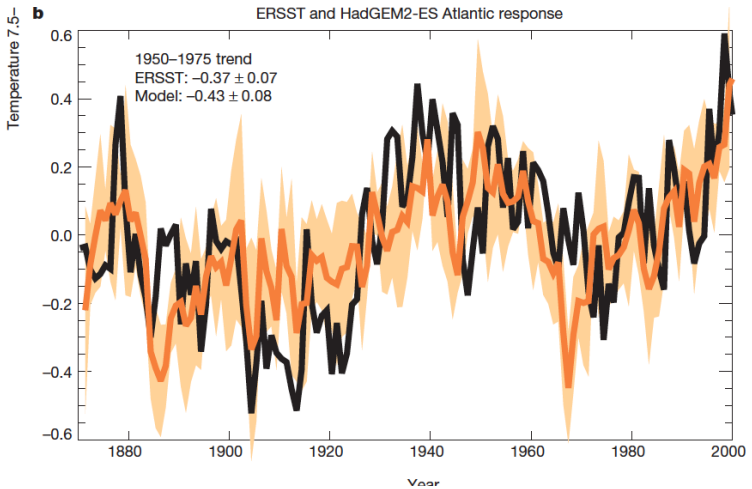




AMO in historical runs has more multi-decadal variability than pre-industrial runs

# AMO driven by anthropogenic aerosols?



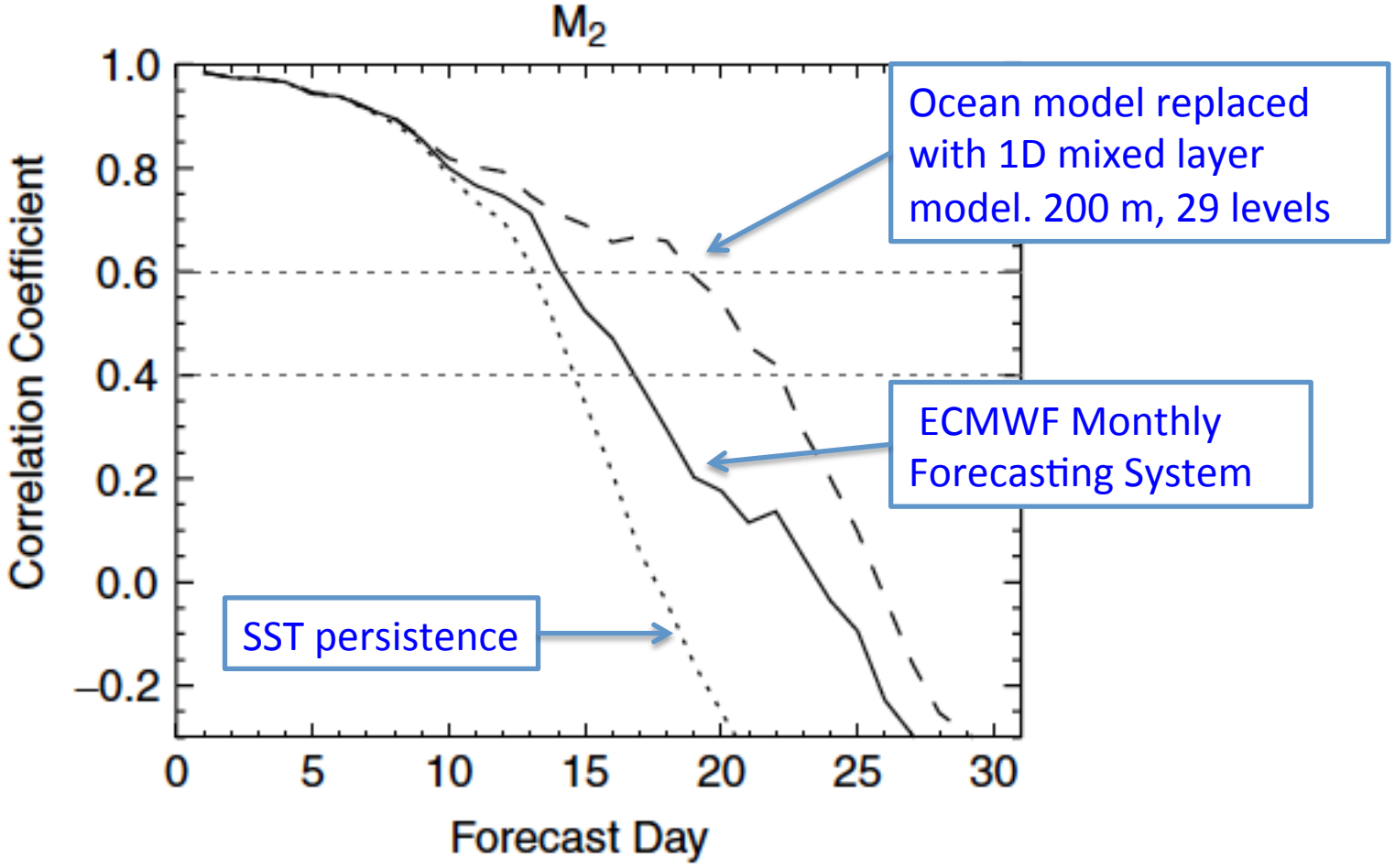

Booth et al. 2012

- But Zhang et al. (2013), Stevens et al. (2015), argue that aerosol impacts are over estimated in many current generation models
- And other forcings are changing as well…
- Different ‘swings’ of the AMO may have different causes

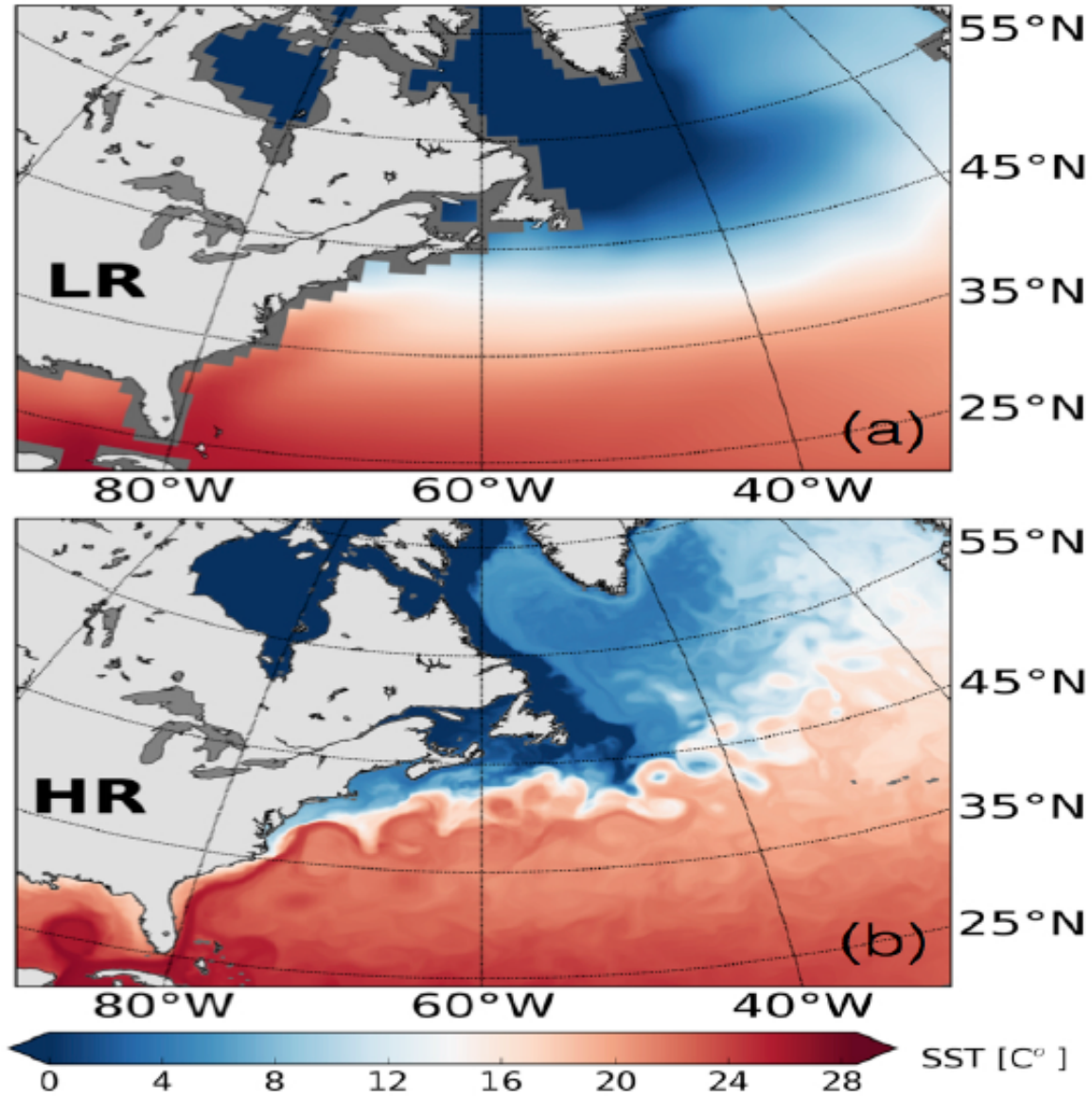
# What about the ocean circulation?

- Are models wrong? Are they missing some oceanic source of low-frequency *climate* variability? Is simulated AMOC variability too weak?
- Can an ocean circulation response to the atmosphere give some decadal predictability in the subpolar gyre? (McCarthy et al 2015; Robson et al. 2012; Yeager et al. 2012; Msadek et al. 2014)
  - What are the impacts? Does the atmosphere 'feel' the subpolar gyre heat content?
  - What is the mechanism? → a Hierarchical approach to prediction systems

# Prediction system hierarchy
# Slingo et al. 2007: predicting the phase of the MJO

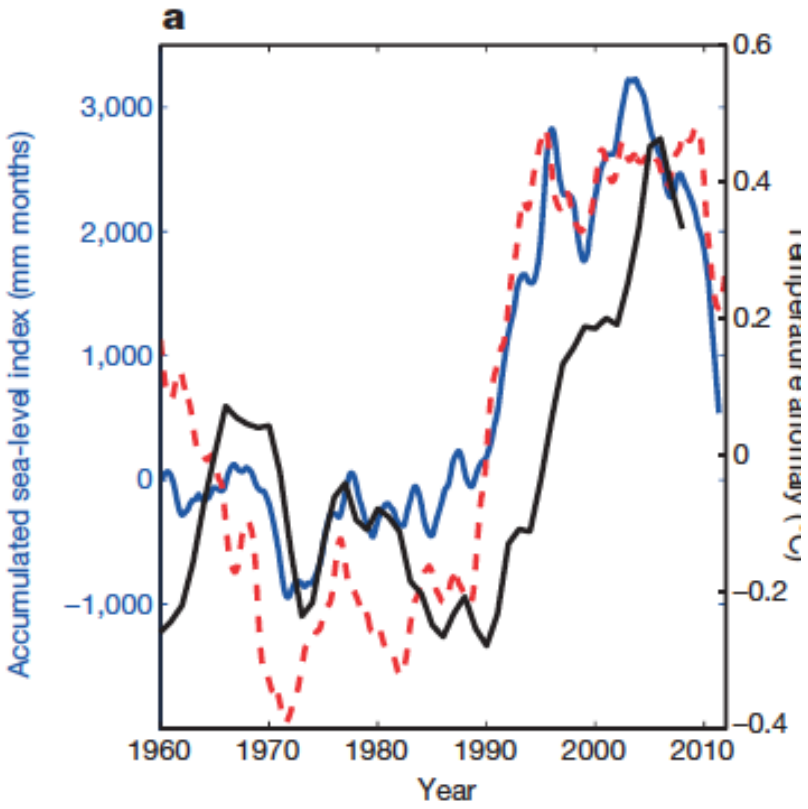



Higher vertical resolution improves simulation of upper ocean mixing

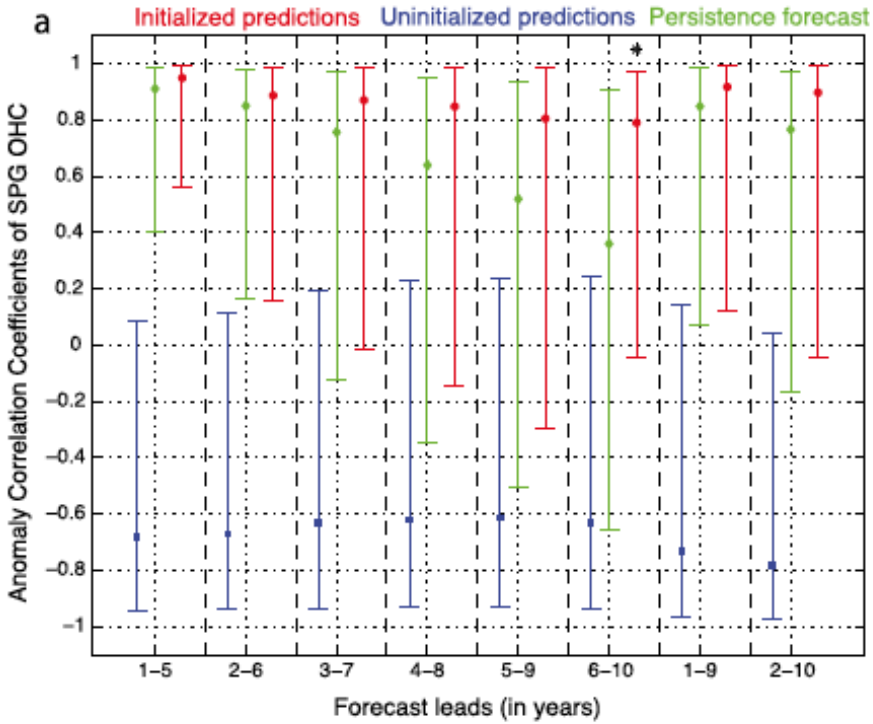



Siqueira and Kirtman – submitted

# Predicting the 1990's shift

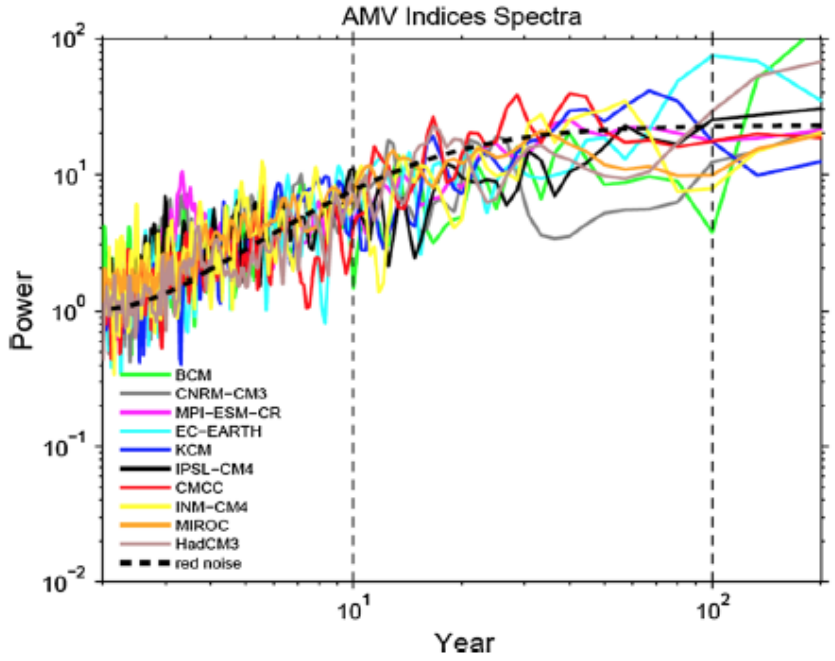



McCarthy et al. (2015): observations of NAO (red), sea-level (blue), and OHC SPG (black)




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

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



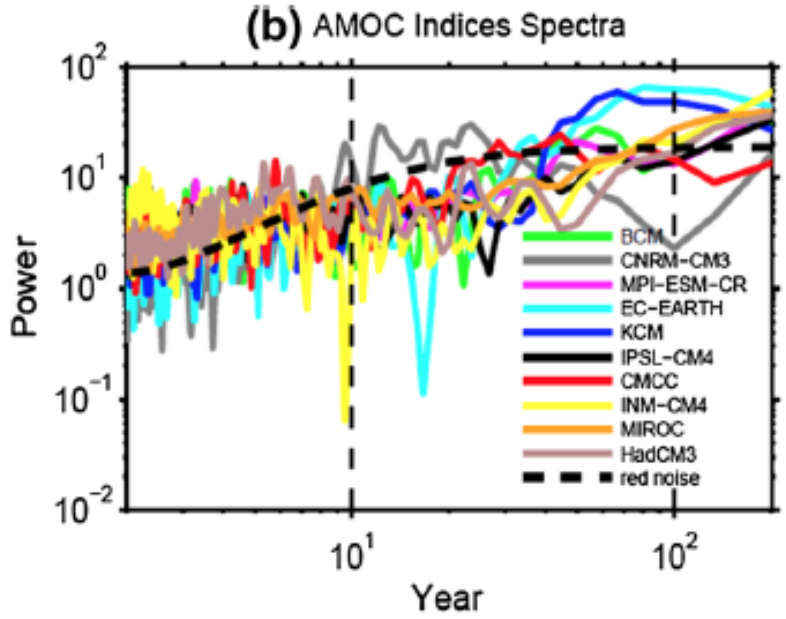
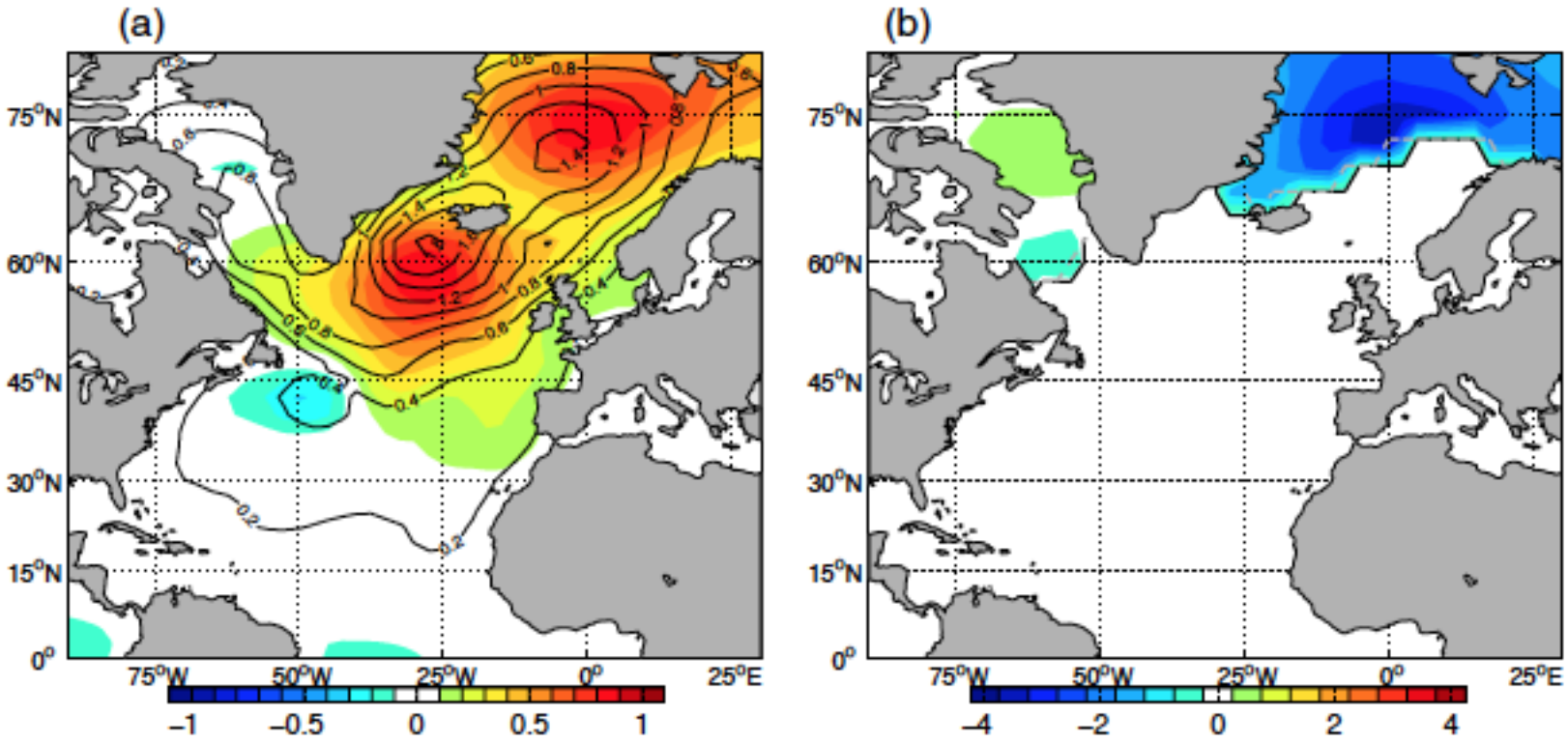




**Fig. 2** The spectra of detrended AMV Indices in ten coupled general circulation models (CGCMs). The AR1 red noise fit is the mean of the AR1 red noise fits from ten models. Due to the varying autocorrelation for the models, the individual red-noise spectra are not shown

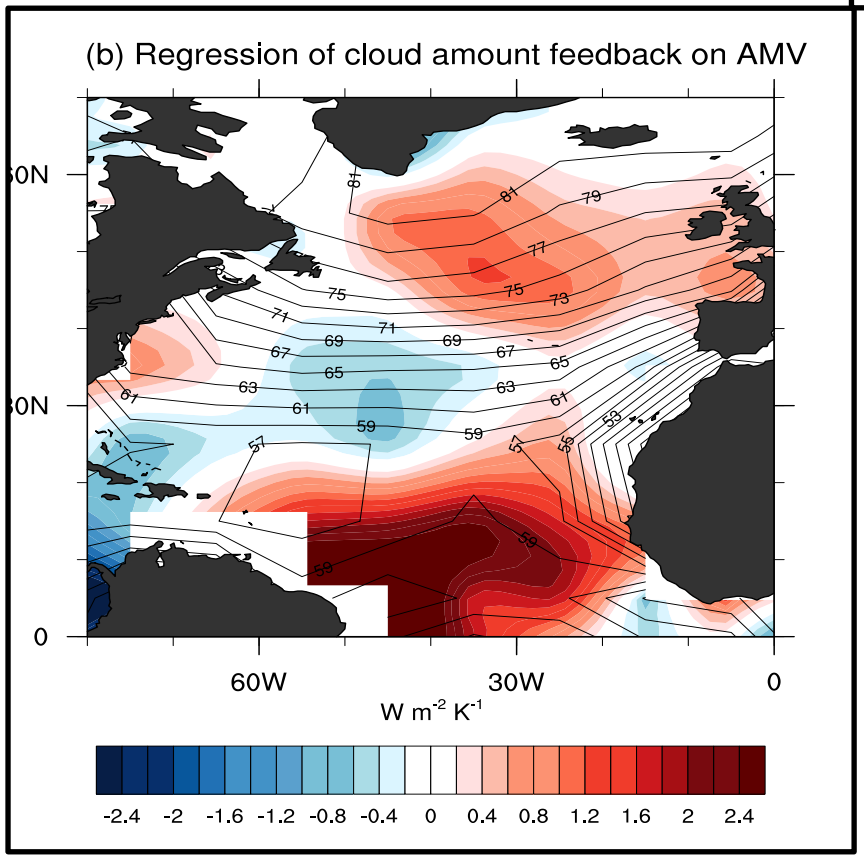
# Ba et al. (2014): multi-model AMOC signal in temperature and sea ice

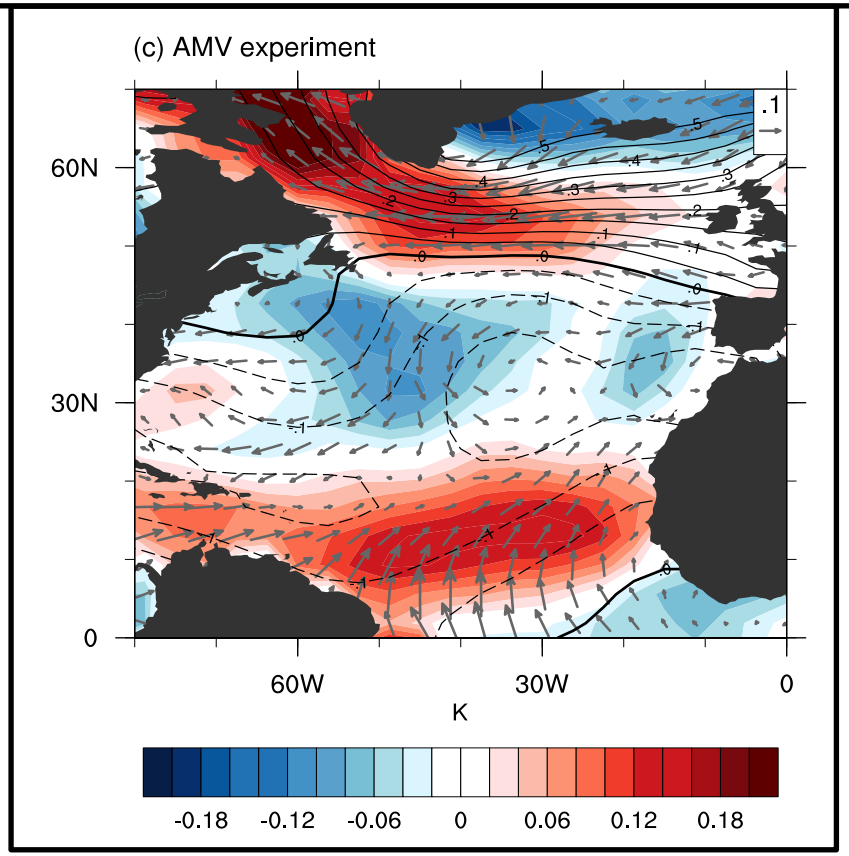


# When this cloud forcing is imposed, SST and circulation pattern is reinforced

Cloud Amount Feedback

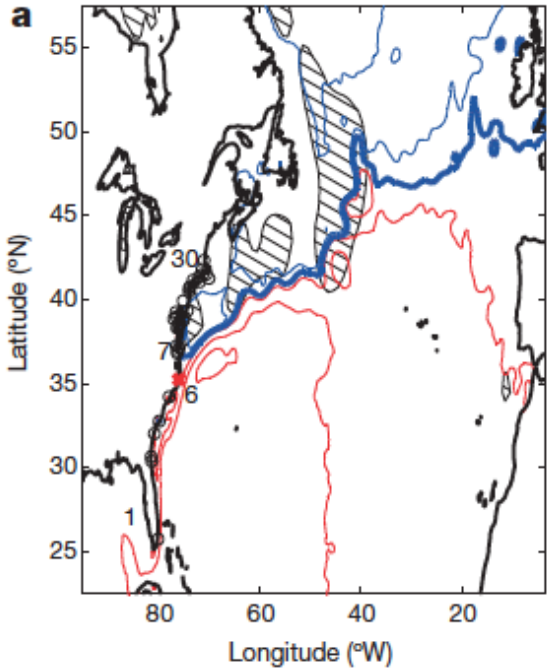
ECHAM6-Slab response to cloud forcing (left) imposed as a q-flux

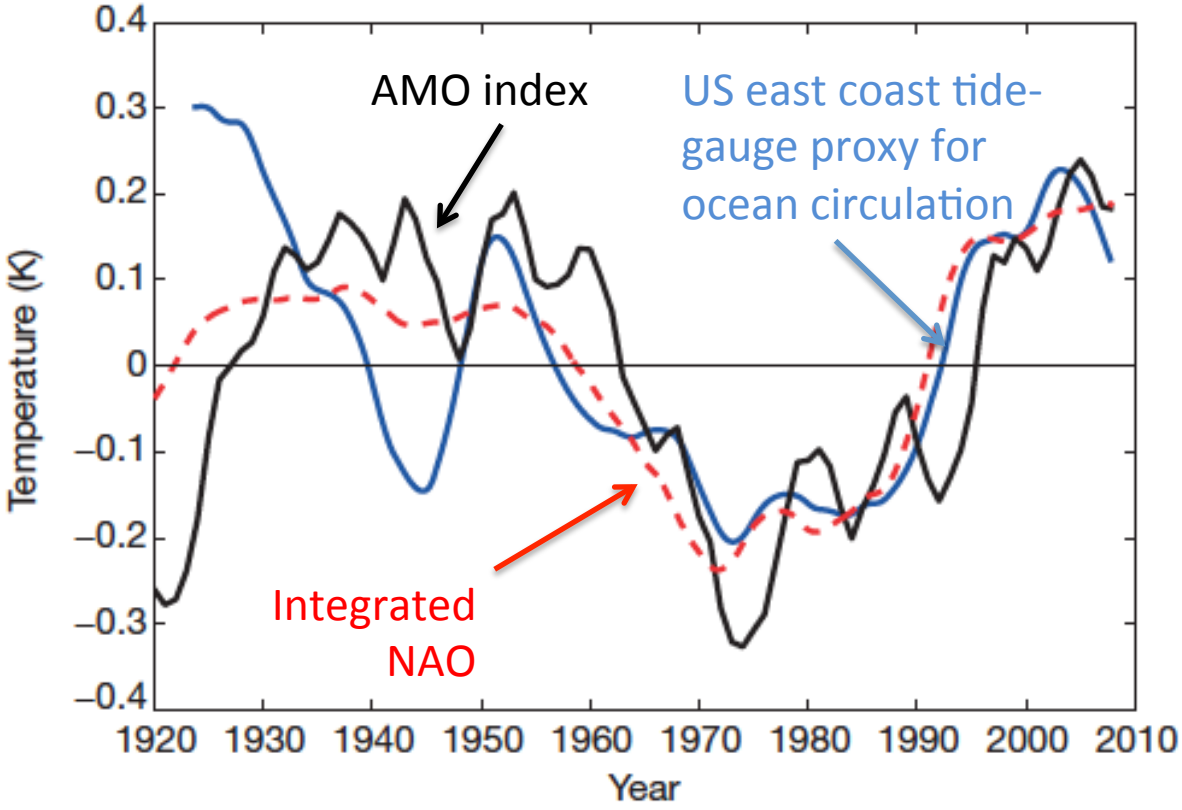


# Indirect observations of AMOC (McCarthy et al. 2015)

Dynamic topography




Ocean circulation is driven by atmospheric circulation (not the other way around)