Challenging the AMOC-Climate Paradigm

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The AMOC-Climate Paradigm

- Changes in surface heat fluxes and/or freshwater input affect the amount of deep water formed at high latitudes in the North Atlantic, which, in turn causes coherent AMOC variability throughout the North Atlantic basin.
- For the case of an increasing AMOC, more heat is transported across the equator, warming the surface waters of the North Atlantic.
- These ocean-driven changes warm the northern hemisphere and affect the atmosphere to produce impacts over land around the basin and possibly throughout the world.
- Therefore, knowledge of the strength of the circulation implies some knowledge of the surface climate on multi-decadal to millennial timescales, and/or vice versa.

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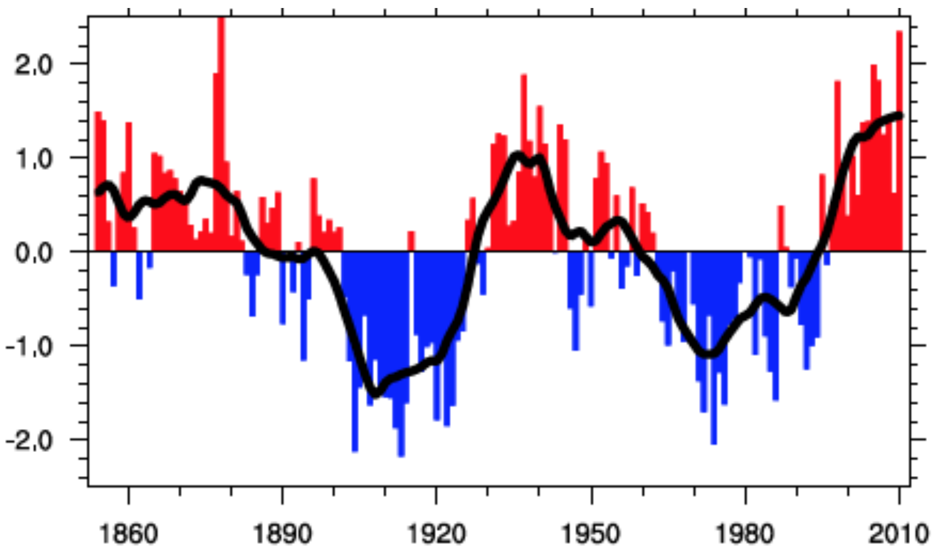
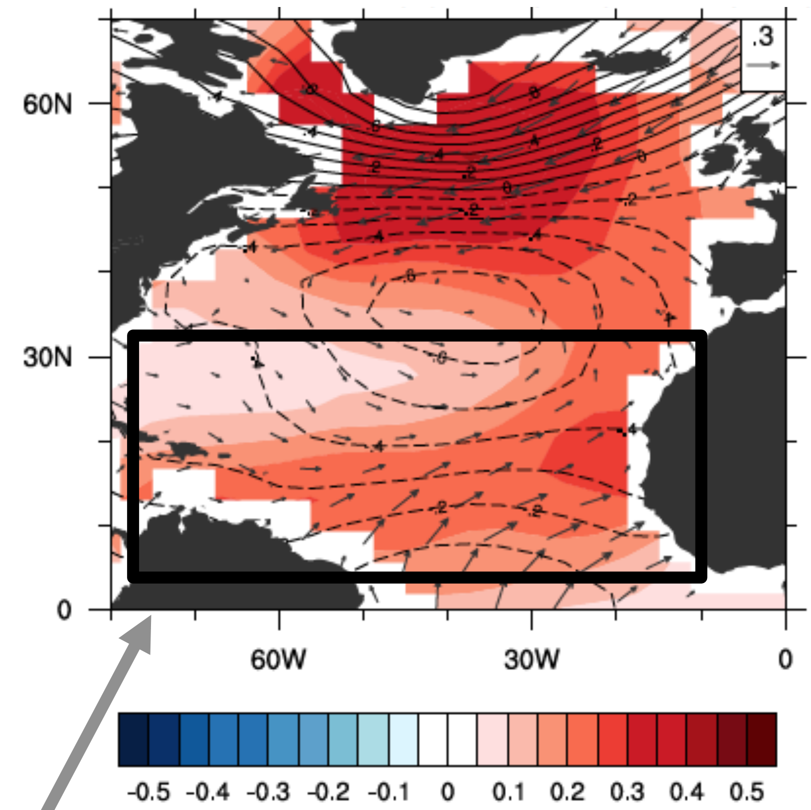
Atlantic Multi-decadal Variability

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

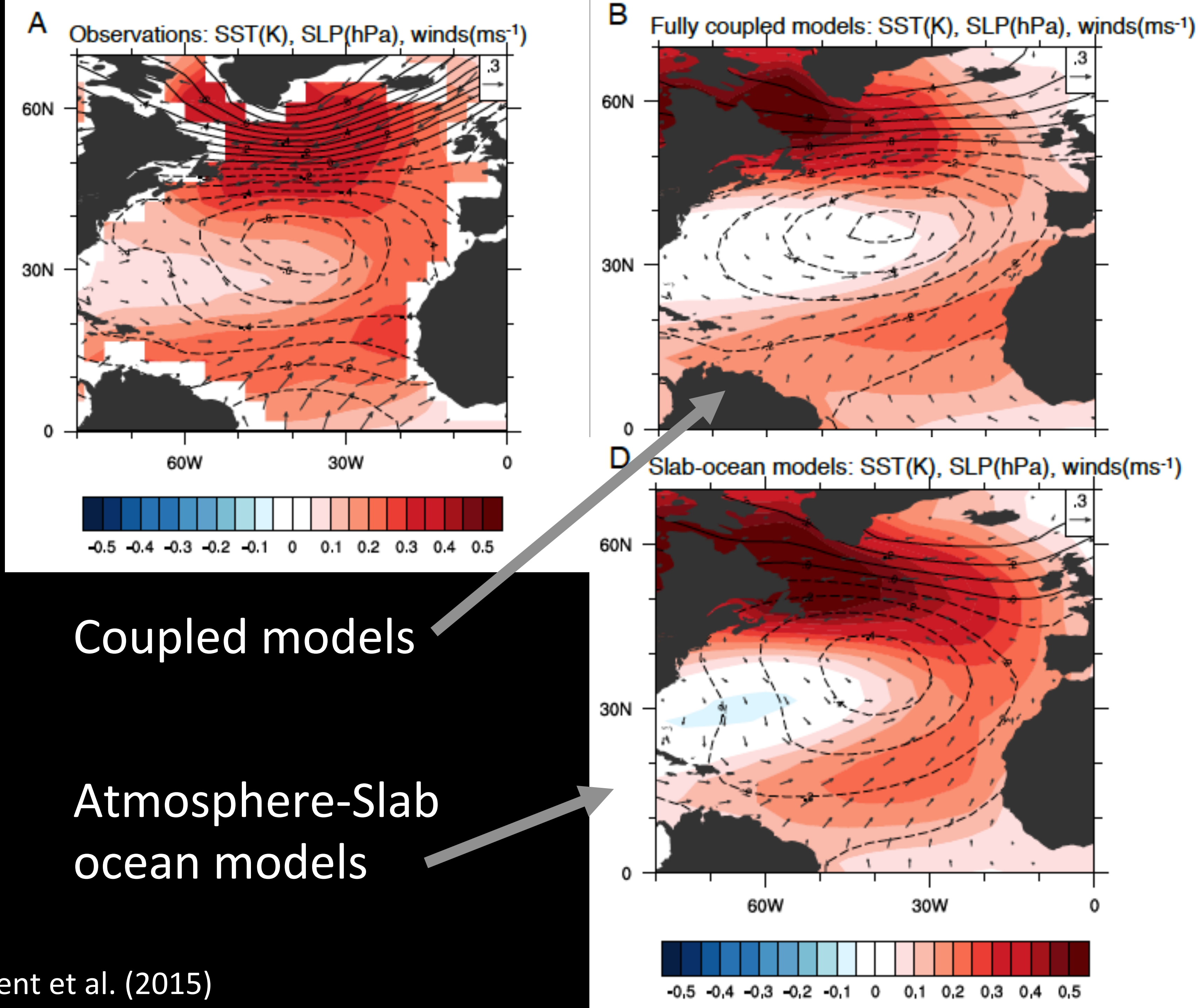


Regression of SST, SLP, and winds on AMO index (NCEP reanalysis)

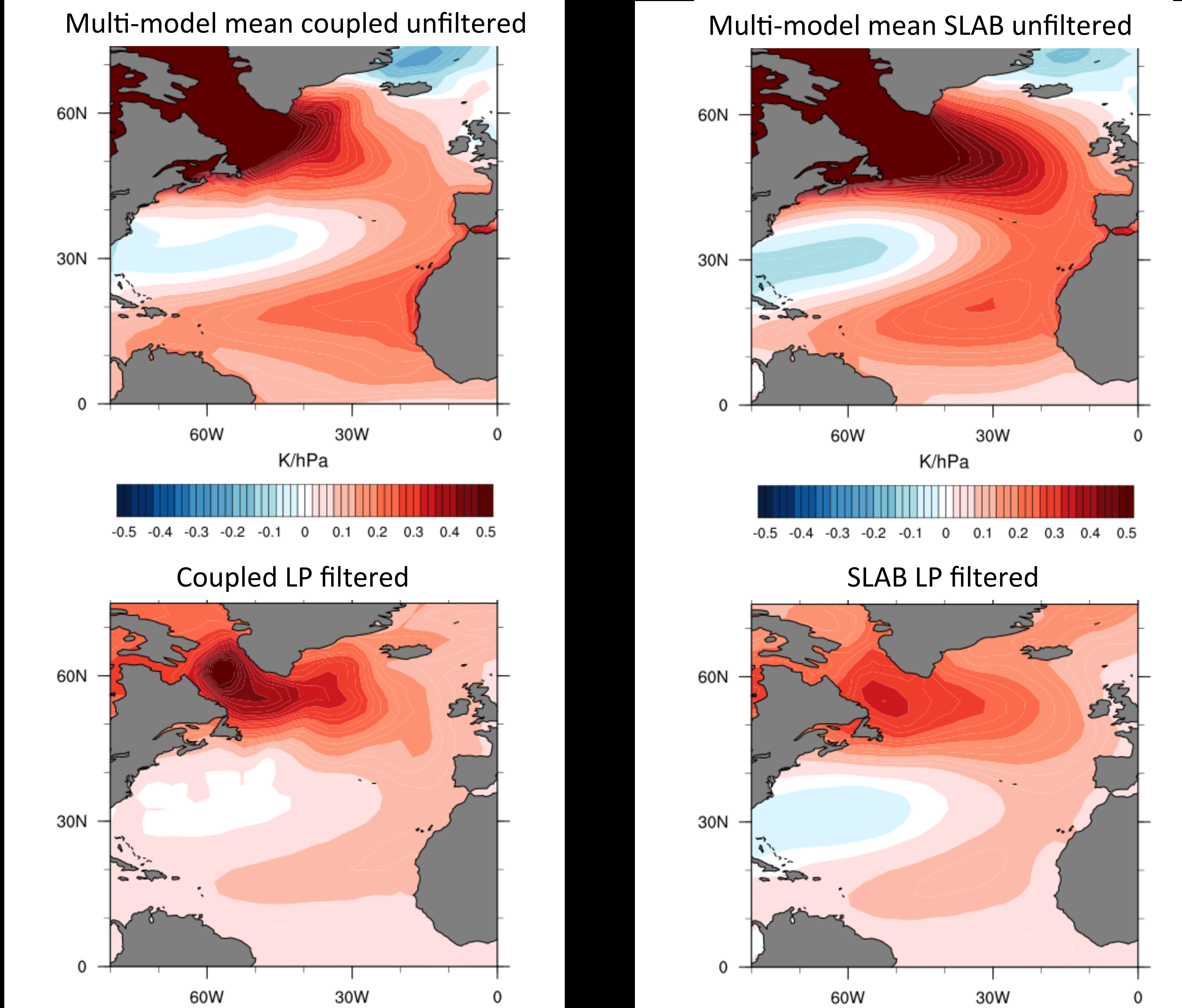


Warm North Atlantic – weak subtropical high– weak winds throughout

Impacts appear to be tied to the tropical Atlantic (Sutton and Hodson 2005, Kushnir et al. 2010)

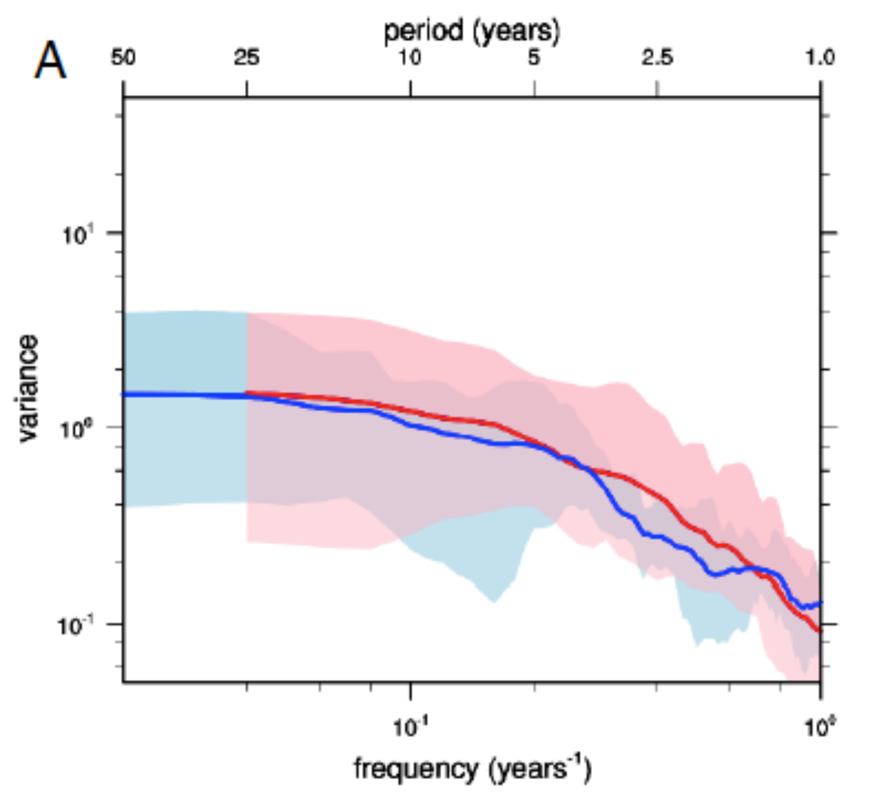


Clement et al. (2015)



Multi-model mean coupled unfiltered
Multi-model mean SLAB unfiltered
60N
30N
0
60W
30W
0
K/hPa
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5
Coupled LP filtered
SLAB LP filtered

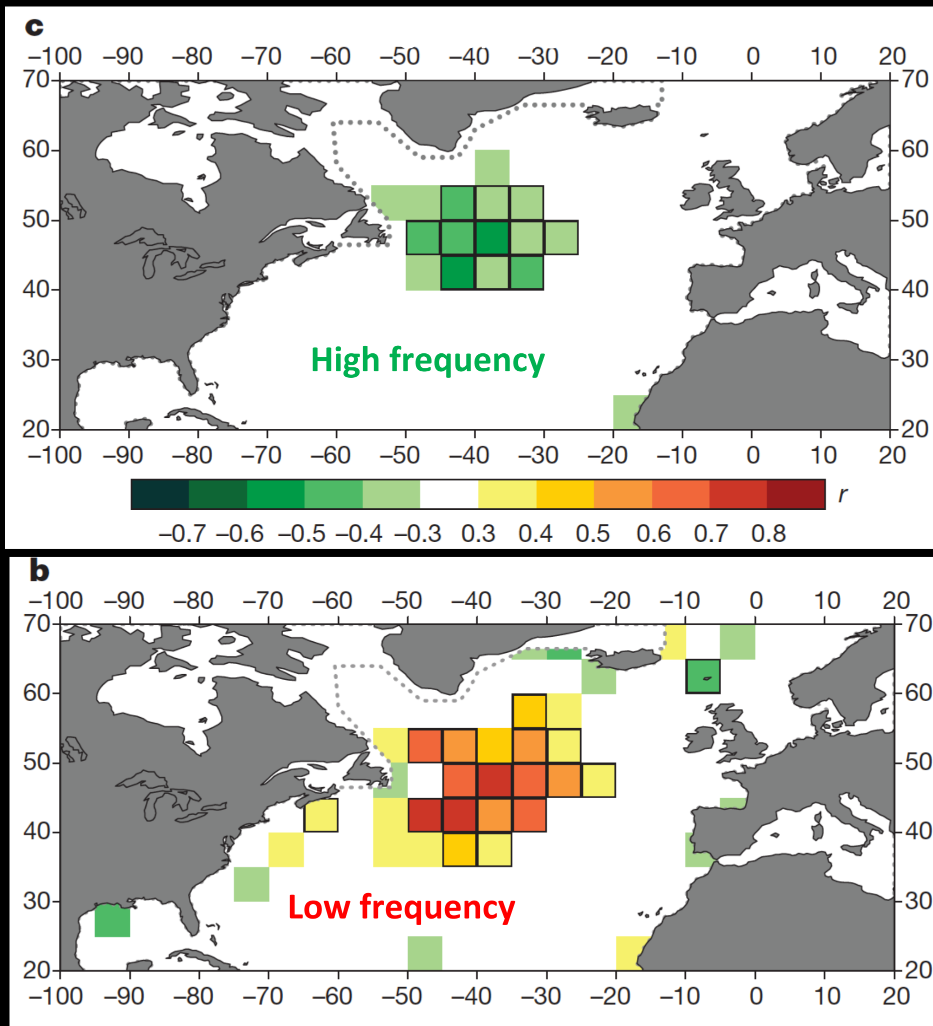
AMV index spectra slab models (red) ; coupled models (blue) *PREINDUSTRIAL*



Interactive ocean circulation is not necessary to produce the space-time features of AMV in most climate models; the dominant mechanism is stochastic atmospheric forcing

The Bjerknes (1964) hypothesis

Correlation between AMO and
surface turbulent heat flux (+ upward)



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

High Frequency

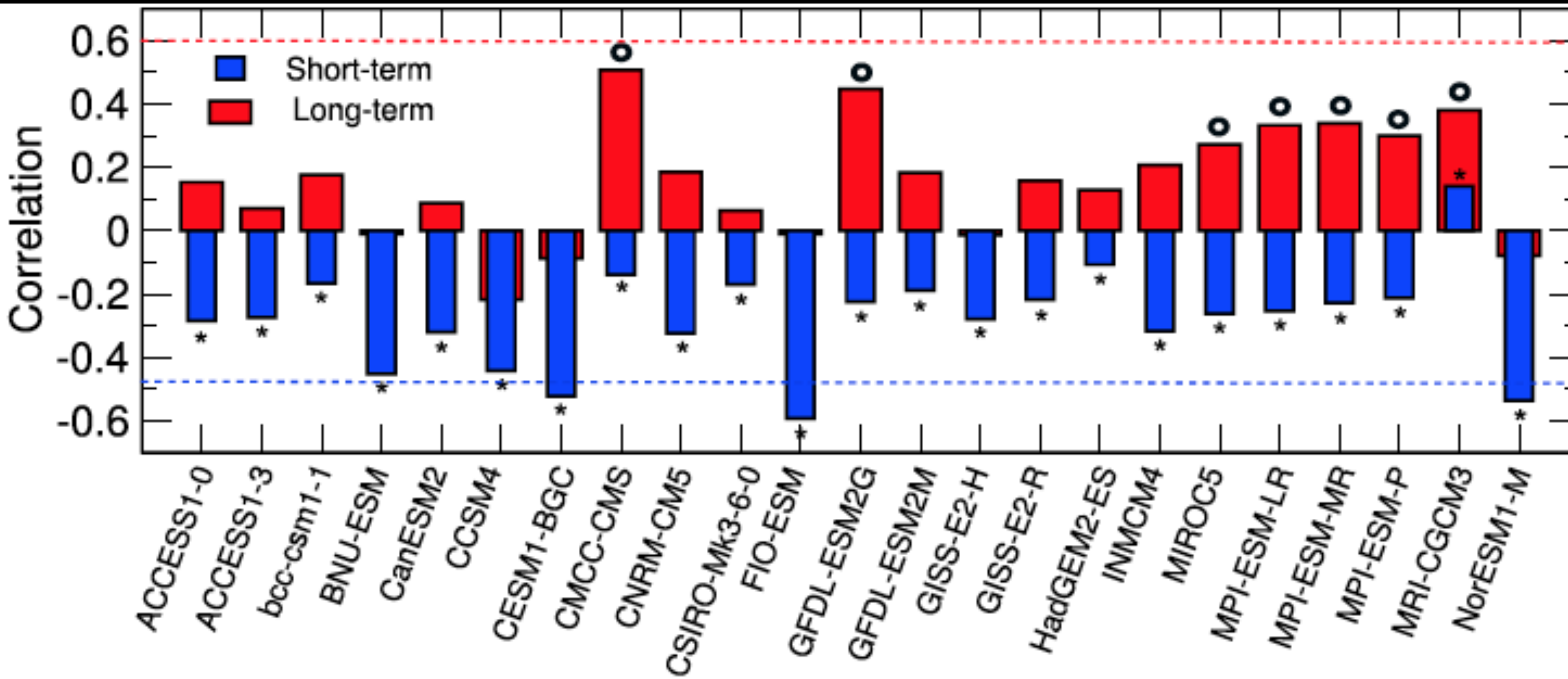
The atmosphere drives the ocean; heat goes into the ocean when it is warm

Low Frequency

The ocean drives the atmosphere; heat leaves the ocean when it is warm

Gulev et al. (2013, *Nature*)

Fully coupled climate models produce this correlation between net surface heat flux and SST in SPG



Peings et al. (2016)

In SLAB models, the low-frequency correlation is ~ 0 (O'Reilly et al. 2016; Zhang et al. 2016)

Paradox?

Simulation of AMV is the same in slab and coupled models, but heat fluxes have different behavior at low frequencies

Consider the heat equation for the mixed layer: (Cane et al. 2017)

$$\rho C_p d[hT]/dt = Q_s + Q_o$$

Take h = constant:

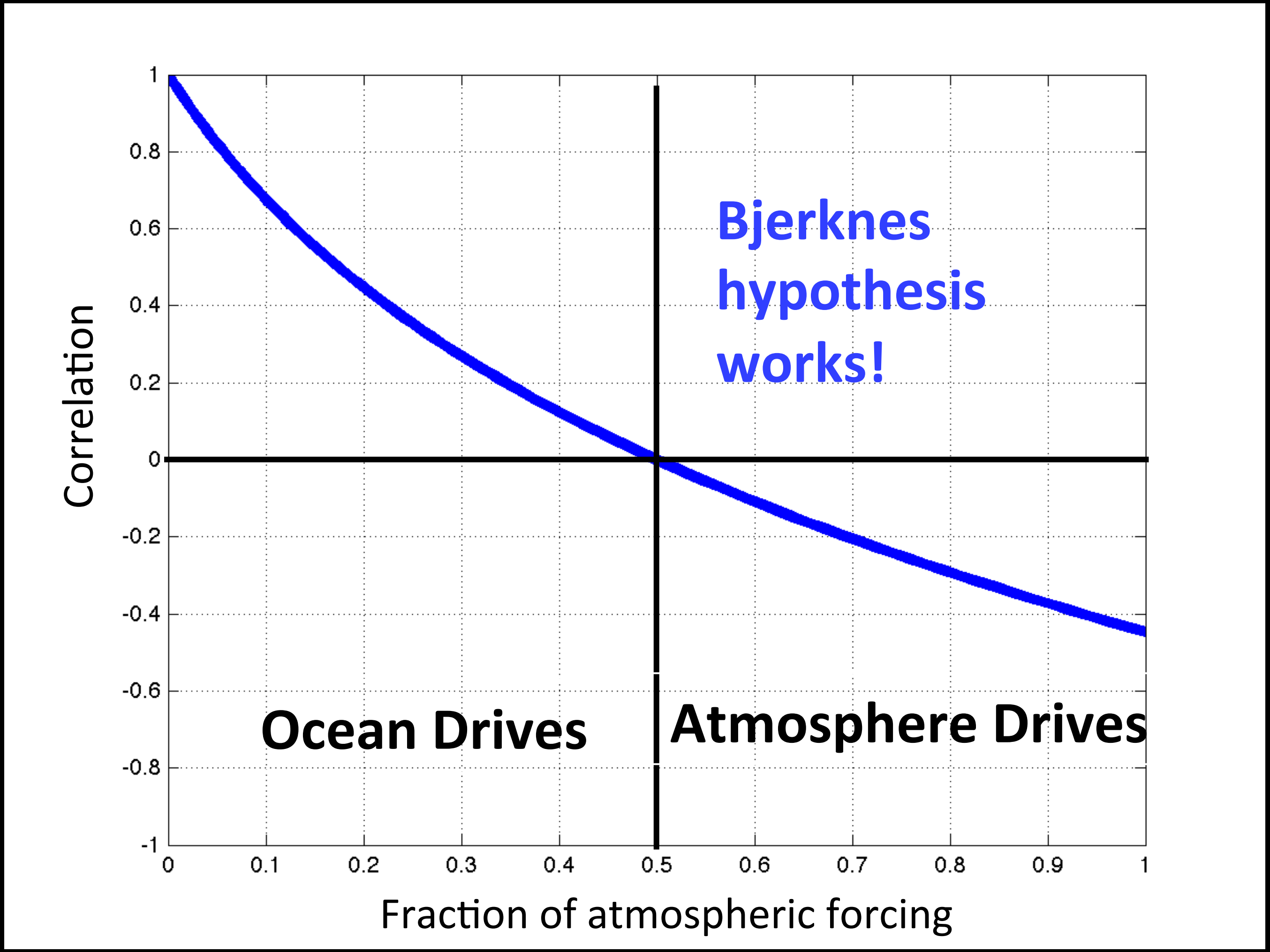
$$dT/dt = \underbrace{-\alpha T + q_a}_{Q_s} + Q_o$$

Now, we take qa and Qo to be uncorrelated white noise such that

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

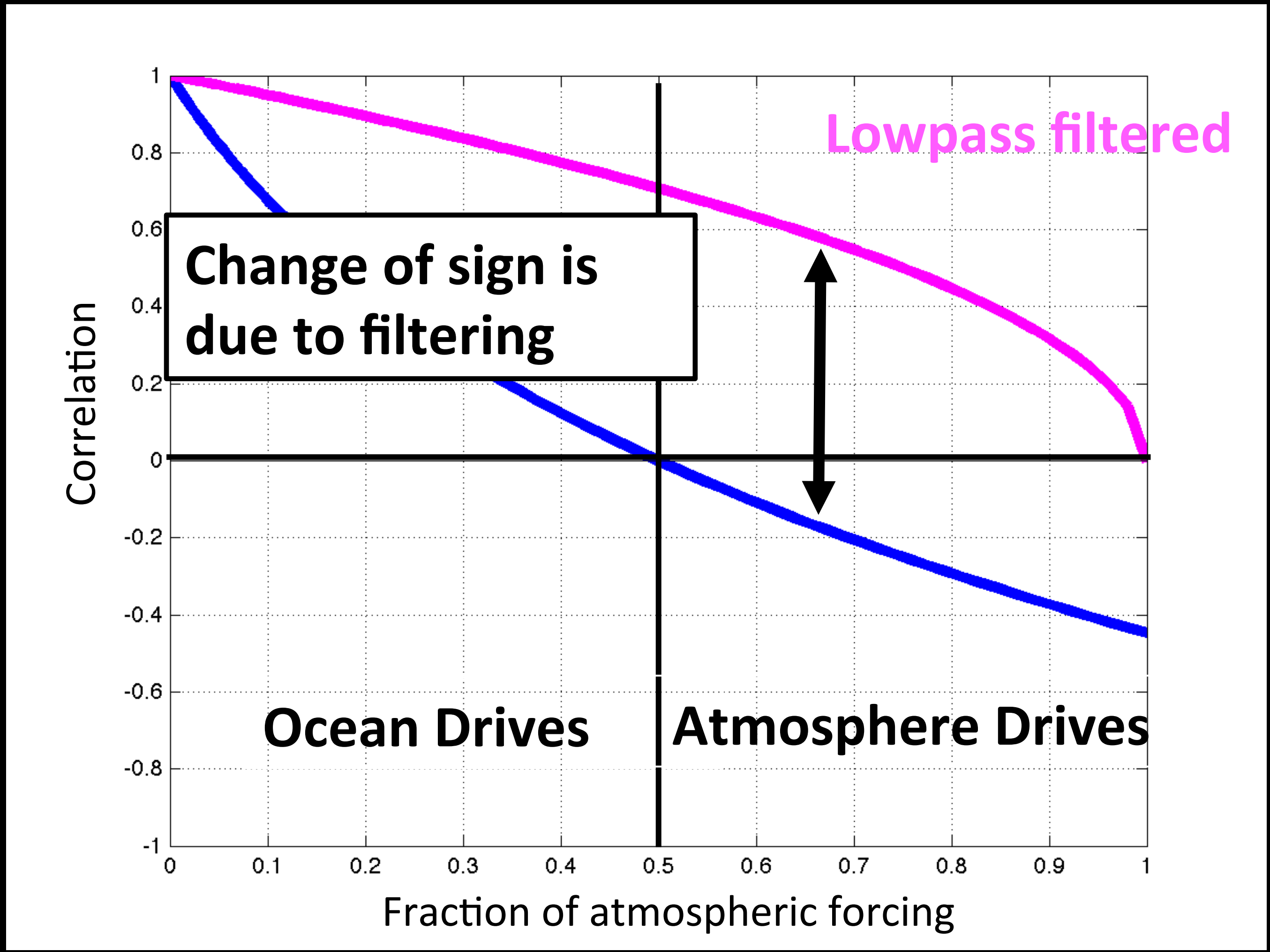
a^2 is the fraction of ‘atmospheric forcing’
b^2 is the fraction of ‘ocean forcing’

Correlation of net surface heat flux and surface temperature



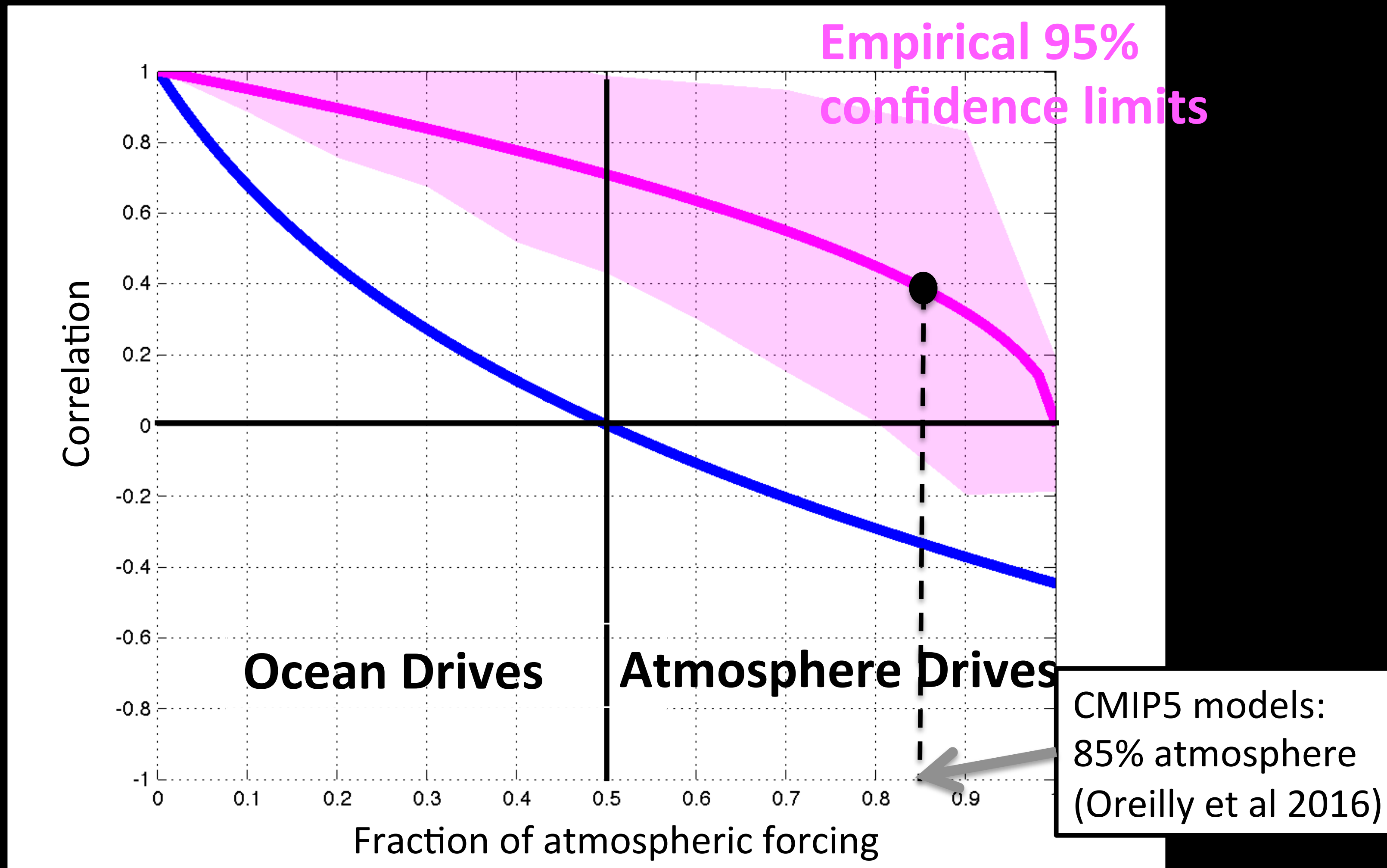
$$\rho(Q_s, T) = \frac{\sqrt{\varepsilon}[2a^2\mathrm{H}(-\tau) - 1]}{[a^2 + \varepsilon(b^2 - a^2)]^{1/2}} e^{-|\tau|} \approx \frac{\sqrt{\varepsilon}[2a^2\mathrm{H}(-\tau) - 1]e^{-|\tau|}}{a}$$

Correlation of net surface heat flux and surface temperature



$$\rho_{\mathrm{LP}}(Q_s, T) = -[b^2 R(s) - \omega_c a^2 R_s(s)]/[R(0) Q_0]^{1/2} \approx -bR(s)/R(0)$$

Correlation of net surface heat flux and surface temperature



Coupled and slab models can be brought into agreement with a small amount of ocean 'noise'

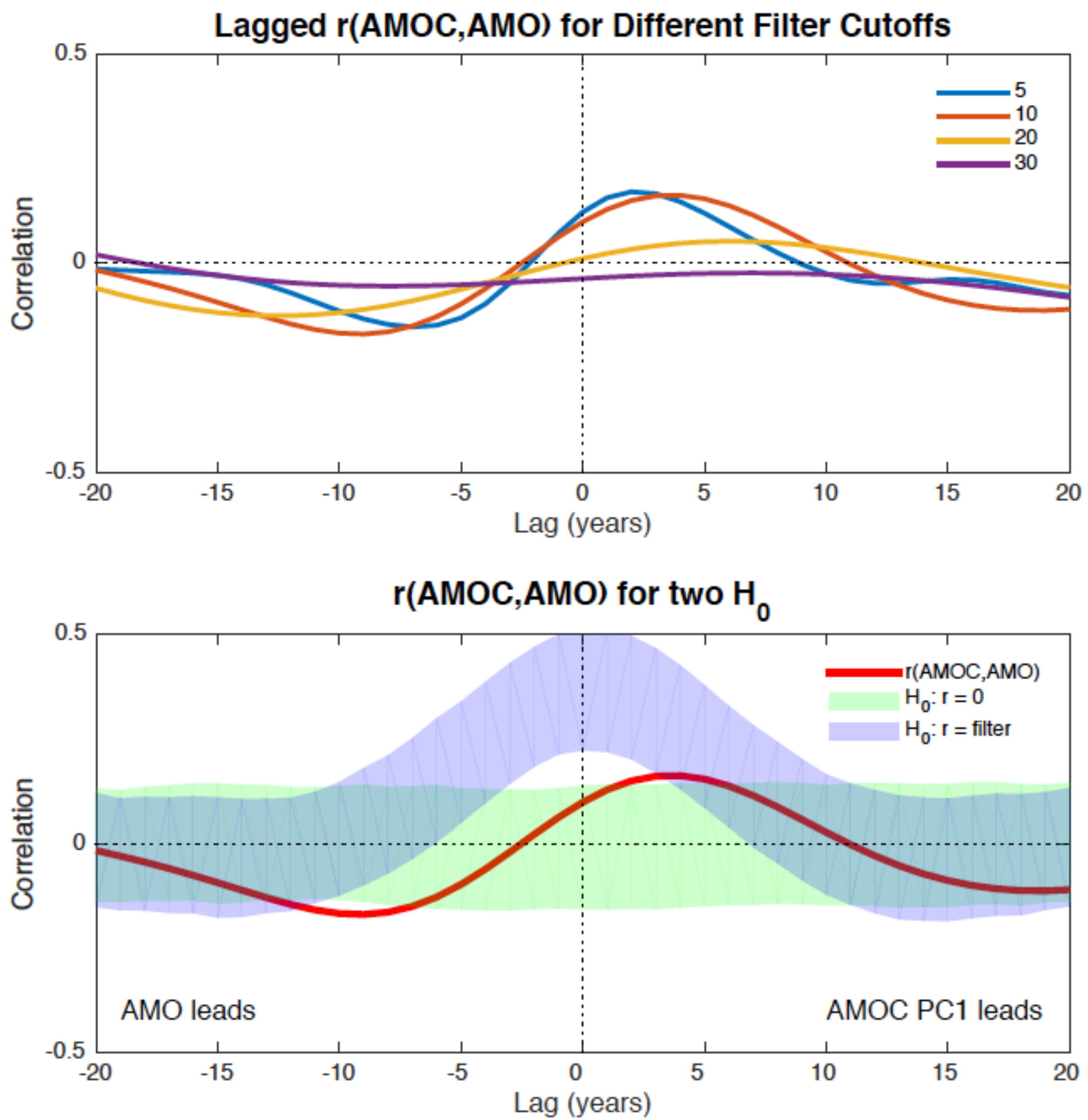
Conclusions

- Pattern and spectra of the AMV are similar in slab and coupled models, suggesting that the dominant process is stochastic atmospheric forcing
- This can happen despite different behavior in the surface fluxes between the slab and coupled models
- AMV pattern and spectra and surface fluxes are not good diagnostics for the role of the ocean
- Alternatives:
  - Subpolar OHC -- but then it's not clear how these are tied to basin-wide impacts ; and atmosphere is highly variabile
  - Lead-lag relationships (e.g. Delworth et al. 2017) − but these must be approached with caution with filtered data as well (Trenary and del Sole 2016, Cane et al. 2017)
  - Initialized experiments− but it's not always clear what is the source of predictability (Karspeck et al. 2016); How does this relate to AMV?
  - Start with the impacts: OHC, hydroclimate, hurricanes, sea-ice, European climate; carbon uptake

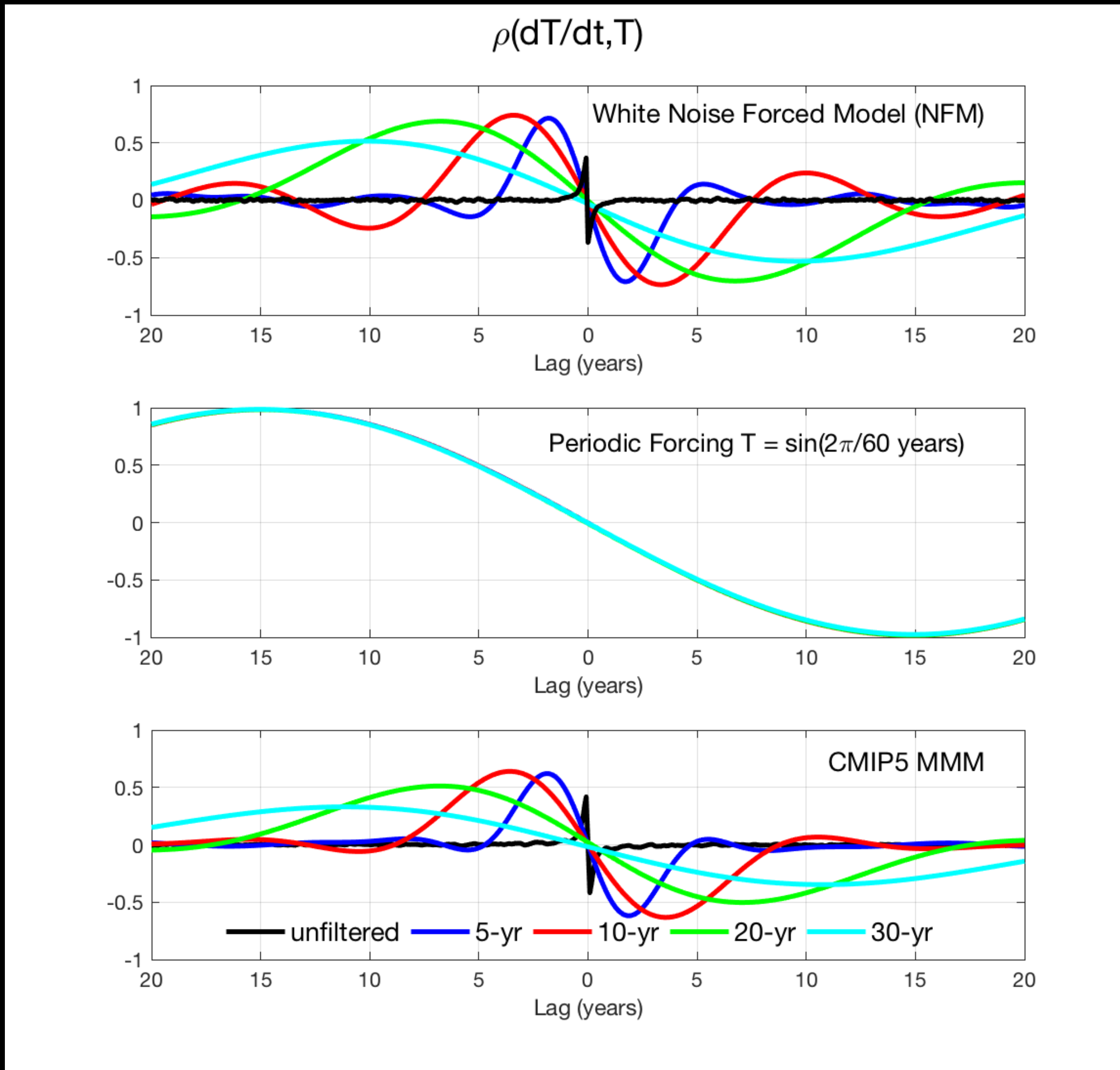
AMOC-Climate Paradigm - revised

- Changes in surface heat fluxes and/or freshwater input affect the amount of deep water formed at high latitudes in the North Atlantic, which, in turn causes coherent AMOC variability throughout the entire North Atlantic basin.
- For the case of an increasing AMOC, more heat is transported across the equator, warming the surface waters of the North Atlantic.
  - BUT the atmospheric circulation has variability on all timescales, and random changes in the strength of the winds can warm and cool the entire upper North Atlantic ocean at multi-decadal timescales, as well as produce ocean circulation variability at all timescales. This appears to be the dominant influence on AMV in many climate models.
- These ocean-driven changes warm the northern hemisphere and affect the atmosphere to produce impacts over land around the basin and possibly throughout the world.
- Therefore, knowledge of the strength of the circulation implies some knowledge of the surface climate on multi-decadal to millennial timescales, and/or vice versa
  - Only if the atmosphere is not changing on these timescales

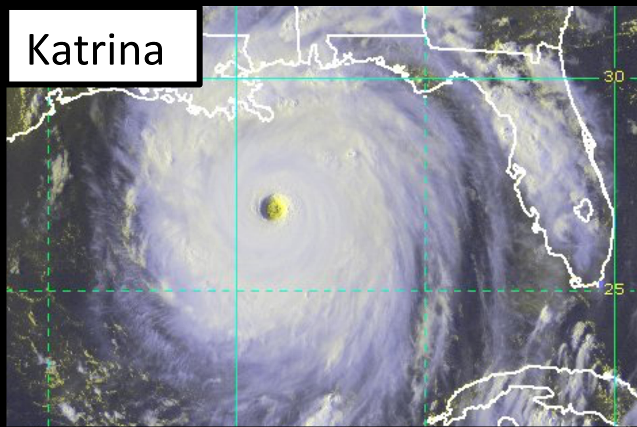
Del Rigor en la Ciencia (1946) Jorge Luis Borges

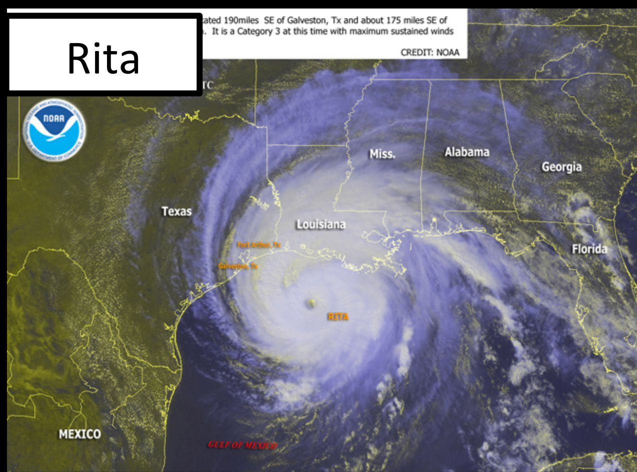


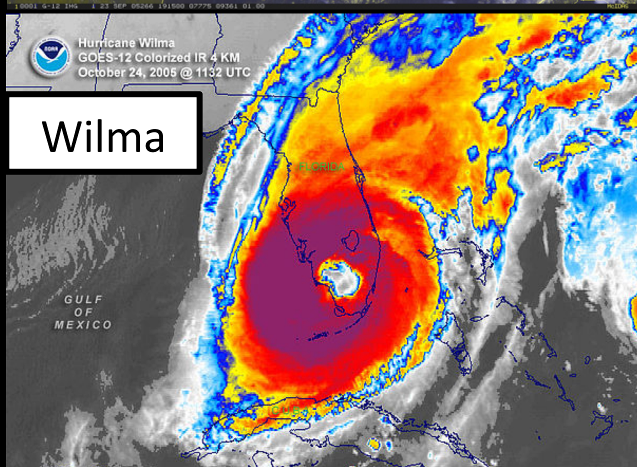
Lagged r(AMOC,AMO) for Different Filter Cutoffs
5
10
20
30
Correlation
Lag (years)
r(AMOC,AMO) for two H_0
r(AMOC,AMO)
H_0: r = 0
H_0: r = filter
AMO leads
AMOC PC1 leads
Correlation
Lag (years)

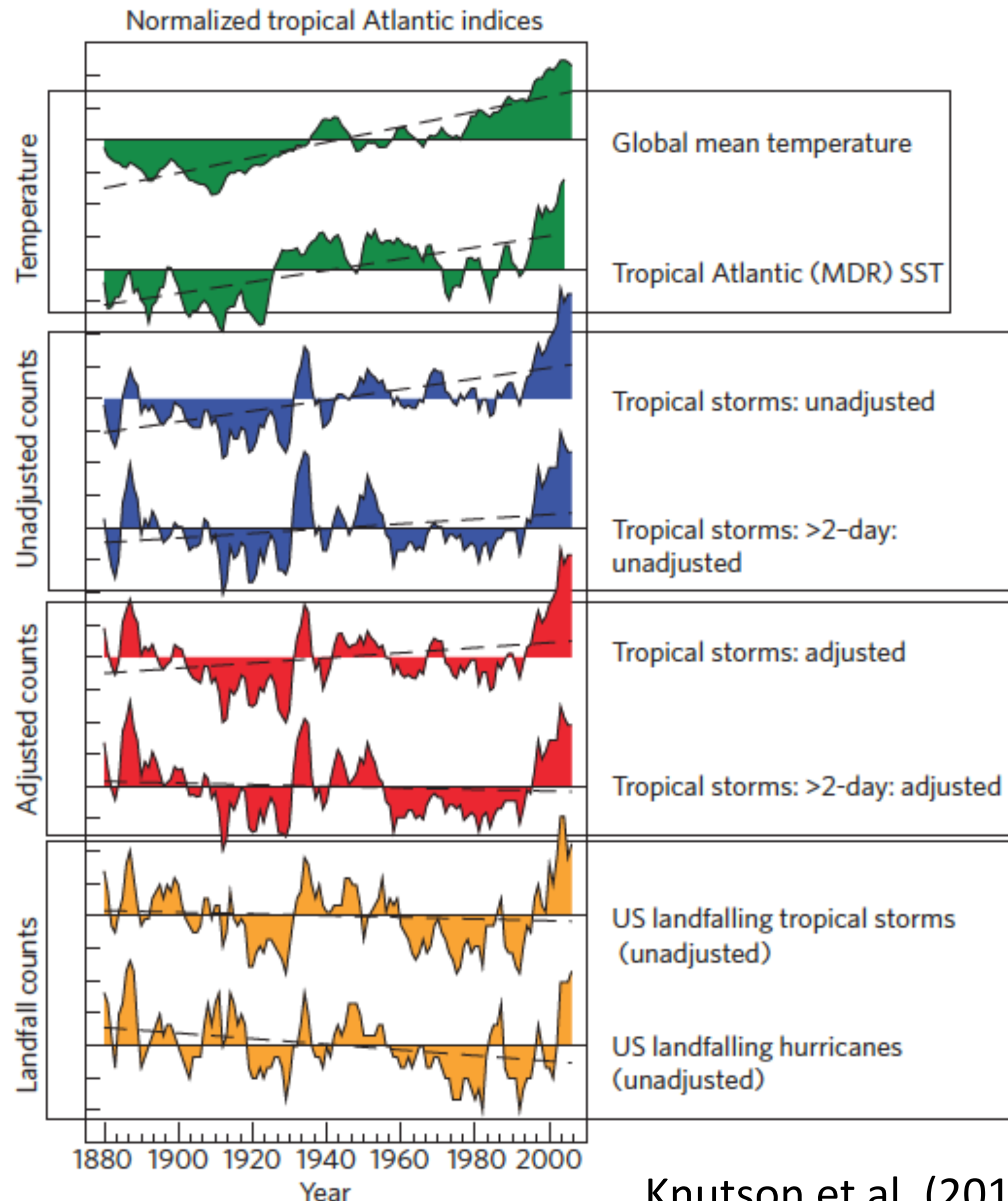


Cane et al. (2017)









Knutson et al. (2010)

Future work

- Observations and coupled models show some non-zero role for the ocean circulation in parts of the extra-tropical North Atlantic, but the magnitude, processes, predictability, and possible impacts are still open questions.
- 'All models are wrong… '
  - Is the AMOC too stable in current models? (Liu et al 2017)
  - Is there more variabiity with a resolved Gulf Stream (Siqueria and Kirtman 2016)
- Multiple causes
  - Applies to pacific- e.g. hiatus
  - Other processes: clouds, aerosols
  - Predictability?

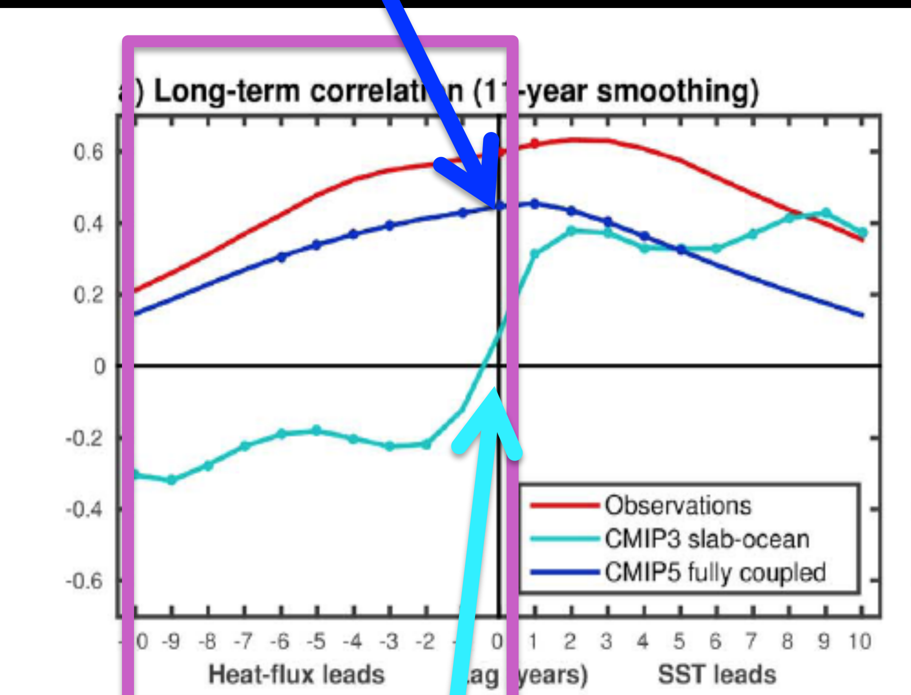
Need a flexible modeling framework to test ideas

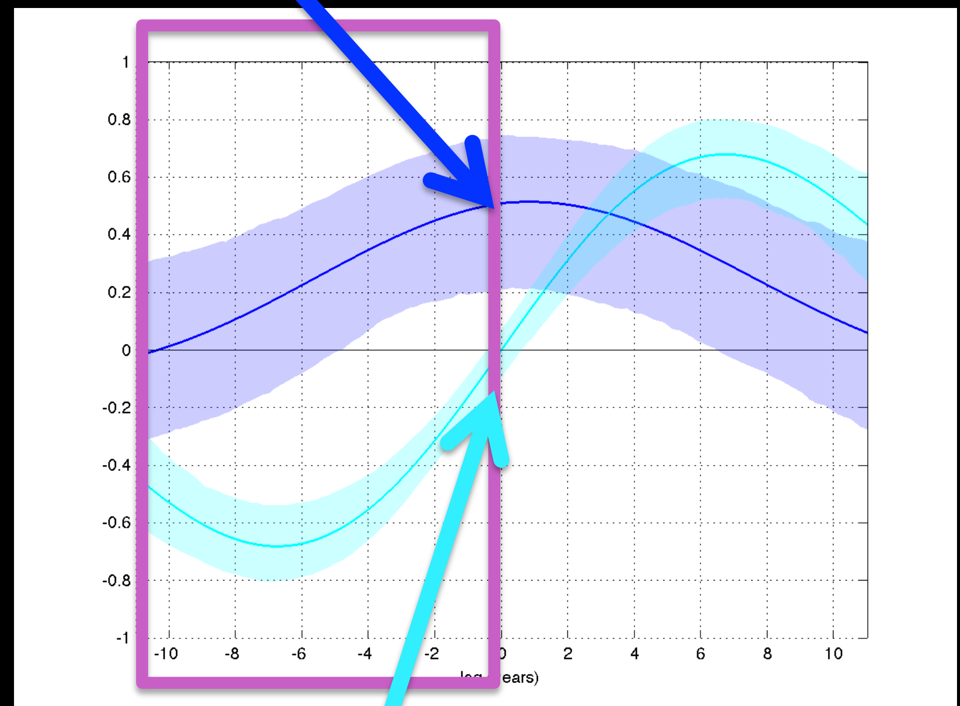
Extra slides

2. Change in sign between the slab and coupled LP filtered correlation can be explained with minimal ocean noise

Fully coupled models

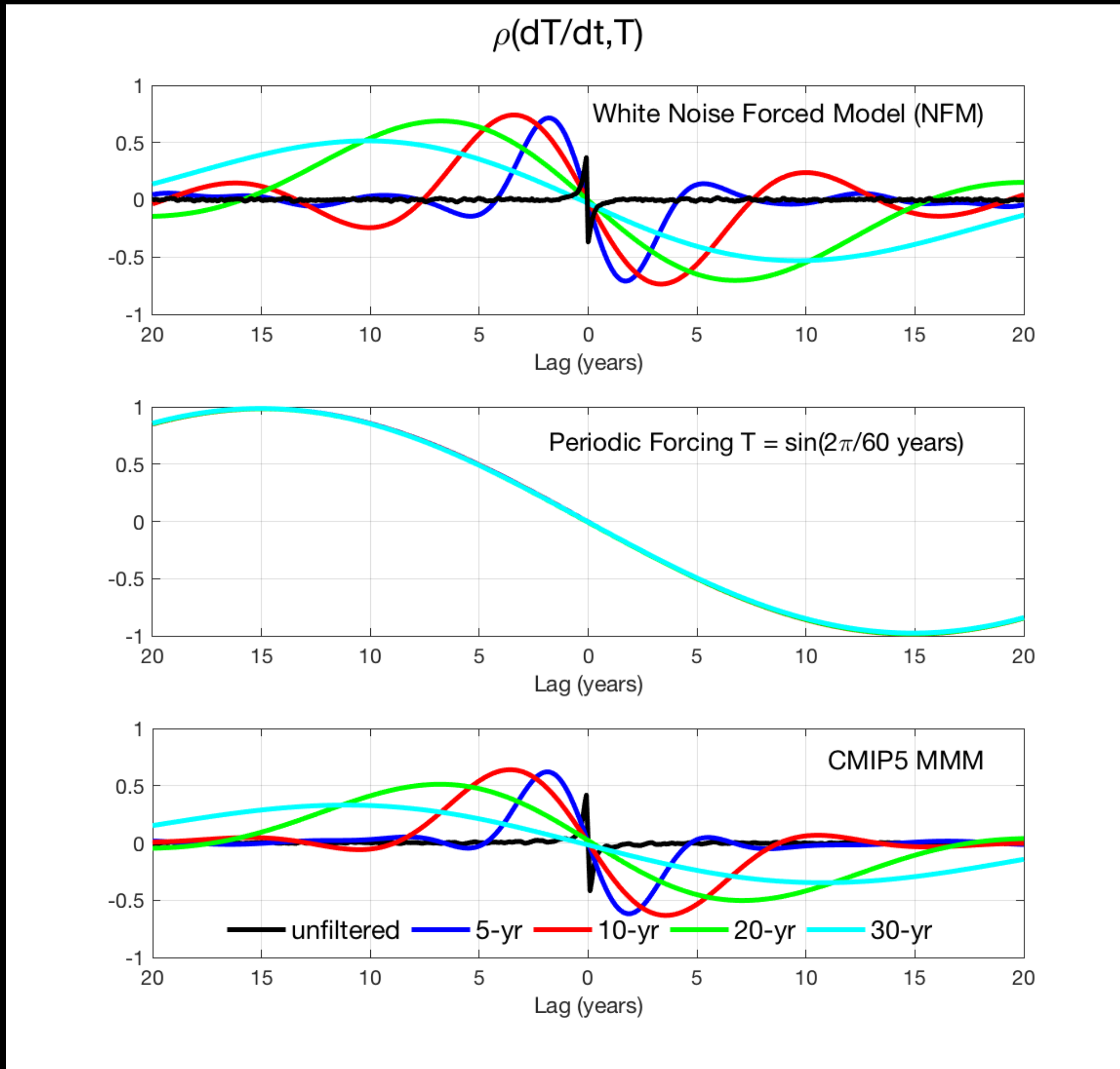
Noise forced model with 85% atmosphere and 15% ocean



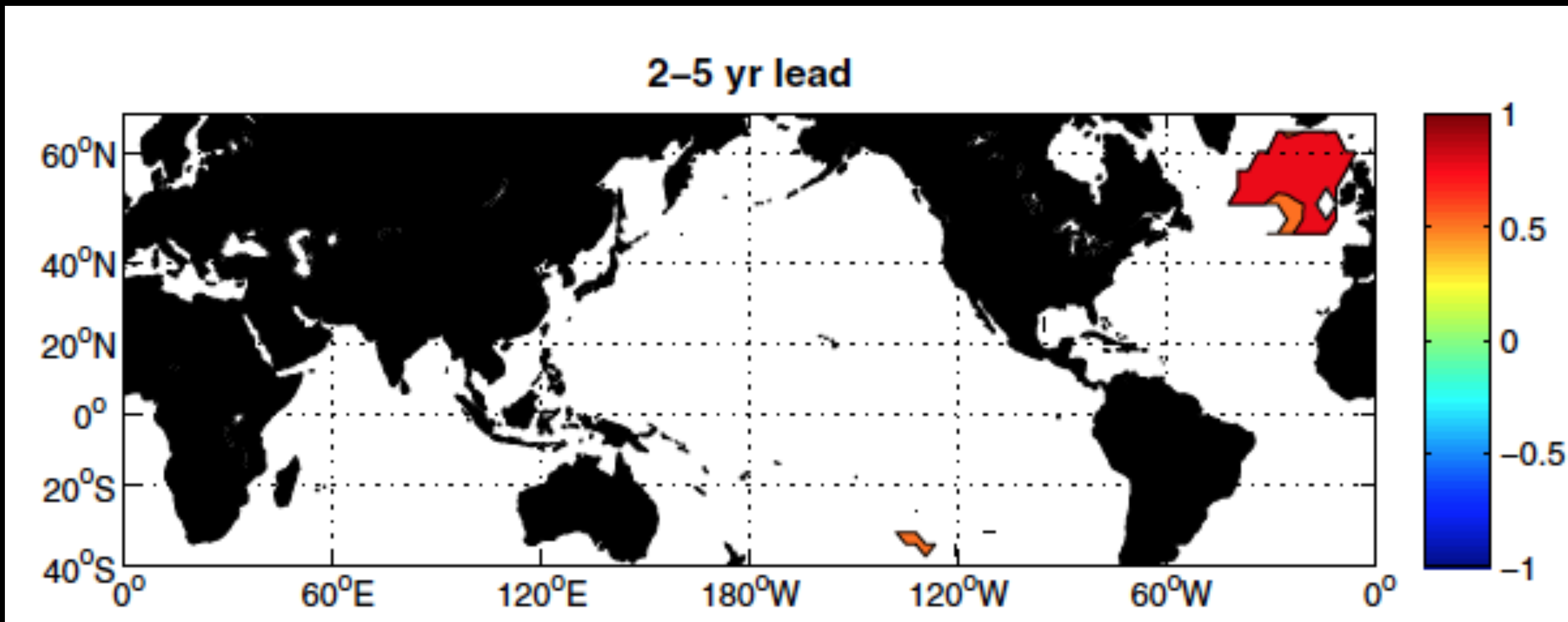


AGCM-slab ocean models

Noise forced model with no ocean



Cane et al. (2017)


2–5 yr lead
60⁰N
40⁰N
20⁰N
0⁰
20⁰S
40⁰S
0⁰
60⁰E
120⁰E
180⁰W
120⁰W
60⁰W
0⁰
1
0.5
0
−0.5
−1

$$\rho(Q_s,T) = \frac{\sqrt{\varepsilon}[2a^2\mathrm{H}(-\tau)-1]}{[a^2+\varepsilon(b^2-a^2)]^{1/2}}e^{-|\tau|} \approx \frac{\sqrt{\varepsilon}[2a^2\mathrm{H}(-\tau)-1]e^{-|\tau|}}{a}$$

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