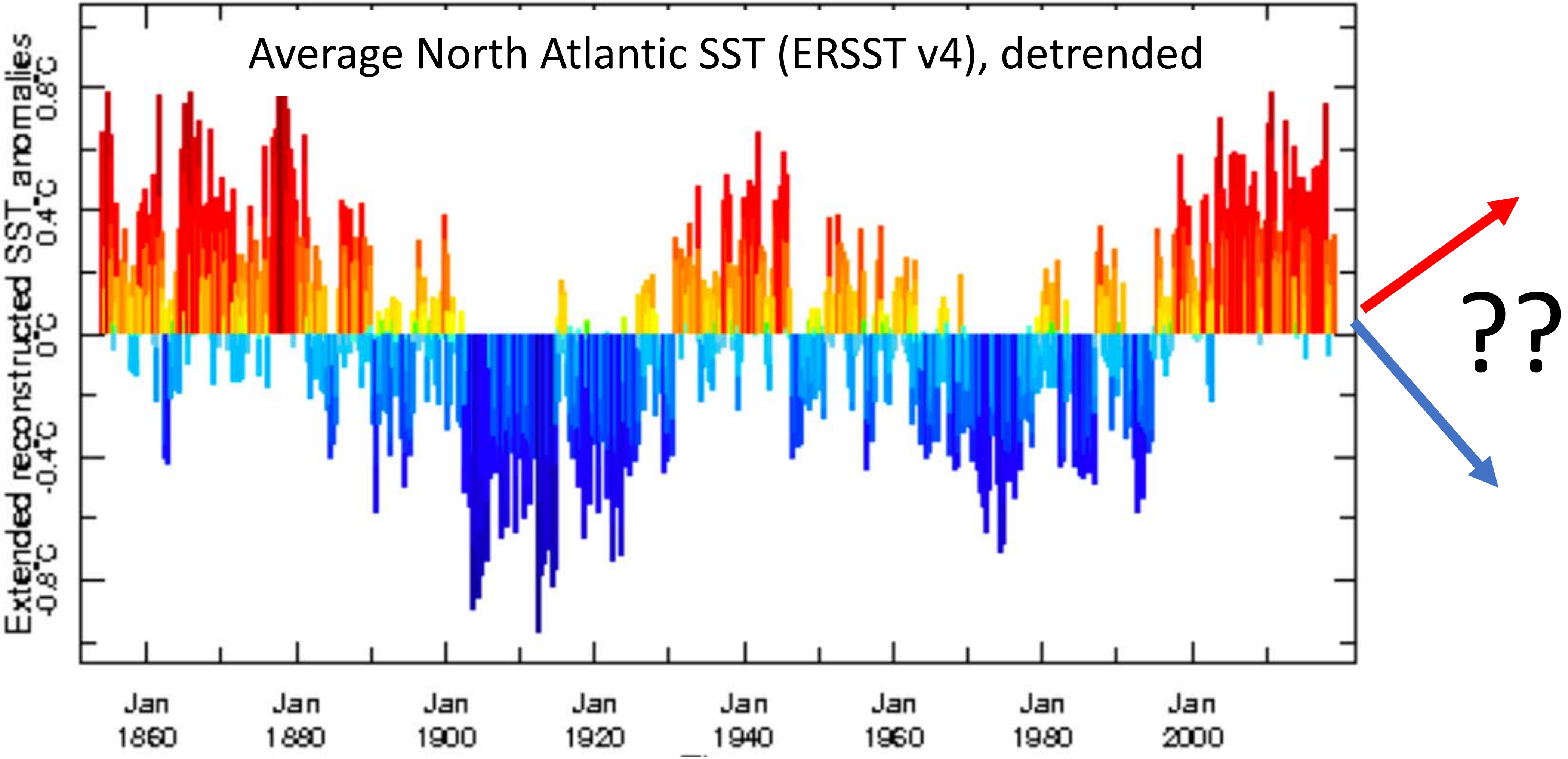
# Atlantic Multidecadal Variability: What are the roles of external forcing and ocean circulation?

Lisa Murphy, Jeremy Klavans, Amy Clement, Mark Cane

# Atlantic Multi-decadal Variability (AMV)



What is the role of external forcing?

What is the role of the ocean?

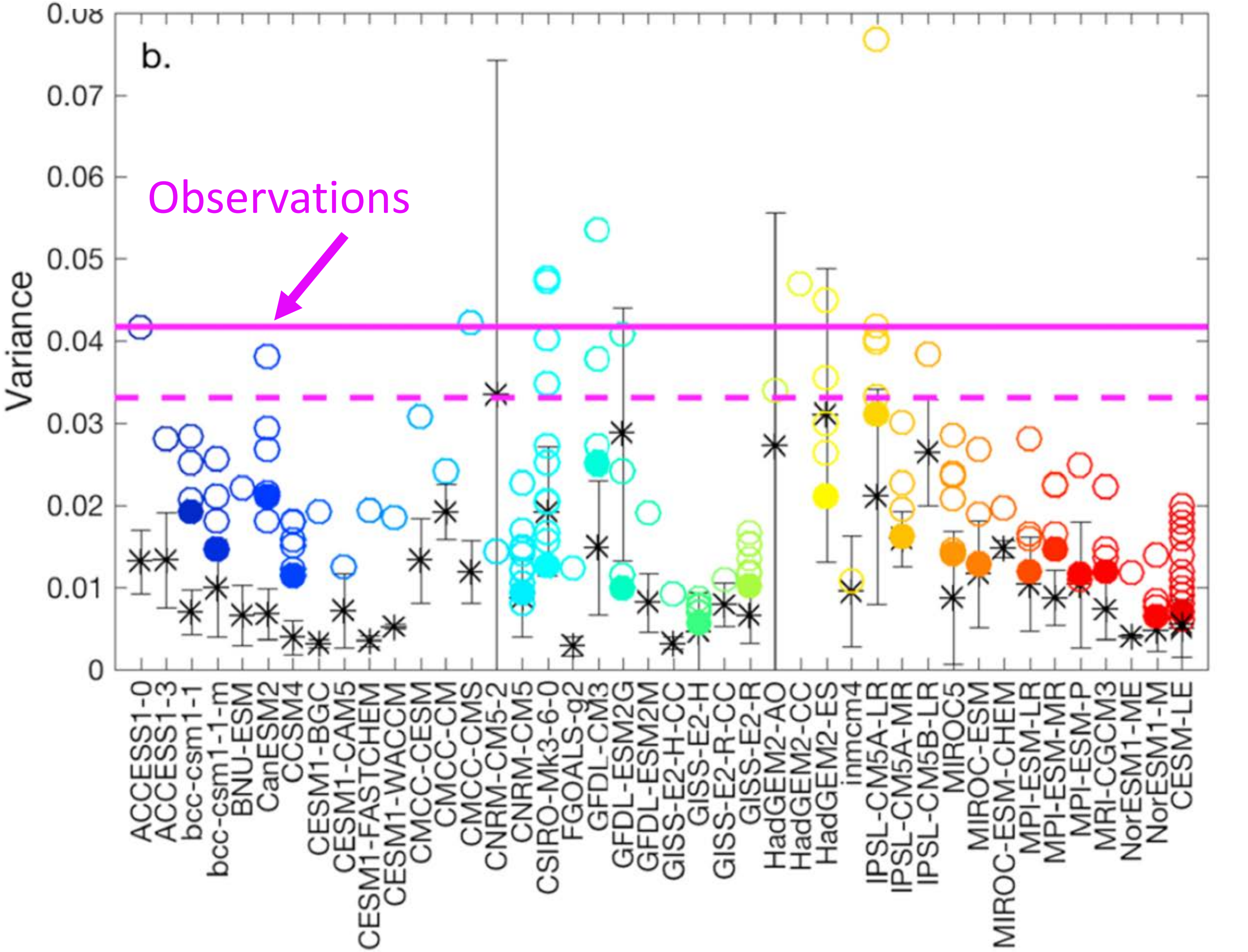
| CESM simulations | Preindustrial Control | Last Millenium | Historical Forcing | RCP8.5 |
| --- | --- | --- | --- | --- |
| Fully Coupled | 2200 years | 10 members (1920-2005) | 42 members (1920-2005) | 42 members (2005-2100) |
| Slab ocean model (SOM)* | 1000 years | **??** | **10 members (1920-2005)** | **5 members (2005-2100)** |

*Mixed layer depth is same as coupled model but fixed in time. Qflux is prescribed and does not vary with time.

# What is the role of external forcing?

PI control multi-decadal variance (black) Historical (colors)

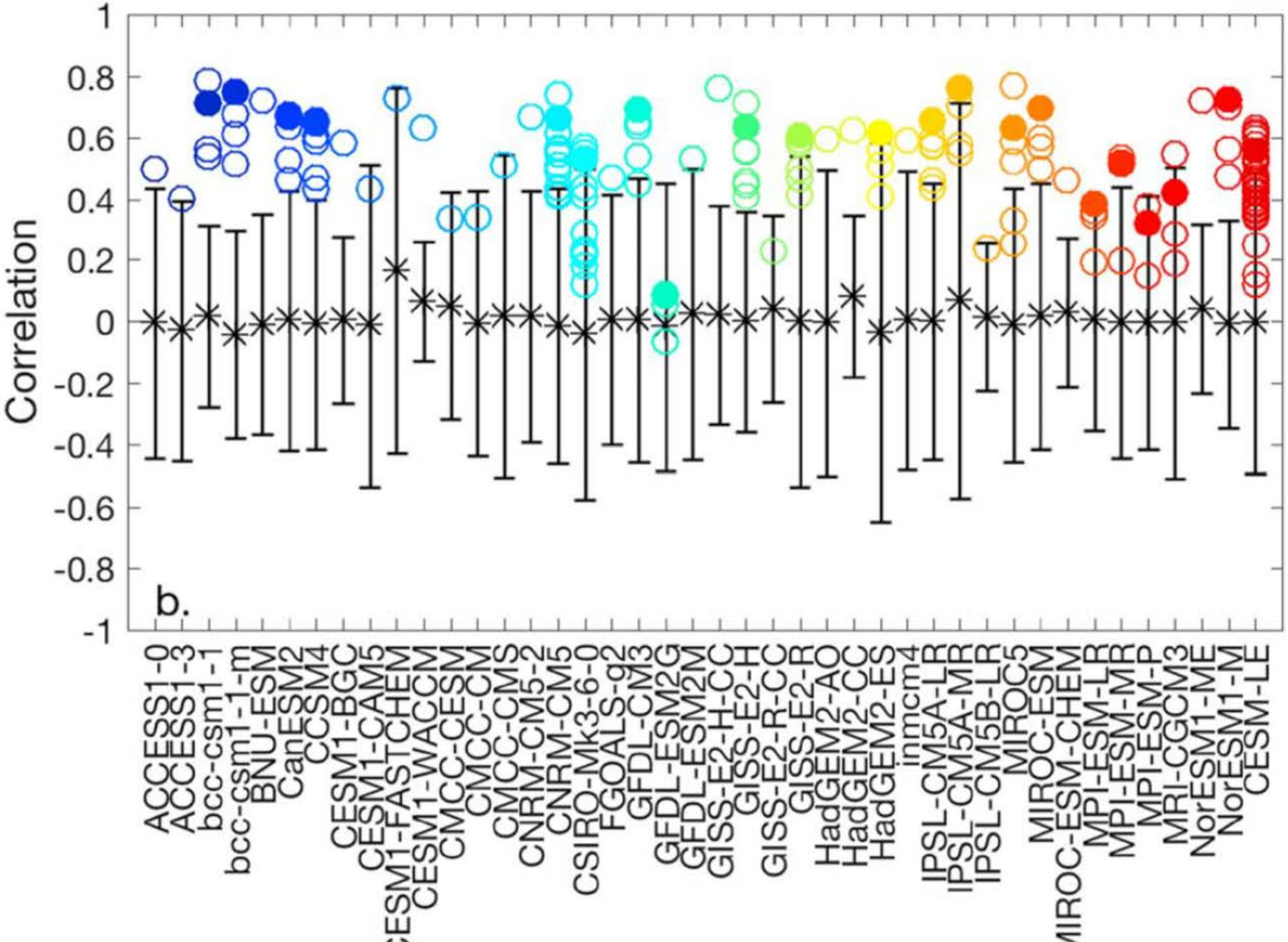
CMIP5 models produce more multi-decadal variance with forcing




Murphy et al. (2017)

The chance of an unforced PI run correlating as well with the observed AMO as the historical run is very small.

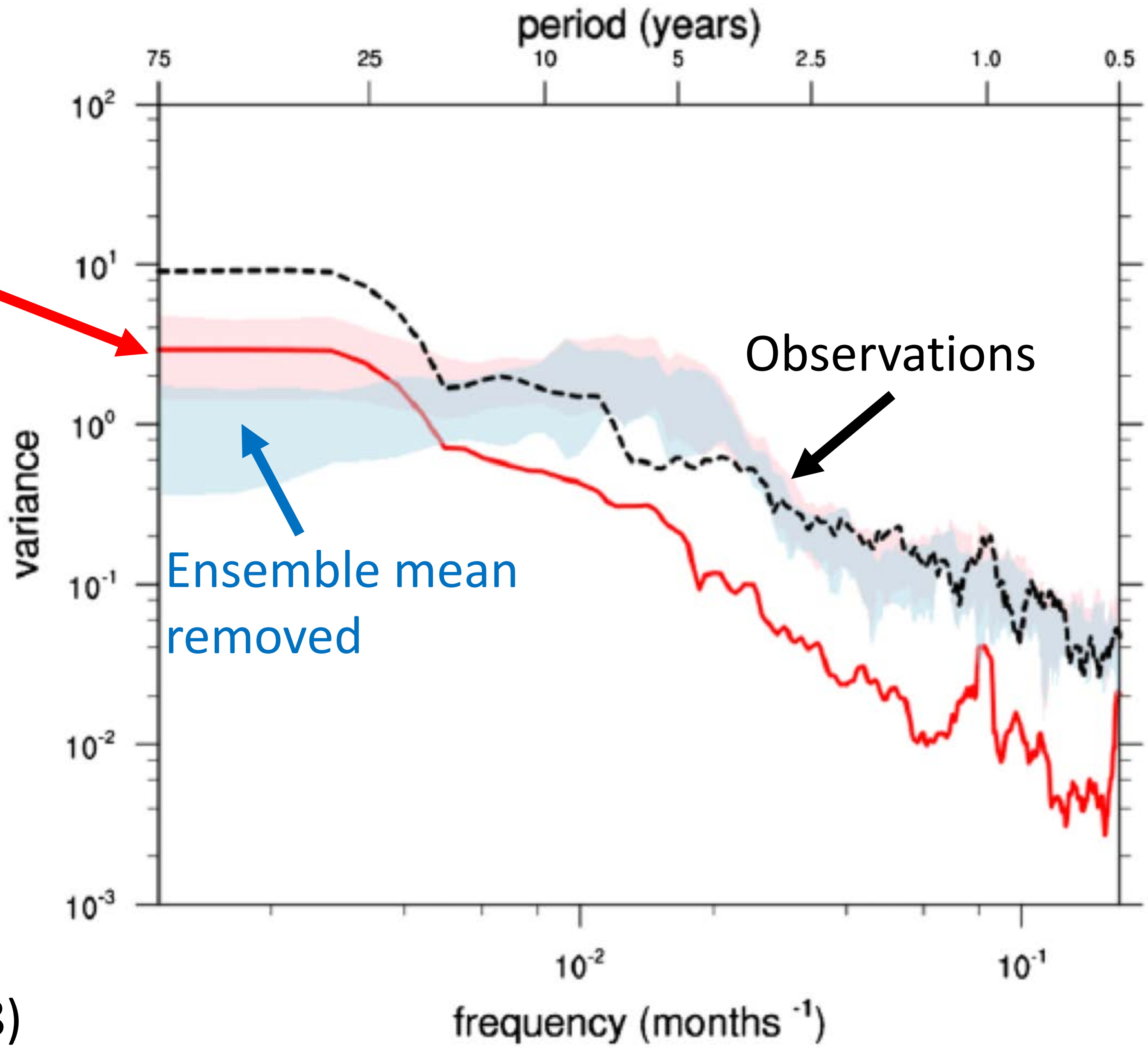
PI control low frequency correlation with observations (black) Historical correlation (colors)




Murphy et al. (2017)

CESM Power spectrum of AMV (1854-2005)

Ensemble mean signal is larger than internal variability

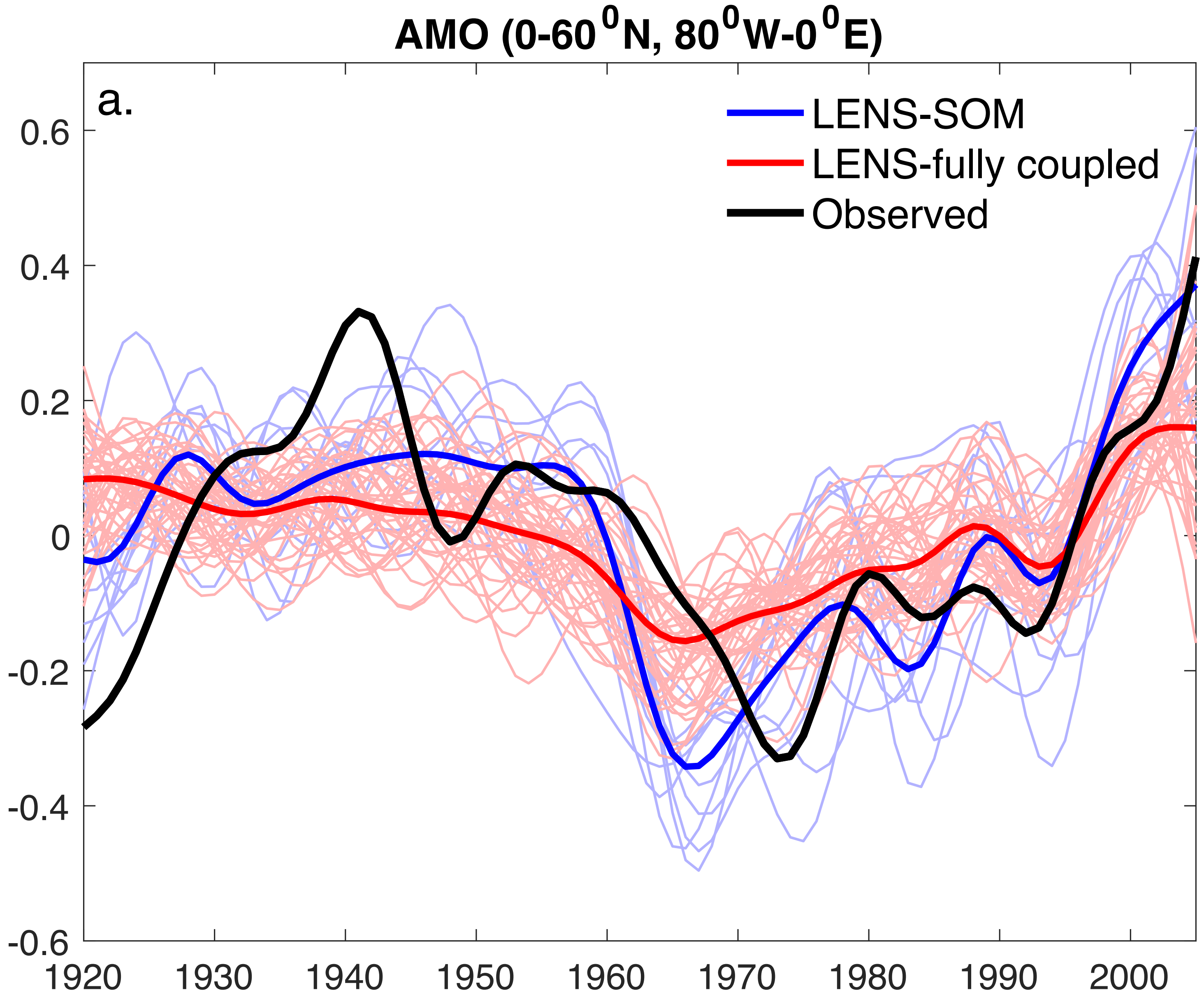



Bellomo et al. (2018)

# What is the role of external forcing?

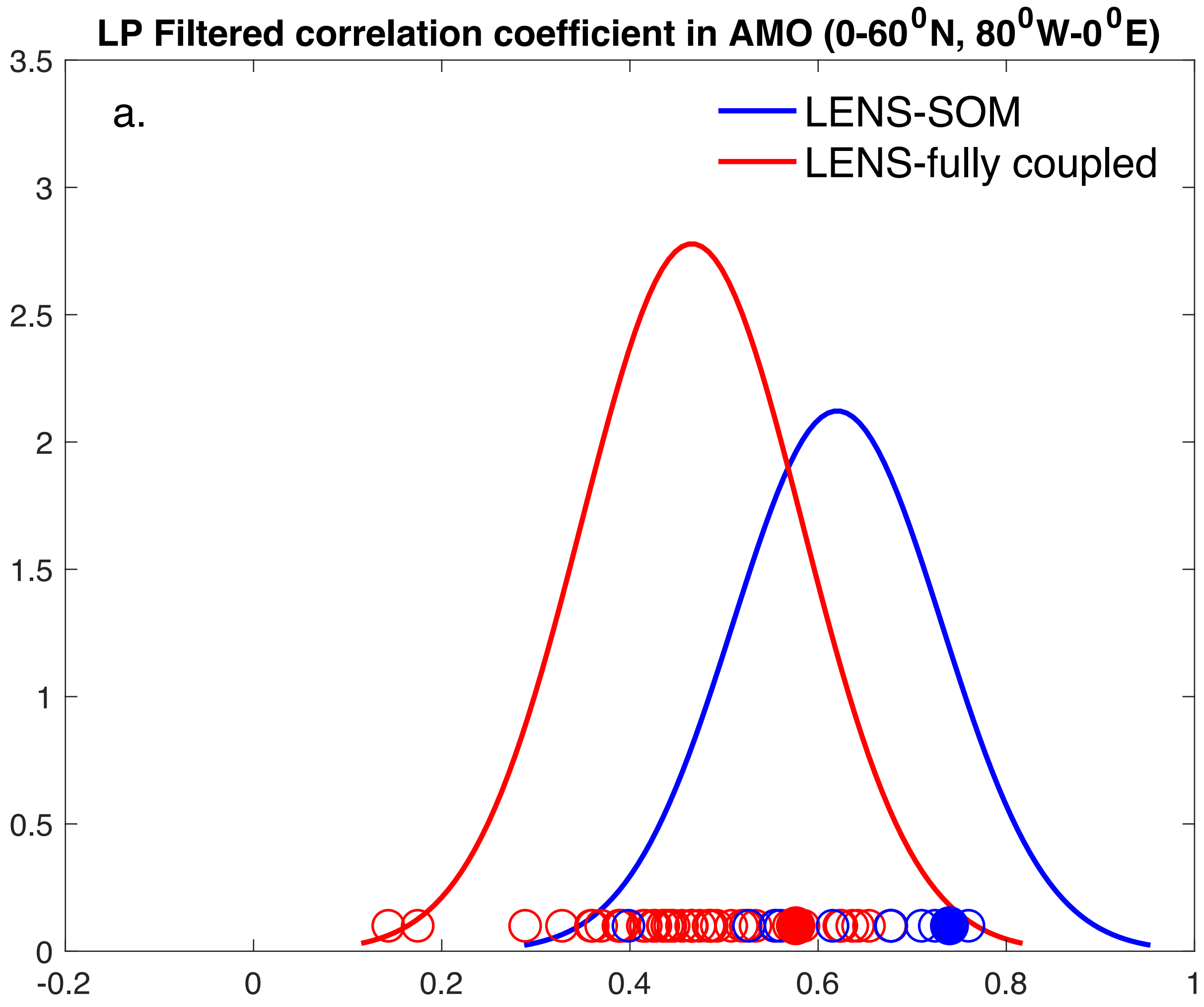
Models need external forcing to simulate the observed magnitude and timing of the observed AMV

# What is the role of the ocean?

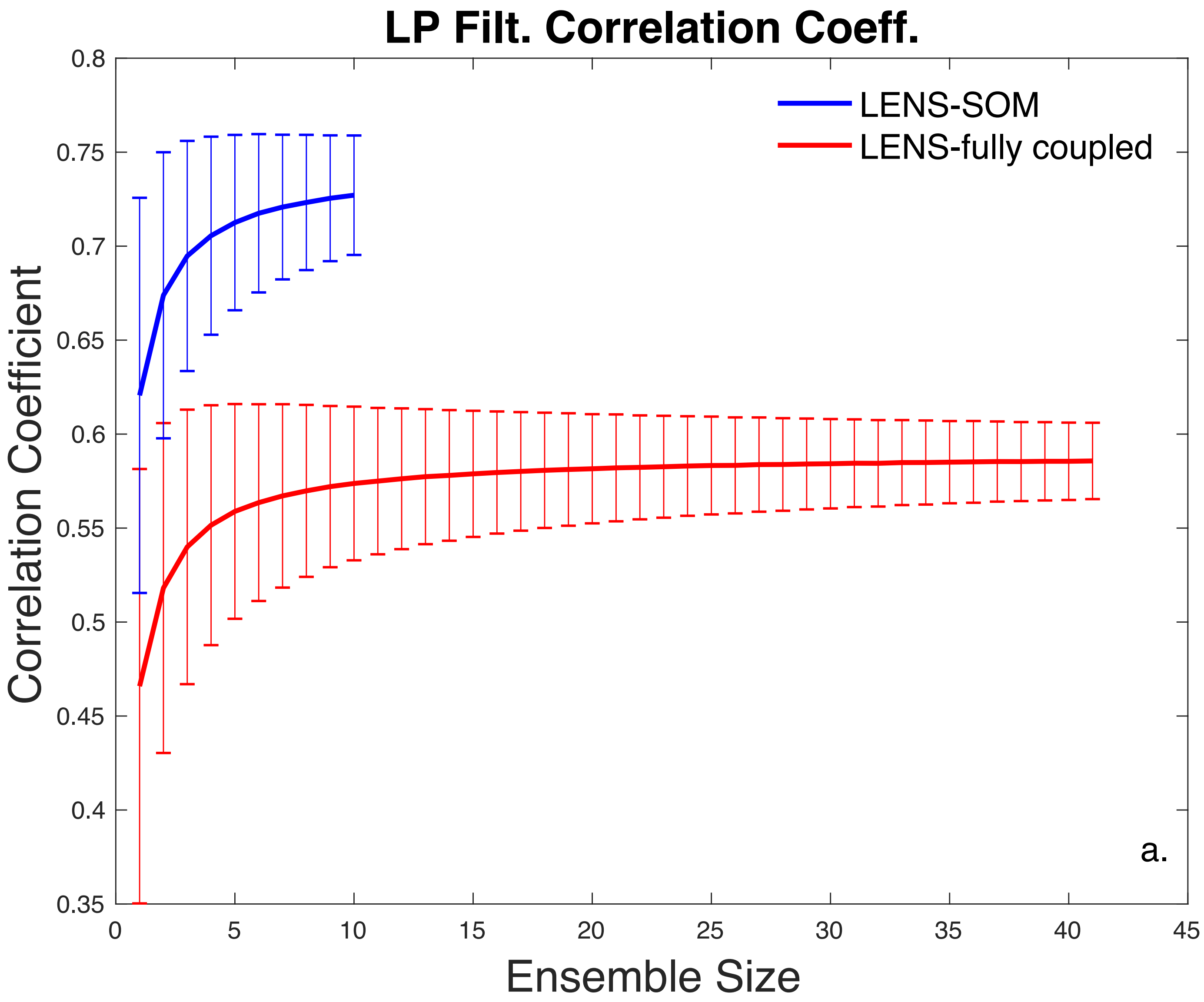


AMO (0-60$^0$N, 80$^0$W-0$^0$E)
a.
LENS-SOM
LENS-fully coupled
Observed
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1920
1930
1940
1950
1960
1970
1980
1990
2000

# Correlation is better with SOM ensemble mean

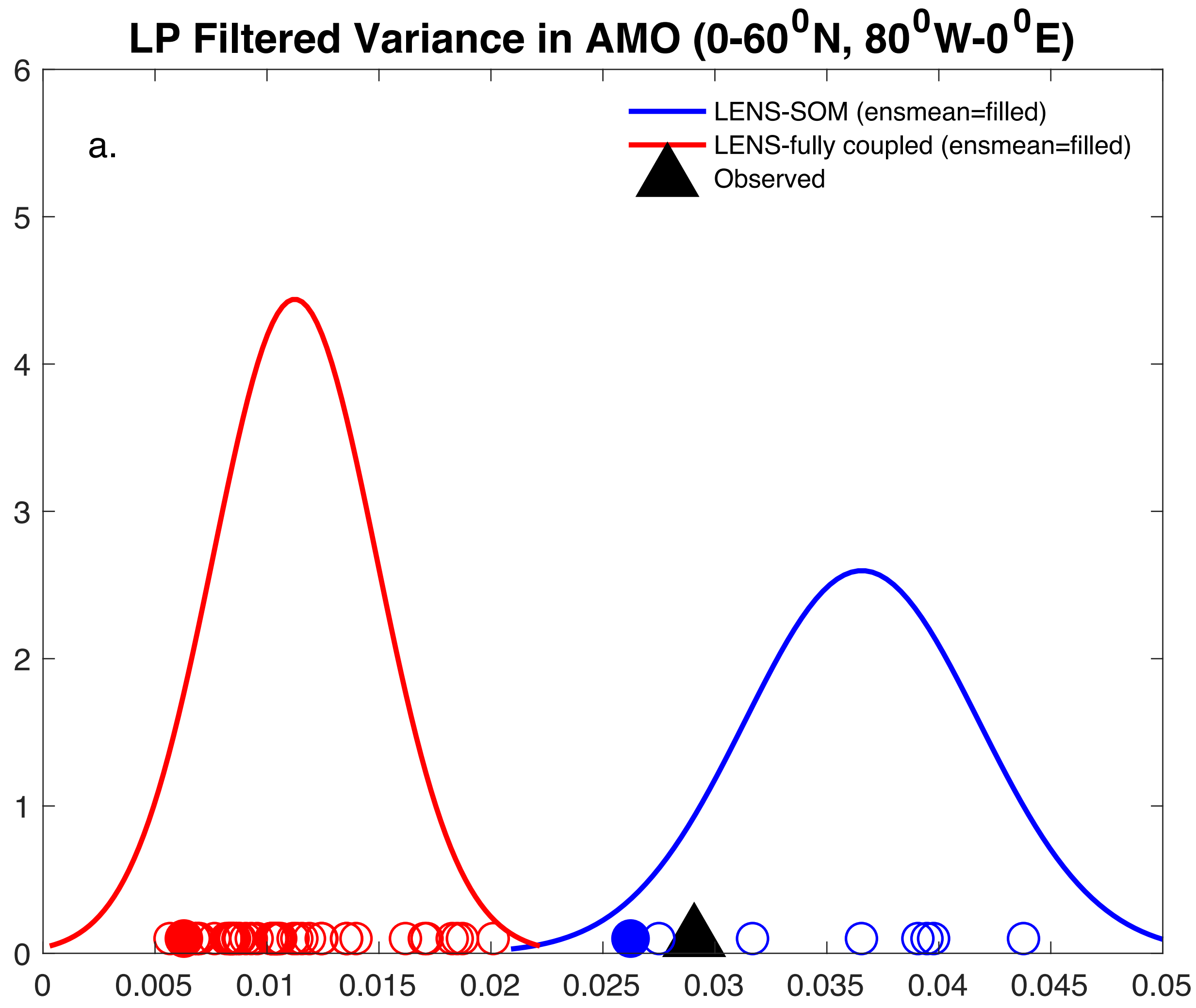



*correlation is higher in CESM LME 1850-2005 and for 1930-2005 due to warm start in 1920

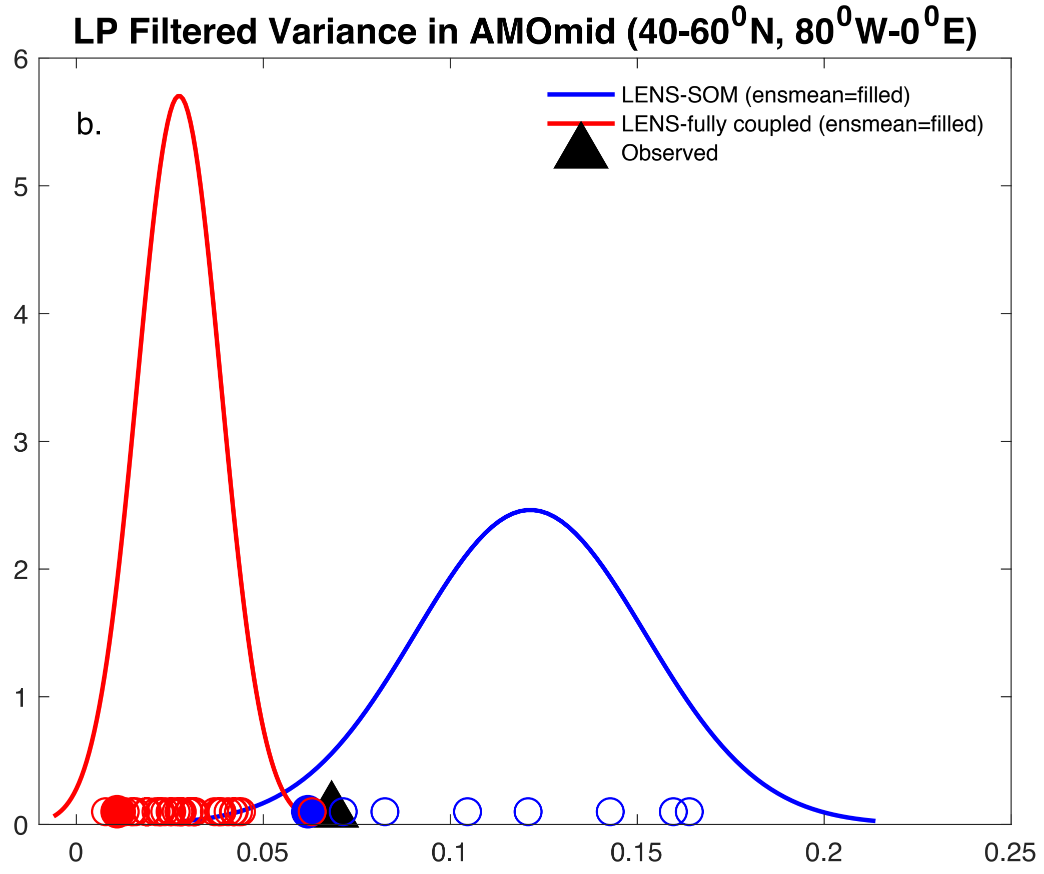


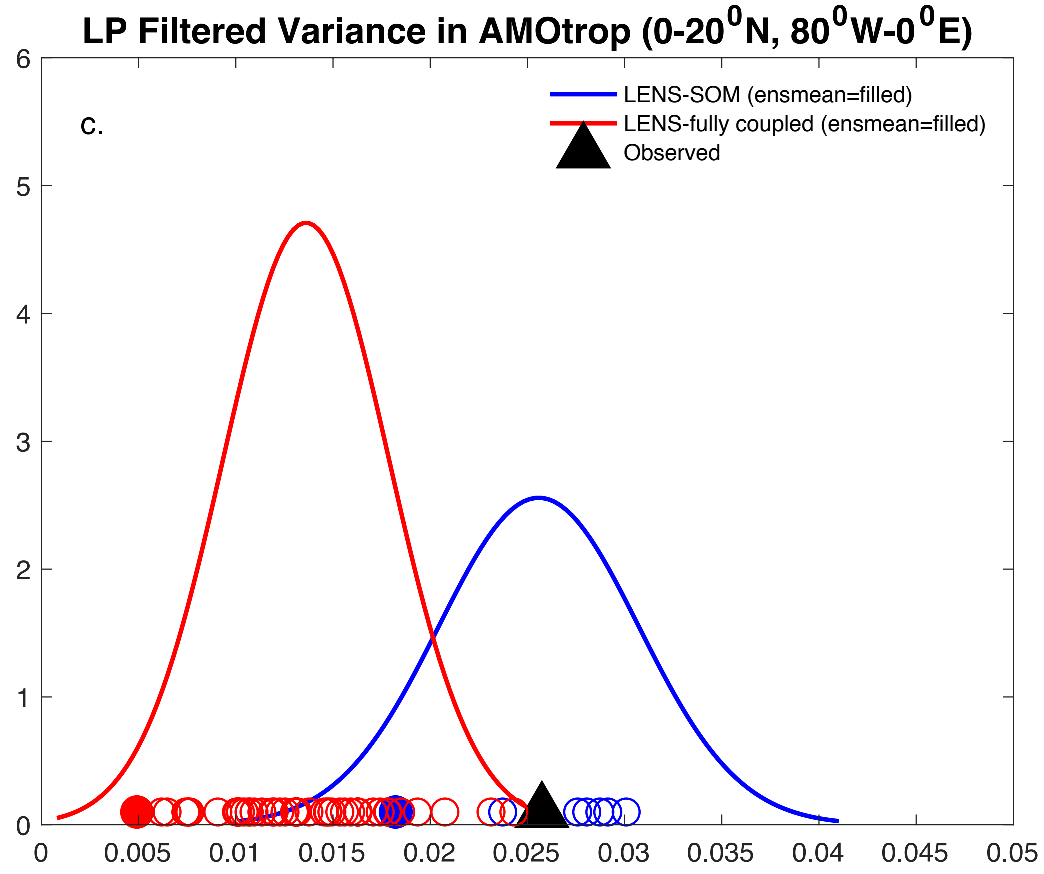
LP Filt. Correlation Coeff.
LENS-SOM
LENS-fully coupled
Correlation Coefficient
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0
5
10
15
20
25
30
35
40
45
Ensemble Size
a.

# The ocean modulates the magnitude of variability (internal and forced)

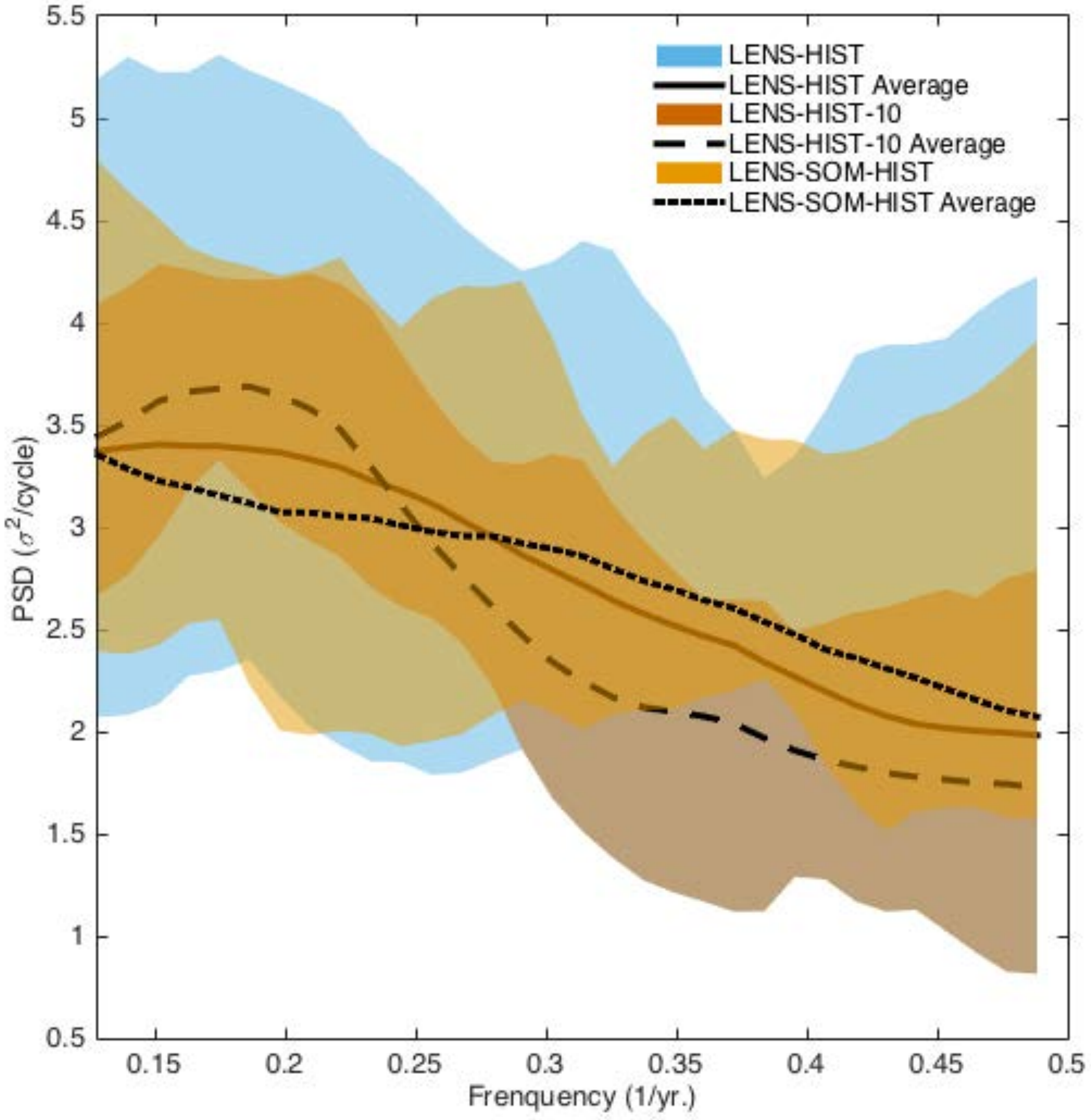


# This is especially prominent in mid-latitudes, and less so in tropics (because of ENSO)



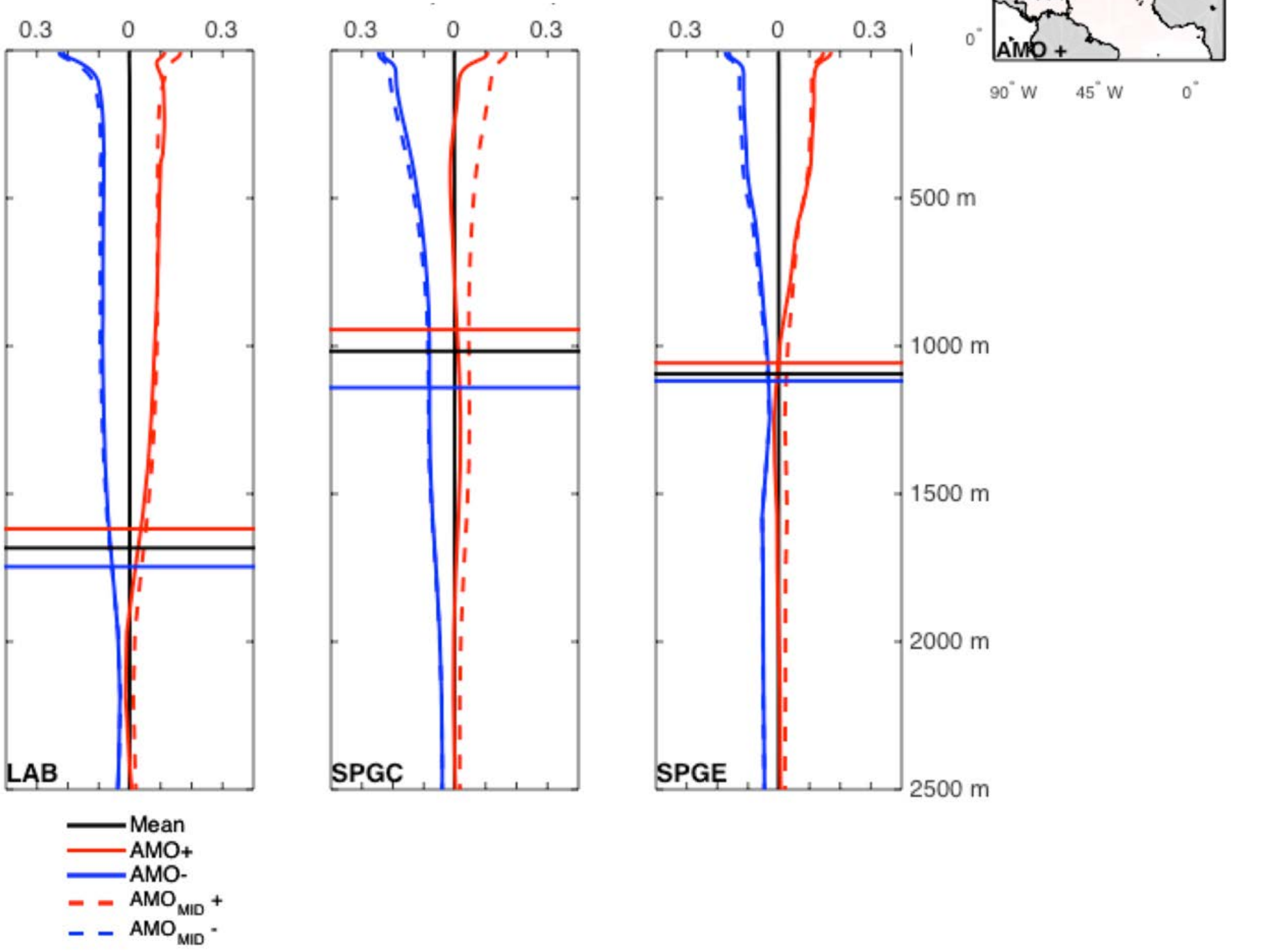



The statistics of atmospheric variability (here, NAO) are the same in SOM and coupled



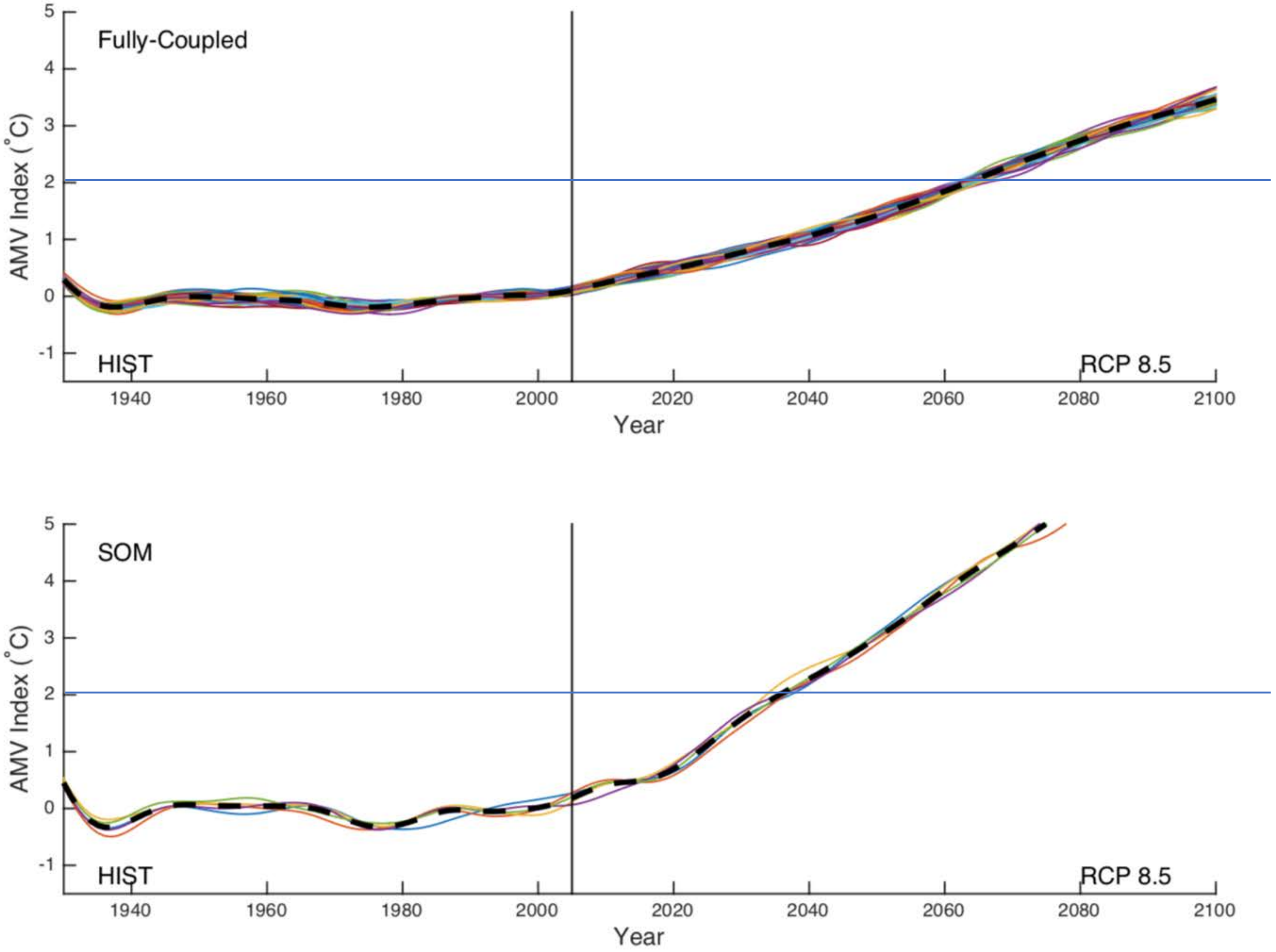
## Composite AMV temperature anomalies in LENS

# Is the ocean modulating the surface signature of the forcing by the correct amount?*



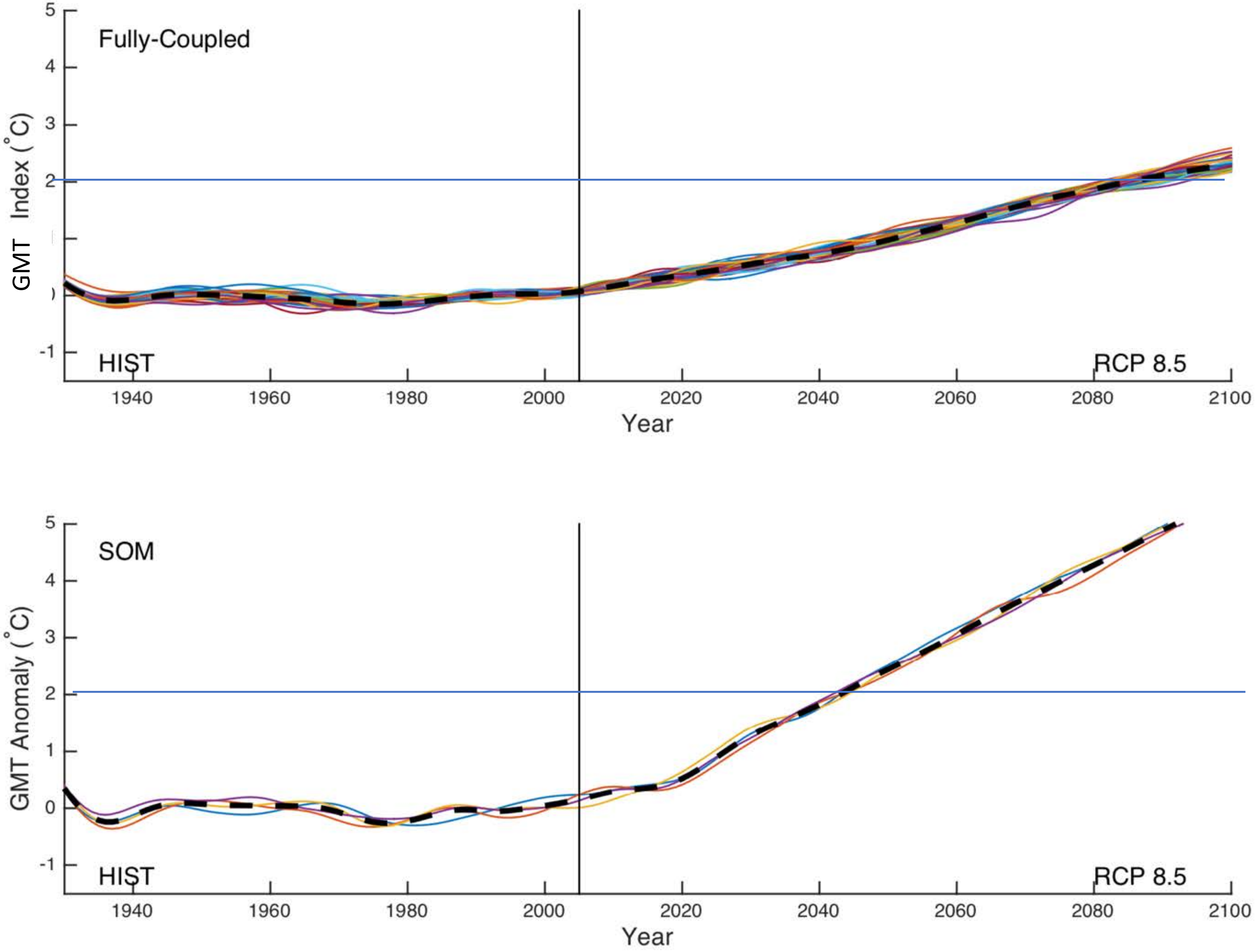

*a plug for developing a model tool to develop this

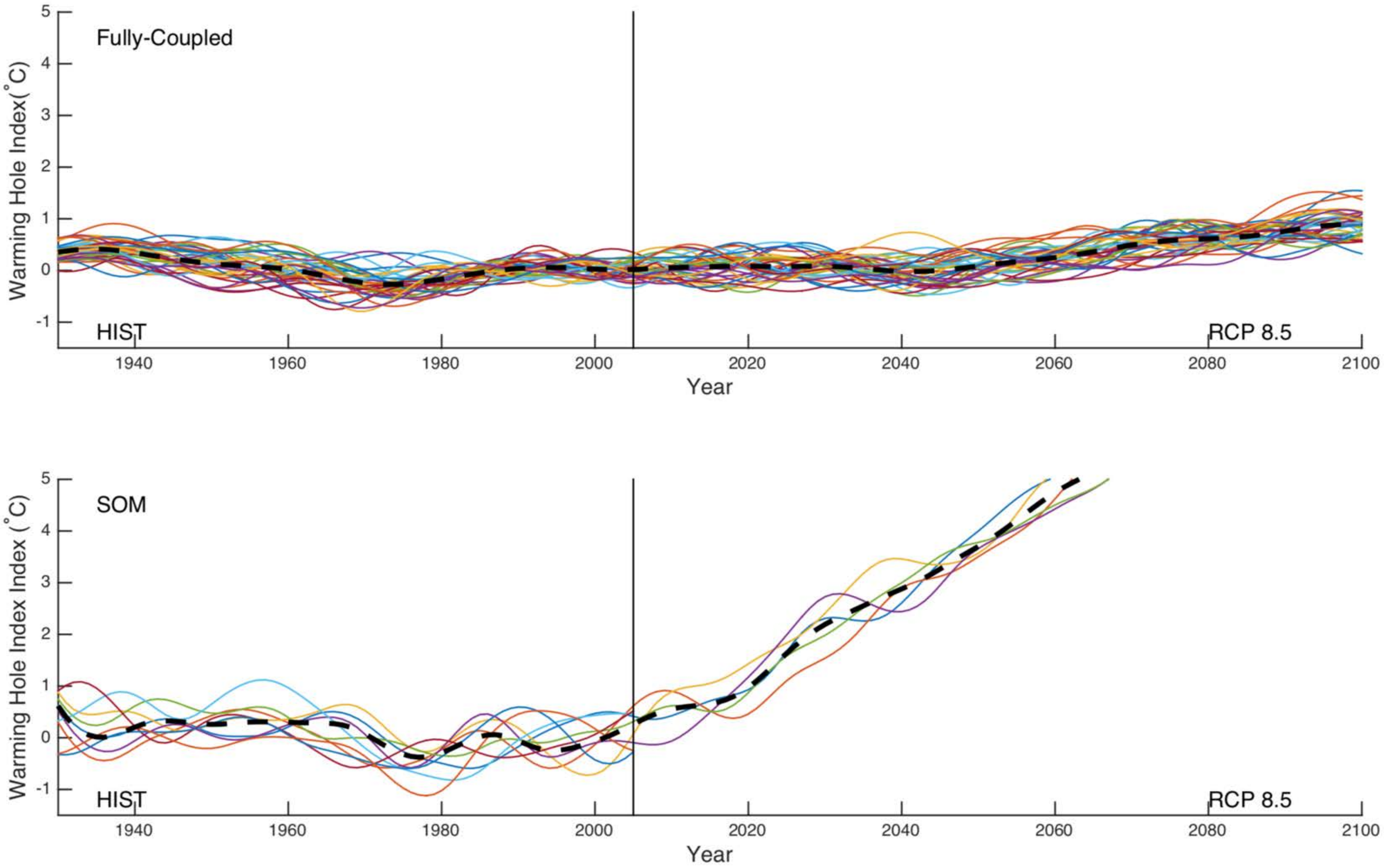
# Future AMV


Fully-Coupled
HIST
RCP 8.5
AMV Index (°C)
Year
5
4
3
2
1
0
-1
1940
1960
1980
2000
2020
2040
2060
2080
2100
SOM
HIST
RCP 8.5
AMV Index (°C)
Year

# Key takeaway: Historical forcing is an important driver of AMV and the ocean modulates its amplitude

- Models need external forcing to explain the magnitude and timing of the observed twentieth century AMO. In CESM, forcing explains half to 2/3 of the variance.
- Interactive ocean heat transport modulates the forced signal in CESM, and damps everywhere. We hypothesize that this is due to mixing heat below the mixed layer.
- There are significant differences between the fully coupled and SOM in the future (and likely Last millennium as well). What is the correct amount of modulation by ocean?


Fully-Coupled
GMT Index (°C)
HIST
RCP 8.5
Year
SOM
GMT Anomaly (°C)
HIST
RCP 8.5
Year



Fully-Coupled
Warming Hole Index(˚C)
5
4
3
2
1
0
-1
HIST
RCP 8.5
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year
SOM
Warming Hole Index Index (˚C)
5
4
3
2
1
0
-1
HIST
RCP 8.5
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year

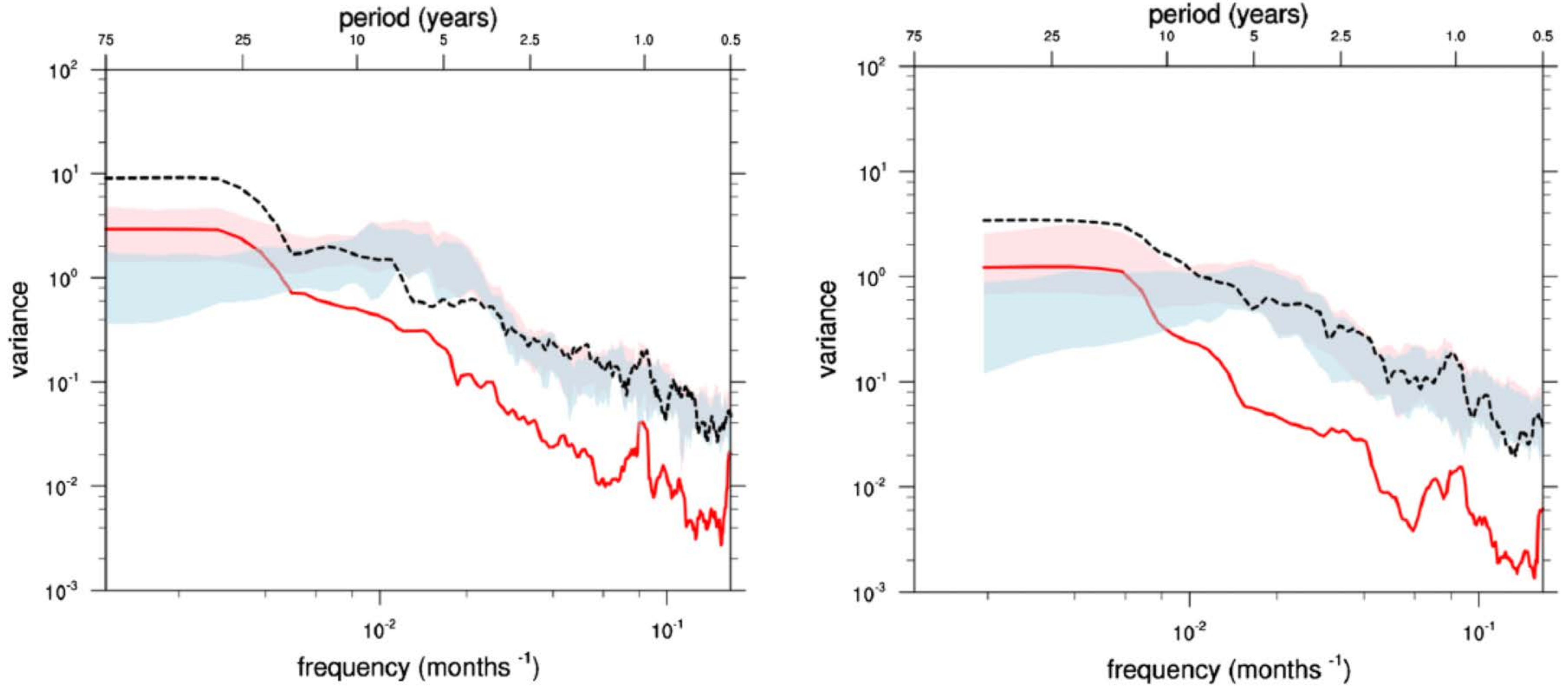
# How does the inclusion of forcing affect the simulation of AMV and associated impacts

- Improves the simulated magnitude of AMV and the timing of the observed shifts (Murphy et al. 2017, Bellomo et al. 2017)
- Improves the connection between AMV with N African rainfall (Group)
- Improves the connection between AMV and wind shear (S. Kramer)
- Can explain paleo AMV (Klavans, Swart et al. 2019)
- Obscures the relation between SST and NAO  (Klavans et al. 2019)
- Does not produce the relation with salinity (Yu et al. 2018)
- Degrades the connection with FL rainfall (Klavans)
- Does not simulate the downturn in AMV after 2000 (Yu et al. 2017)
- European climate??? (Maroon et al., O'Reilly??)

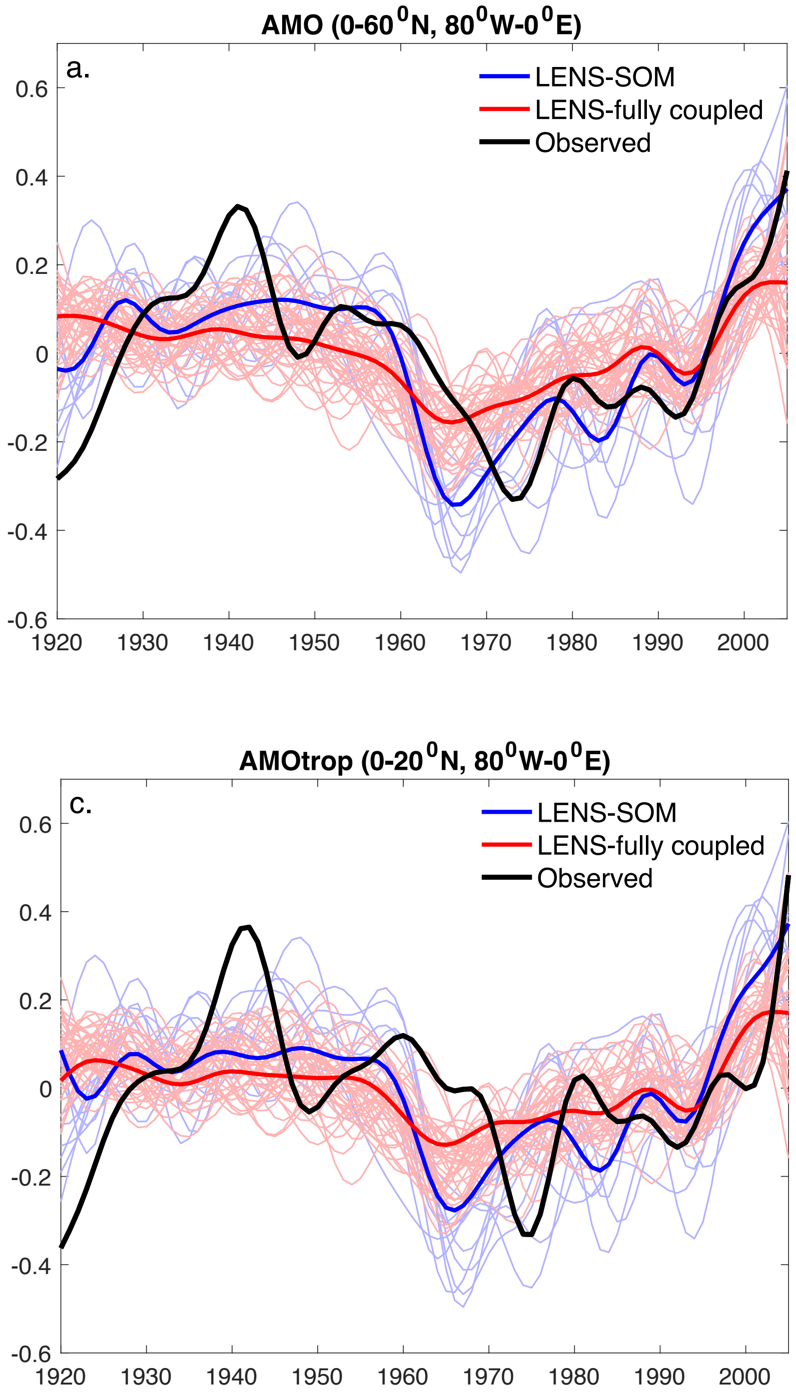
*Ongoing
*Ongoing, but lower priority (?)

# How does the inclusion of interactive ocean dynamics affect the simulation of AMV and associated impacts

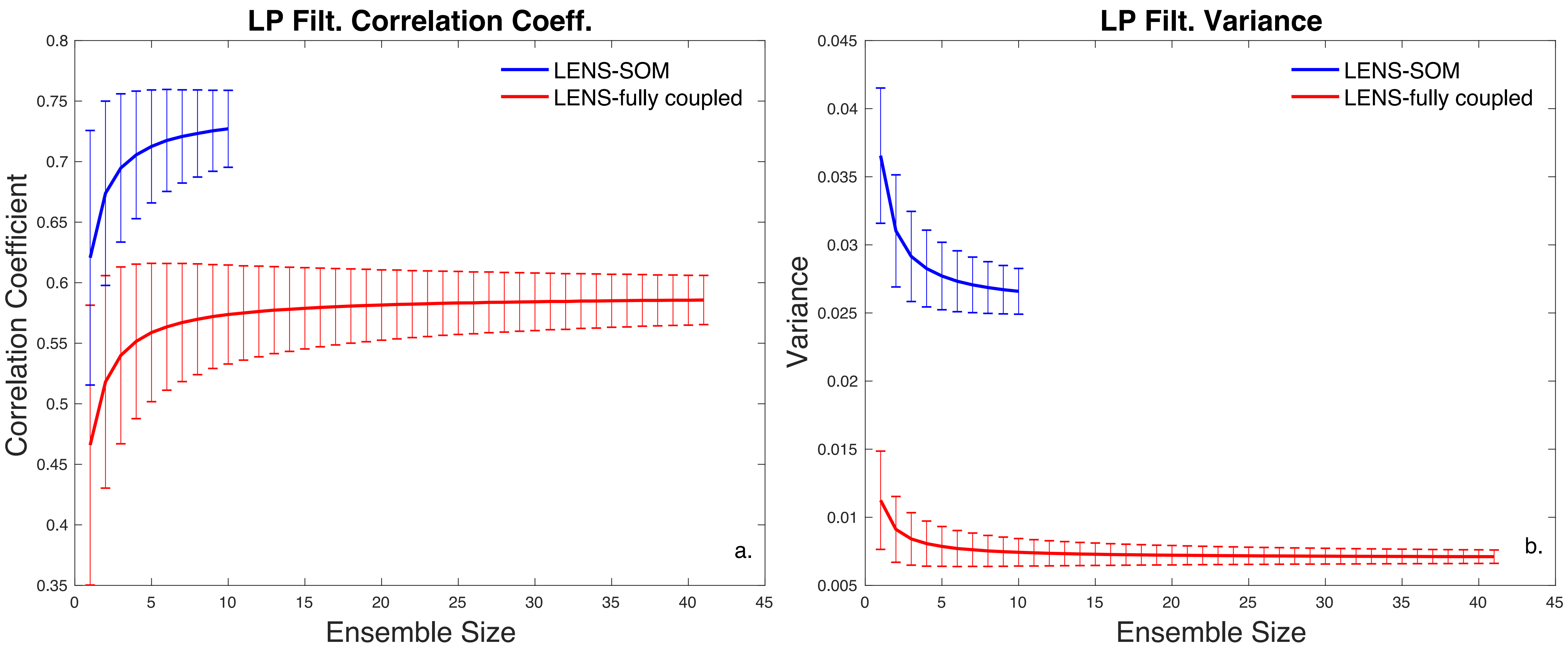
- Weakens the magnitude of AMV, lowers the correlation in CESM (Murphy et al. 2019)
- Weakens future Atlantic warming (Klavans)
- Produces a future warming hole (but not required to get the 20th century warming hole) (Klavans/Clement)
- Degrades the relation between AMV and wind shear (S. Kramer)
- Produces a delayed response to NAO (Delworth)
- *can* change the ACF of temperature (in some models) – Zhang (2017)
- Changes the relation between SST and sfc heat flux in some regions (Oreilly et al. 2016, Zhang 2017, Cane et al. 2017)

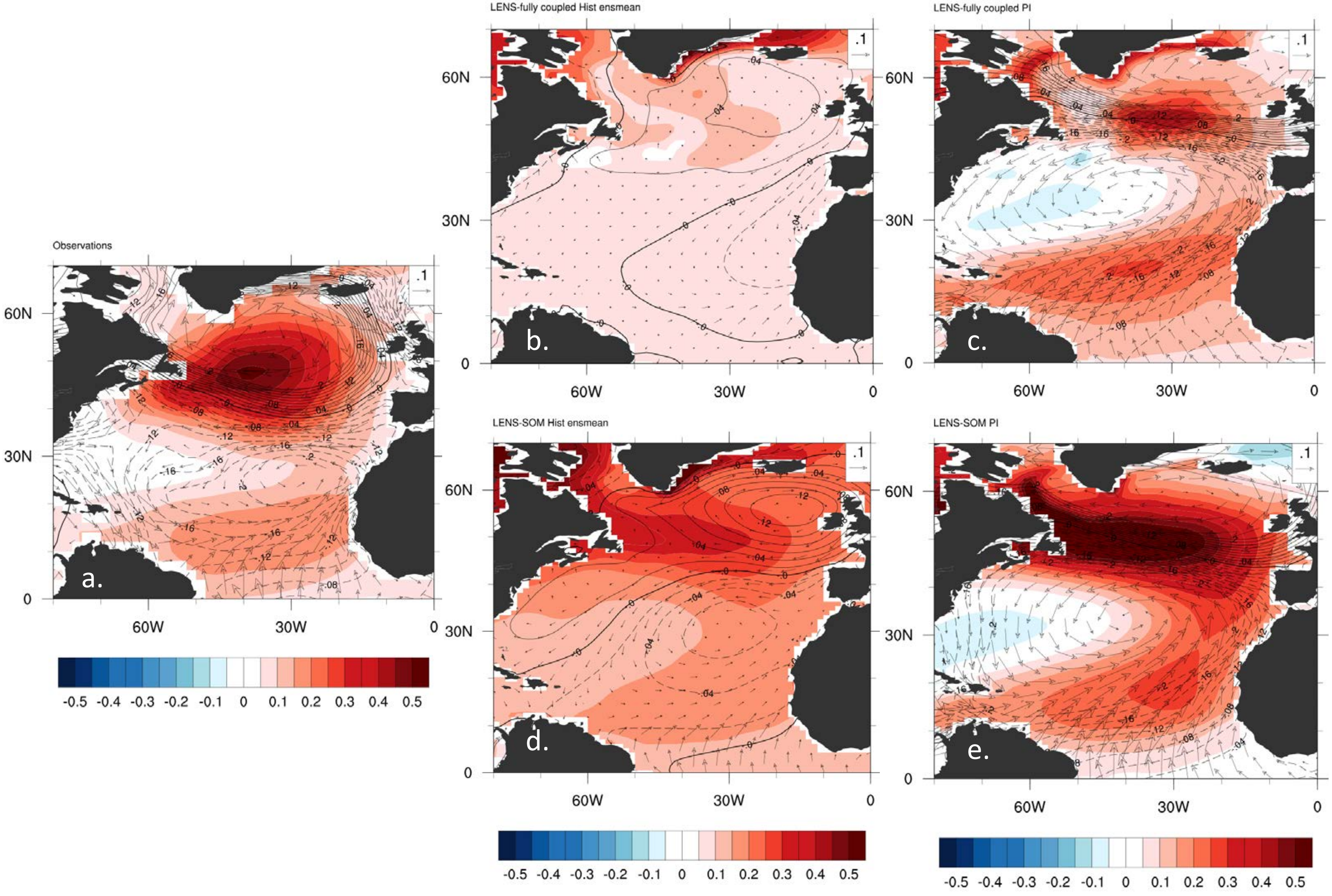


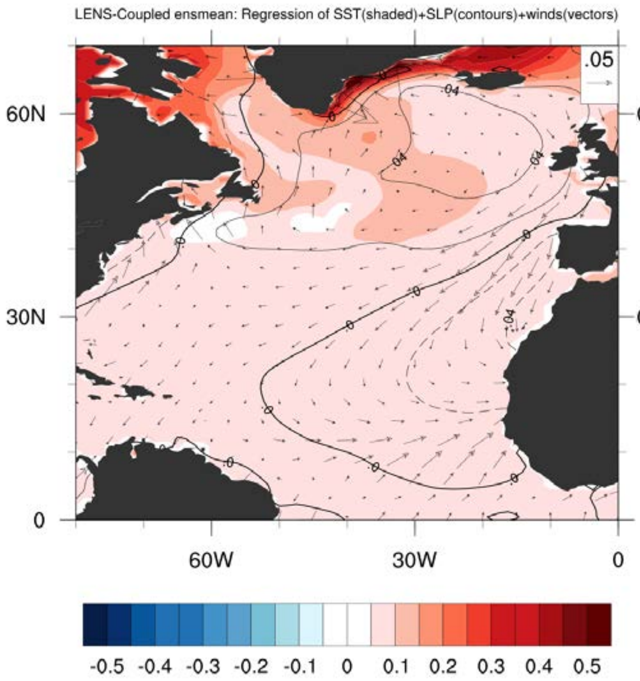
period (years)
75
25
10
5
2.5
1.0
0.5
variance
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
frequency (months $^{-1}$)
period (years)
75
25
10
5
2.5
1.0
0.5
variance
$10^2$
$10^1$
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
frequency (months $^{-1}$)



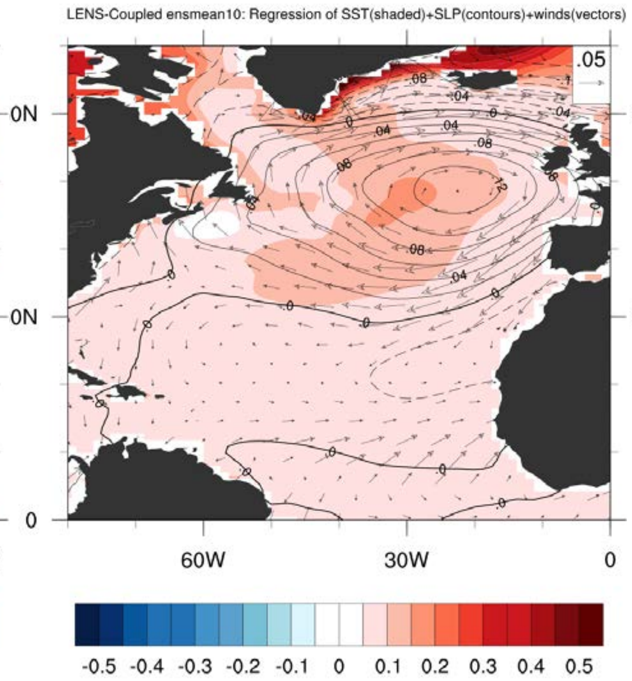

SOM is more variability than coupled everywhere


LP Filt. Correlation Coeff.
Correlation Coefficient
Ensemble Size
LENS-SOM
LENS-fully coupled
a.
LP Filt. Variance
Variance
Ensemble Size
LENS-SOM
LENS-fully coupled
b.

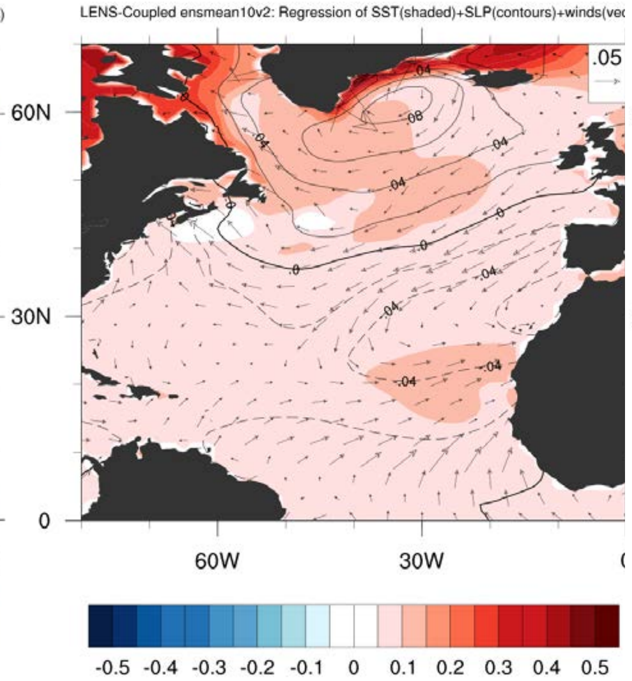

Observations
LENS-fully coupled Hist ensmean
LENS-fully coupled PI
LENS-SOM Hist ensmean
LENS-SOM PI
a.
b.
c.
d.
e.
60N
30N
0
60W
30W
0
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5



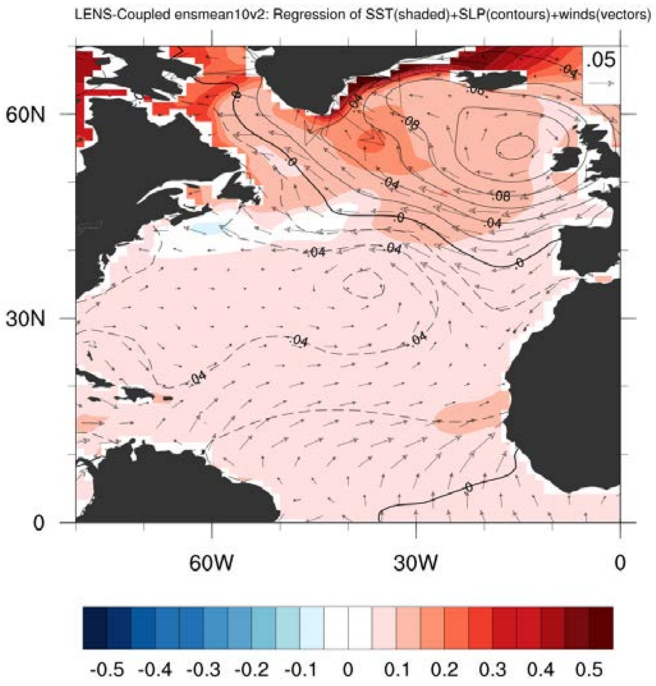

all 42 members



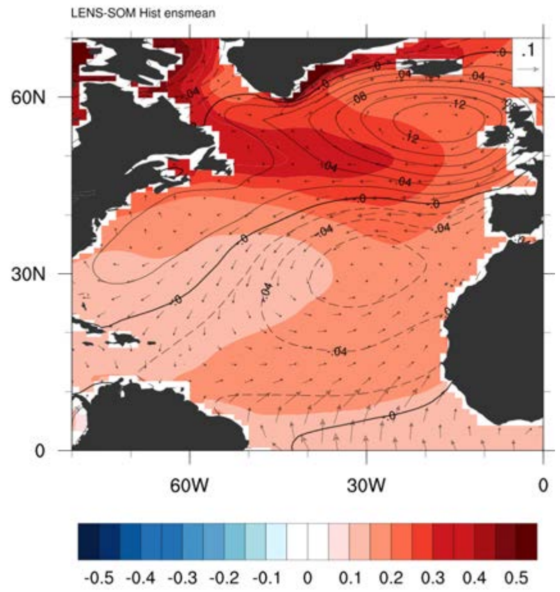

10 members (ens2-11)

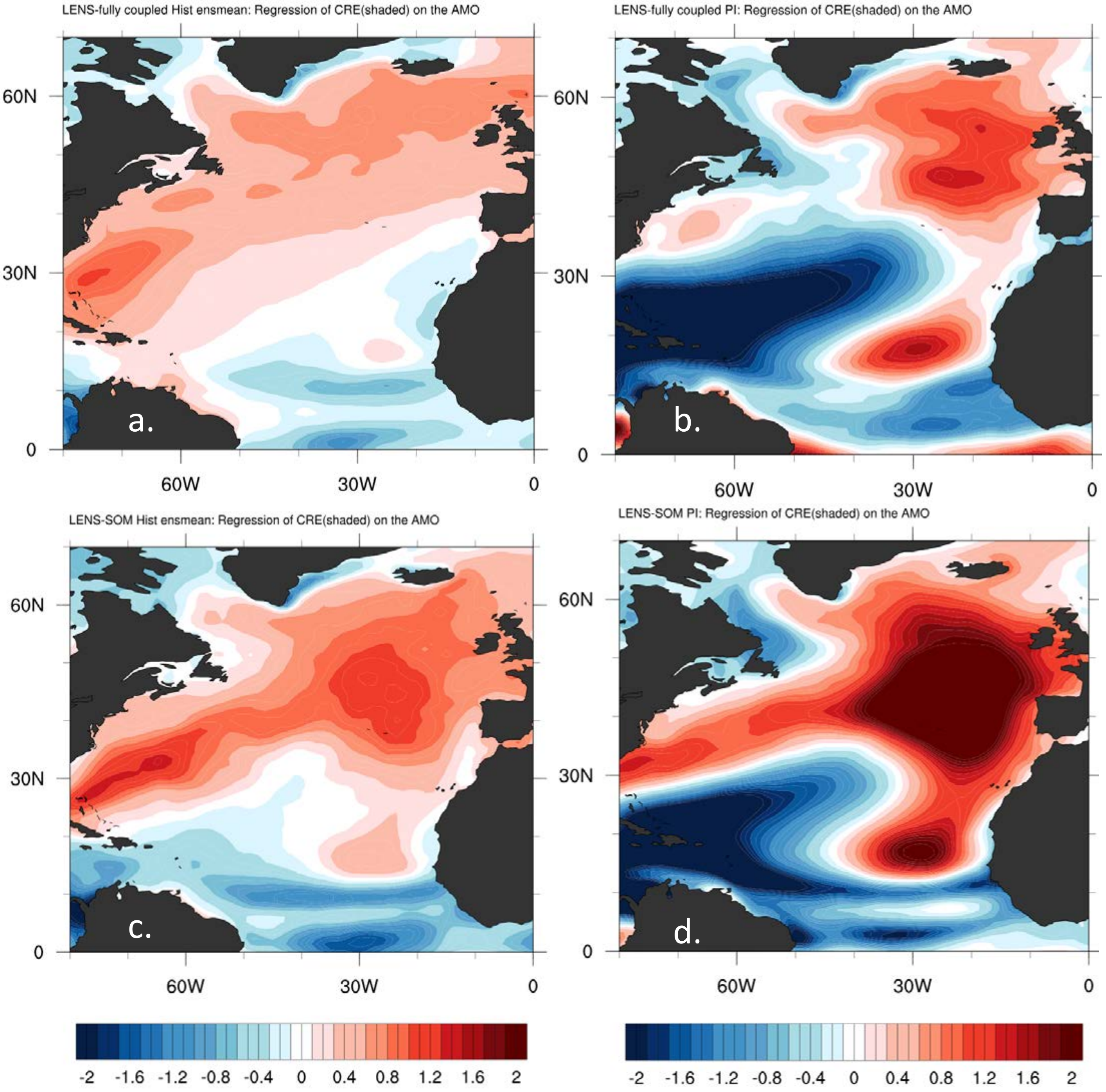



10 members (ens12-21)



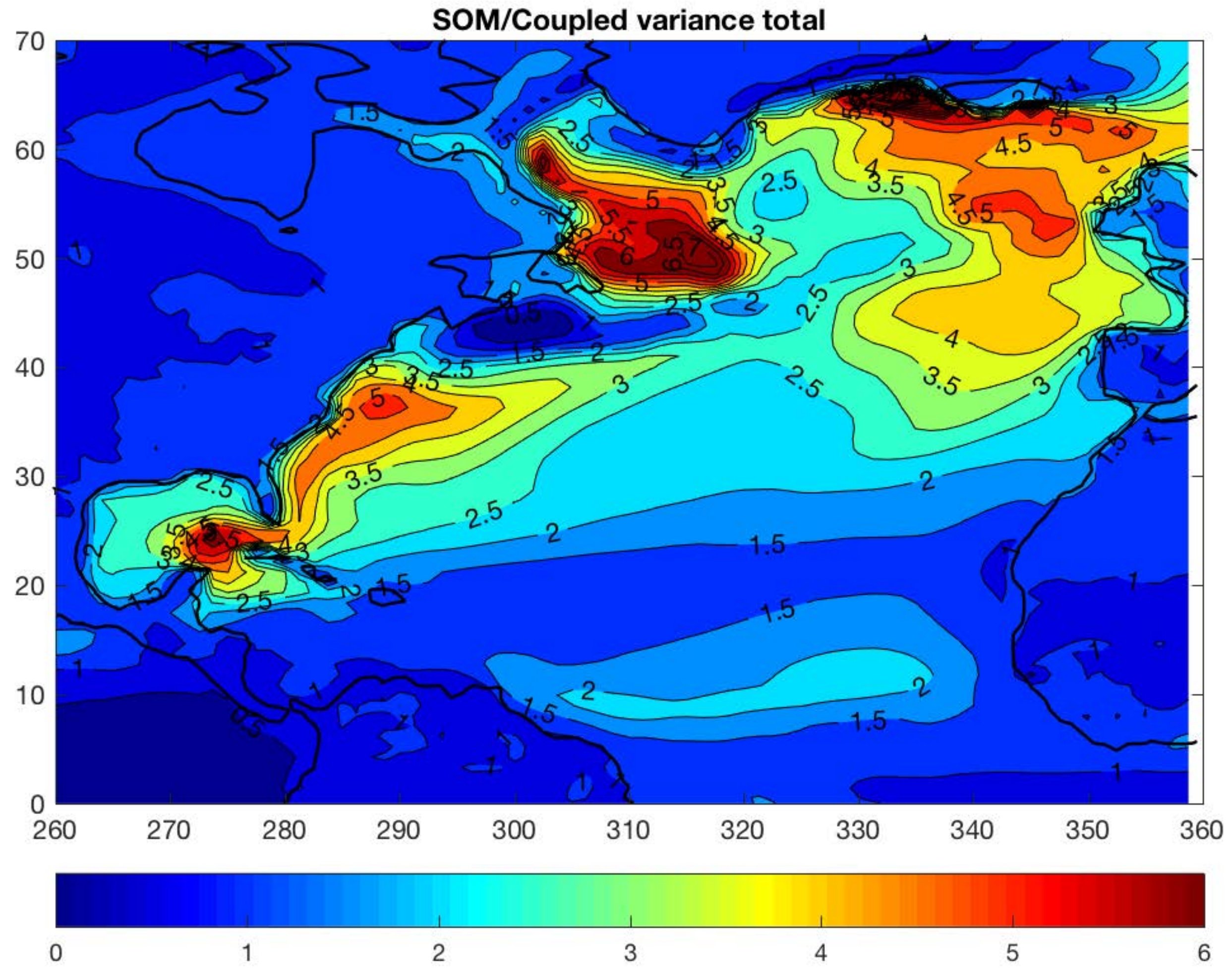

10 members (ens22-31)





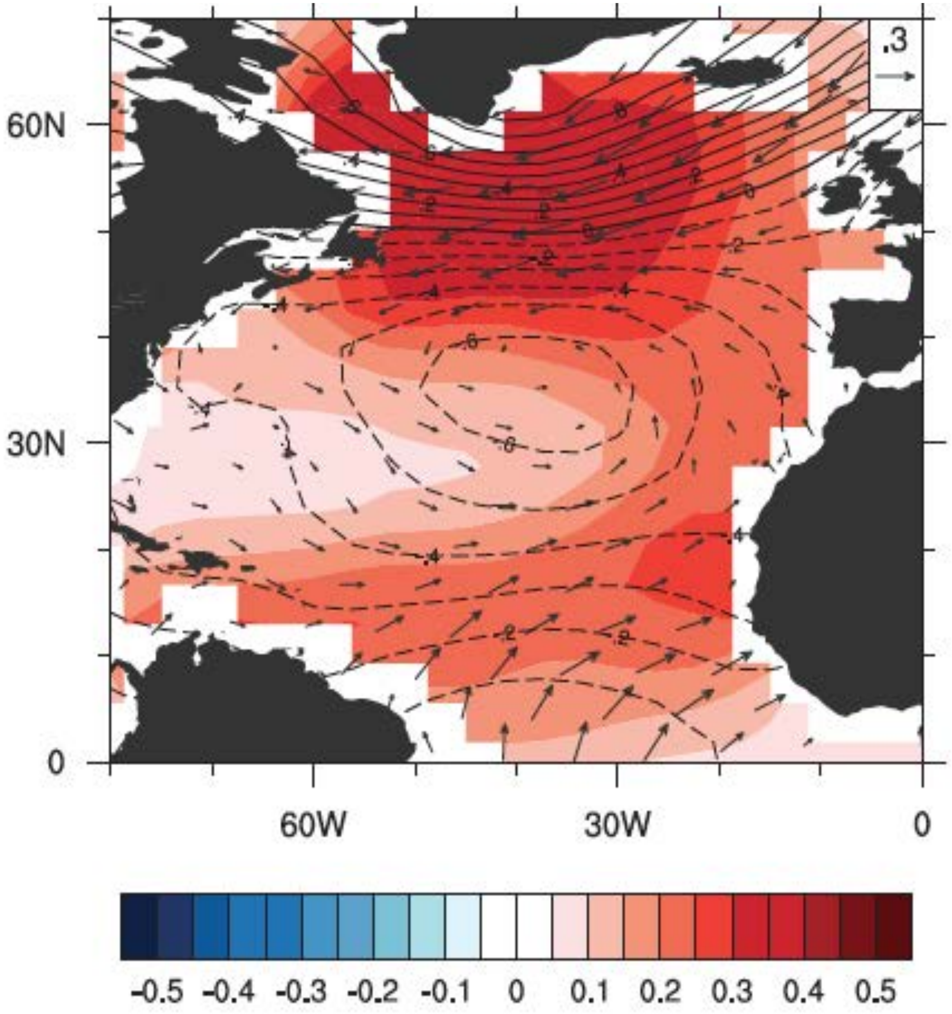
LENS-fully coupled Hist ensmean: Regression of CRE(shaded) on the AMO
LENS-fully coupled PI: Regression of CRE(shaded) on the AMO
LENS-SOM Hist ensmean: Regression of CRE(shaded) on the AMO
LENS-SOM PI: Regression of CRE(shaded) on the AMO
a.
b.
c.
d.
60N
30N
0
60W
30W
0
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2

# Vertical mixing?



# Atlantic Multi-decadal Variability (AMV)

Regression of local SST on index




Average North Atlantic SST (ERSST v4), detrended

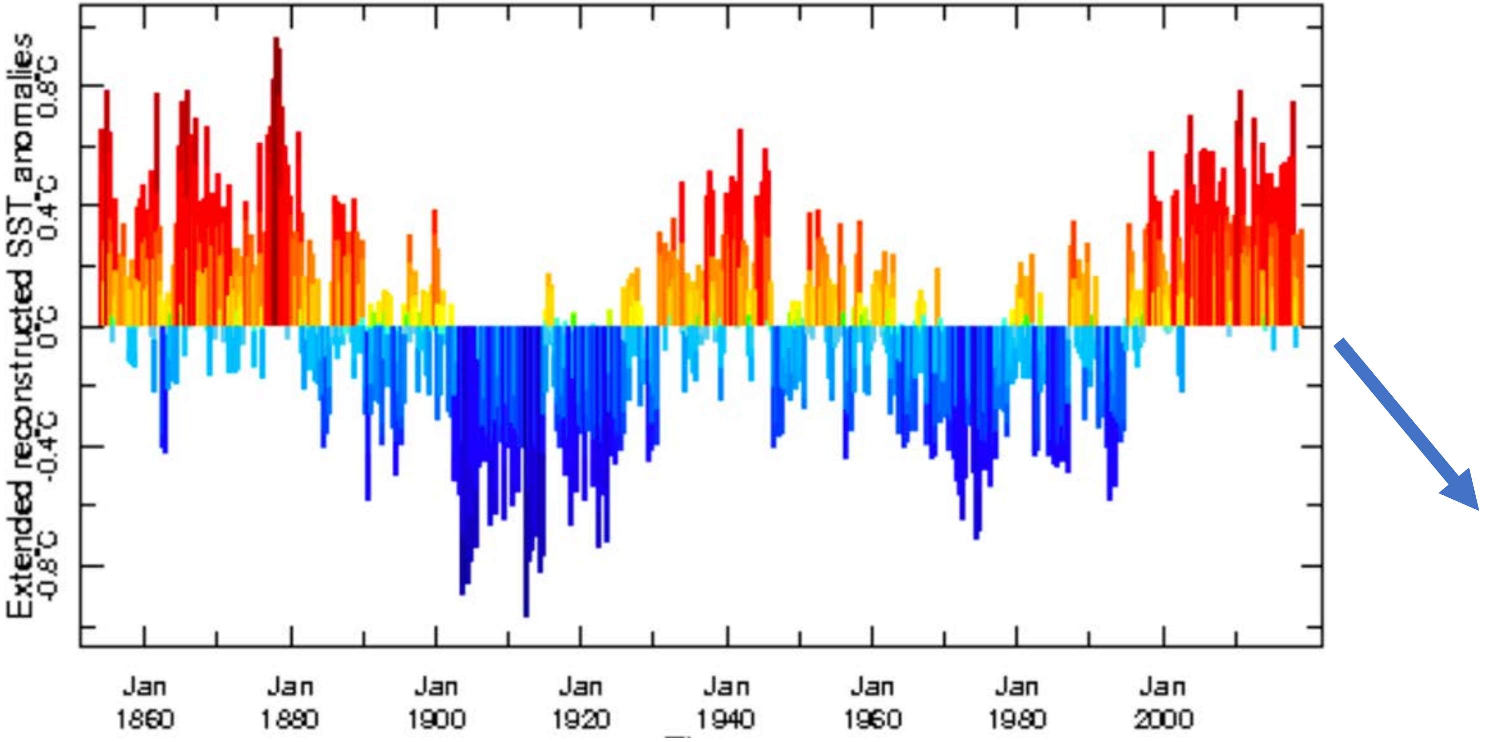


**Figure 3:** Variance of AMV index ($K^2$)