NOAA CVP Webinar Series on
AMOC Mechanisms and Decadal Predictability

Low-Frequency North Atlantic Variability in the CESM Large Ensemble

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Who M. Kim
National Center for Atmospheric Research (NCAR)

S. Yeager, G. Danabasoglu (NCAR), & P. Chang (TAMU)

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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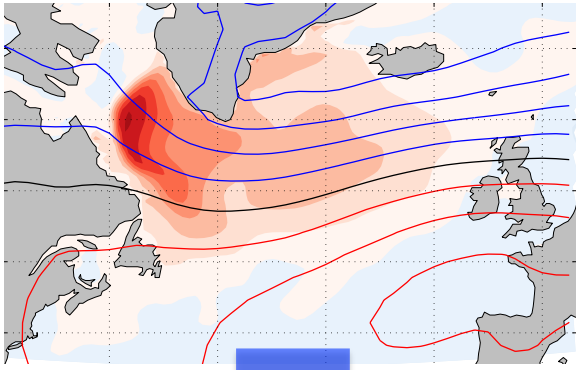
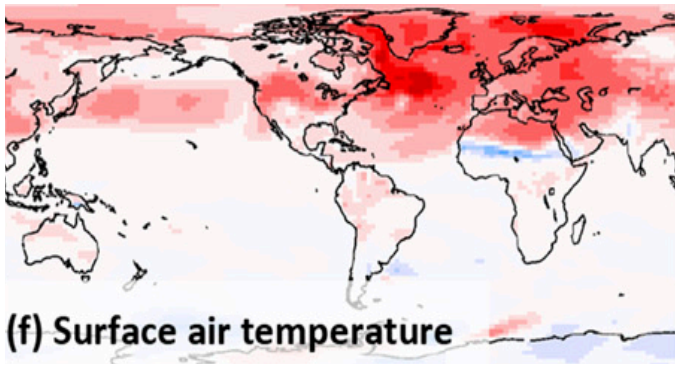
Multidecadal Variability in the North Atlantic



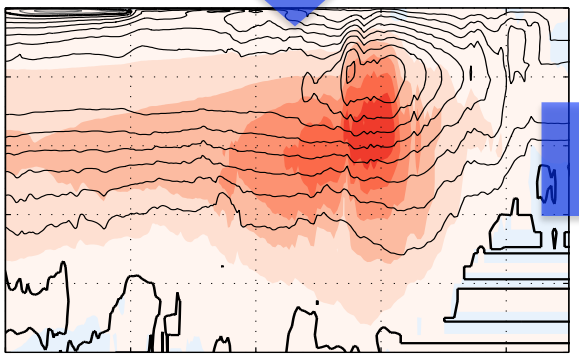
NAO-driven surface heat flux & Deep water formation

Eden & Jung (2001); Dong & Sutton (2005); Böning et al. (2006); Biastoch et al. (2008); Danabasoglu et al. (2012); Yeager & Danabasoglu (2014); Danabasoglu et al. (2016) & many more



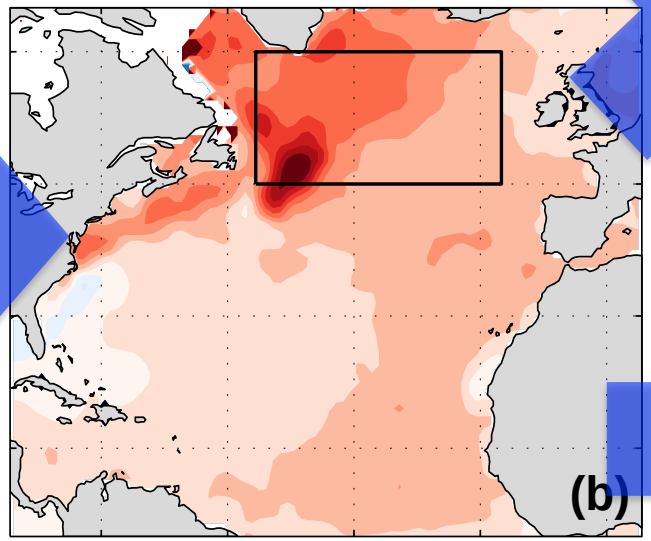
Delworth & Zeng (2015)

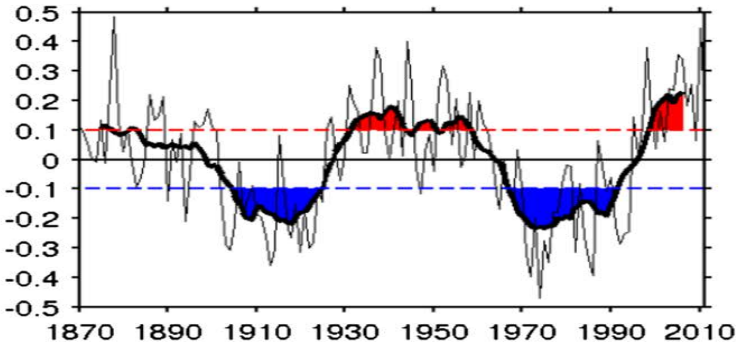
AMOC



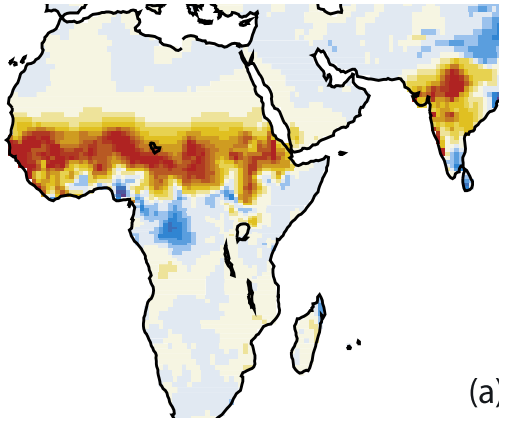
Delworth et al. (1993); Knight et al. (2005); Dong & Sutton (2005); Danabasoglu et al. (2012); Tendon & Kushner (2015); O'Reilly et al. (2016); Zhang et al. (2016) & many more

AMV (AMO)





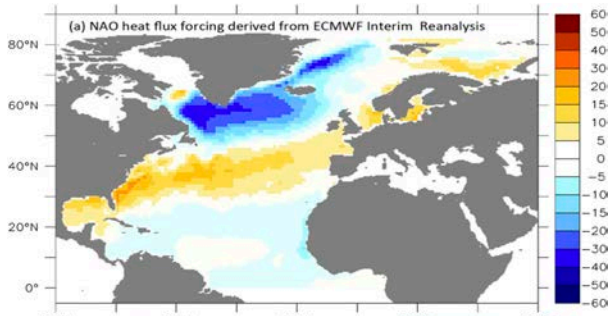
Rainfall



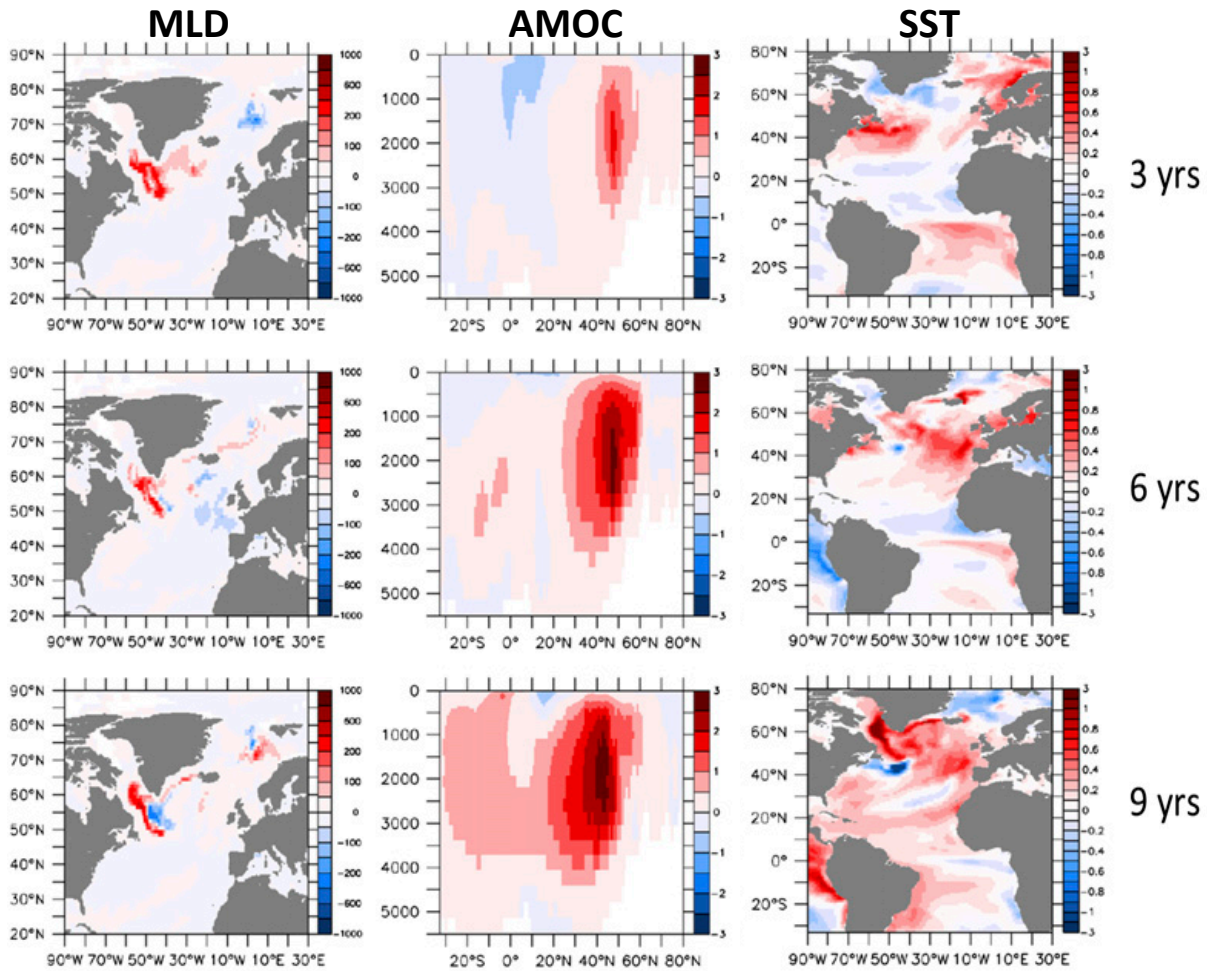
Zhang & Delworth (2006)

Multidecadal Variability in the North Atlantic

Delworth & Zeng (2015)



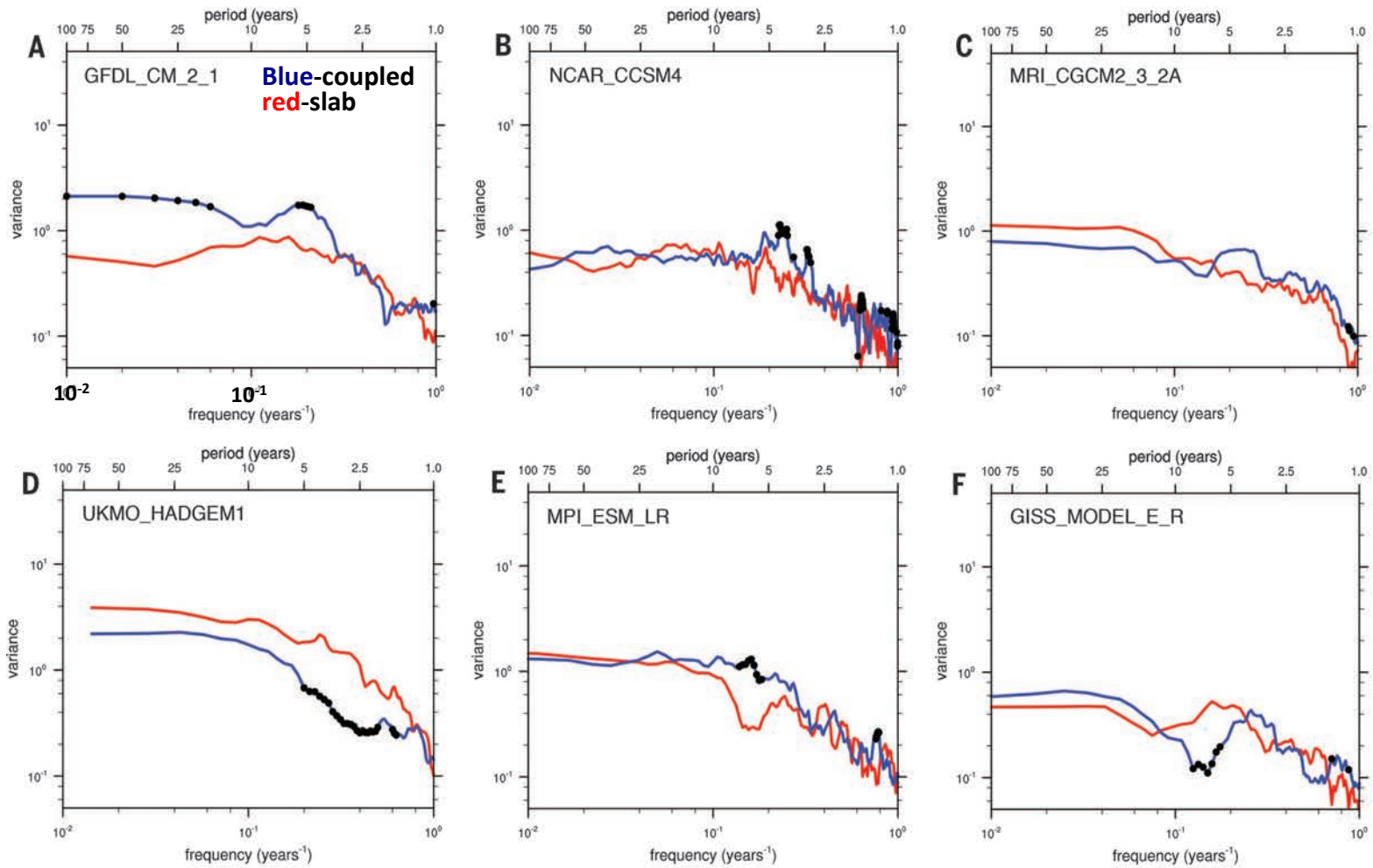
NAO heat flux forcing
: applied to the ocean component of a coupled ensemble simulations



*** Ensemble mean response relative to the control ensemble mean**

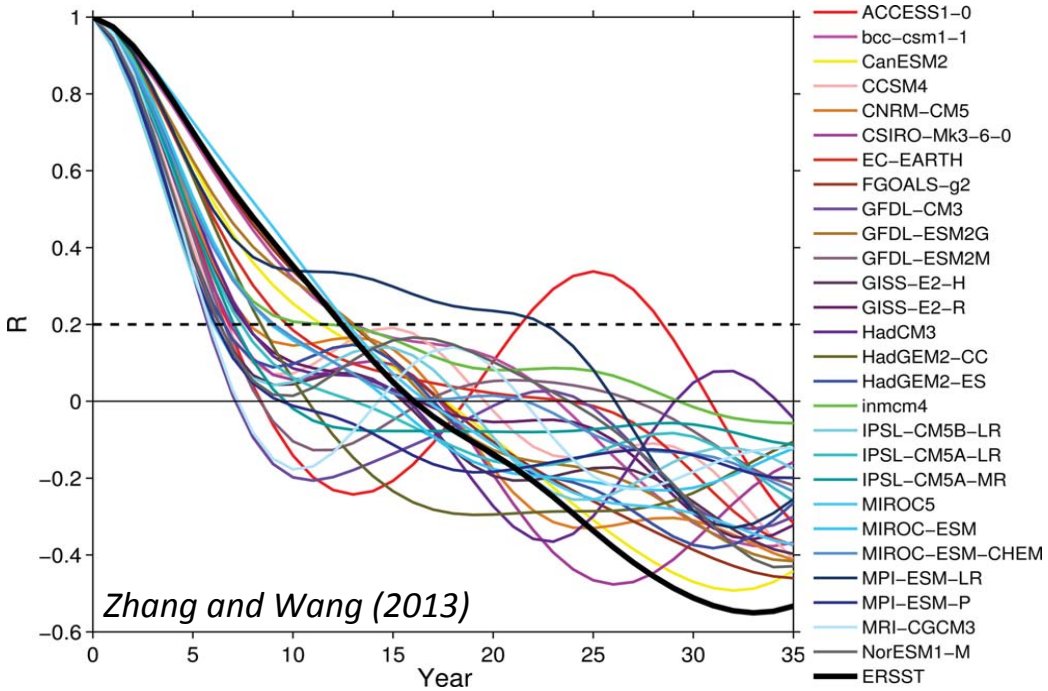
Weak AMV Power in Coupled Simulations

Clement et al. (2015)

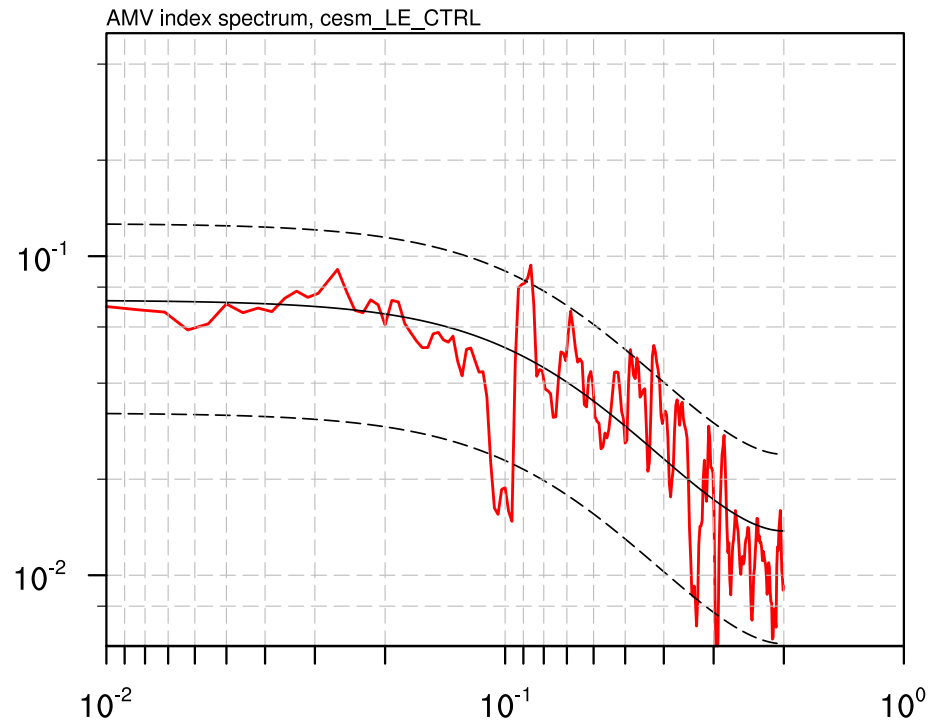


✓ Power spectra of the AMV simulated in coupled models are *not* distinguished from those simulated in corresponding *slab-ocean* coupled simulations (i.e., stochastically driven)

Weak AMV Power in Coupled Simulations



AMV Power Spectrum from the LE PI control



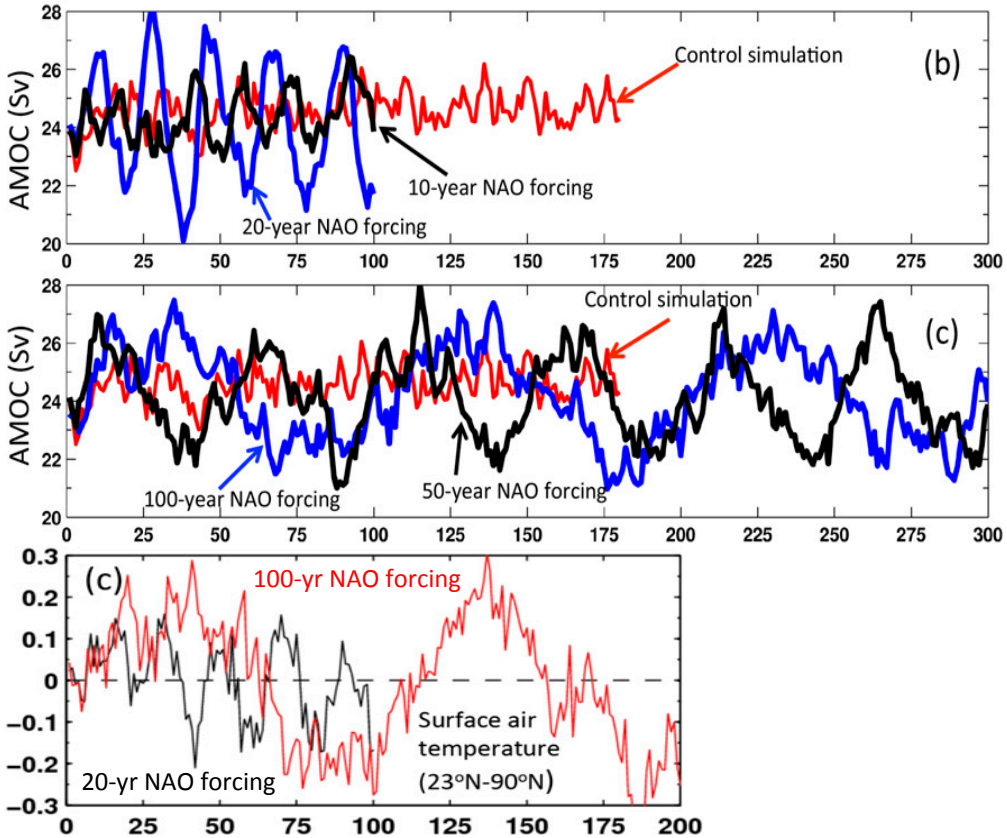
- ✓ Similarly weak multidecadal AMV, compared to obs, is found in many CMIP3/CMIP5 models (*Ting et al. 2011; Kavvada et al. 2013*)

➔ **Why is the AMV power in coupled models weak compared to observations?**

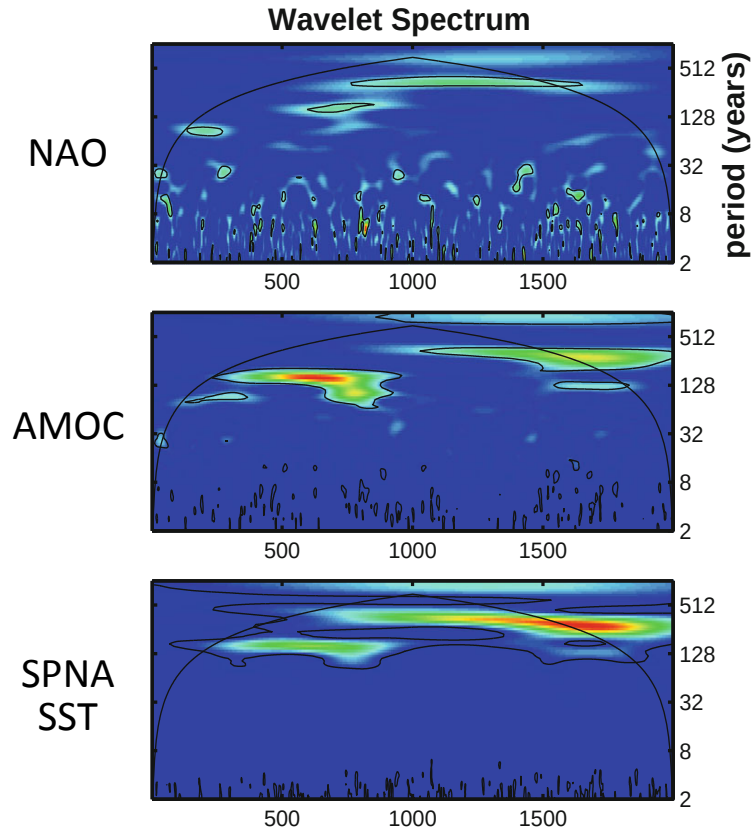
Is Multidecadal NAO Weak in These Models?

Linear relationship between low-frequency NAO-AMOC-AMV

Delworth & Zeng (2015)



Mecking et al. (2015)



- ✓ **The AMOC and surface temperature vary almost linearly with the period of the imposed NAO heat flux forcing**

  * Additional idealized periodic heat flux associated with NAO applied over the NA in coupled simulations with varying time scales

- ✓ **Linear relationship between NAO, AMOC, and SPNA SST frequencies on > multidecadal time scales**

  * Synthetic stochastic NAO forcing (2000 yr) applied in an ocean-only simulation

In this study…

- ✓ **Investigate the the low-frequency North Atlantic variability (AMOC, AMV, NAO, and etc) using the CESM large ensemble simulations (LE)**

  * LE shows NAO-AMOC-AMV link at work and the weak AMV

  - ➢ **Is the weak AMV power in coupled models due to weak simulated multidecadal NAO variability?**

- ✓ **Data and method**

  - ❑ **LE (*Kay et al. 2015*):** • 1º coupled Earth system model • **Large ensemble size (35 members)** • Historical (1920-2005) + RCP8.5 (2006-2009) • 1800-long PI control simulation

  - ❑ **Compared to observations/estimates (for AMOC)**

    - Spectral analysis and distributions of moving trends (e.g., 5- and 30-yr)

  - ❑ **Focus on "internal variability"**

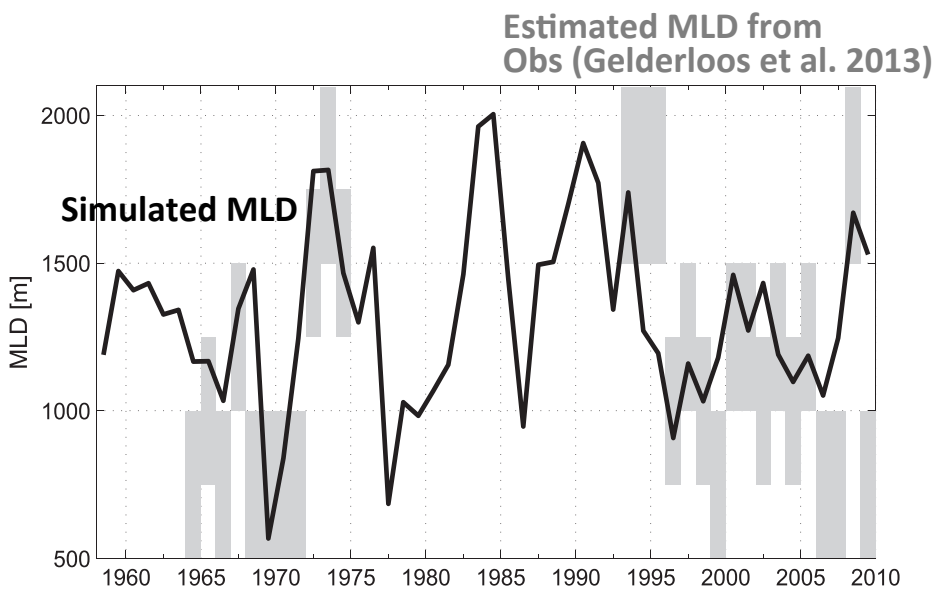
    - Forced signals of some variables from LE are questionable, but the conclusions largely hold even if the forced signals are included

AMOC Estimates

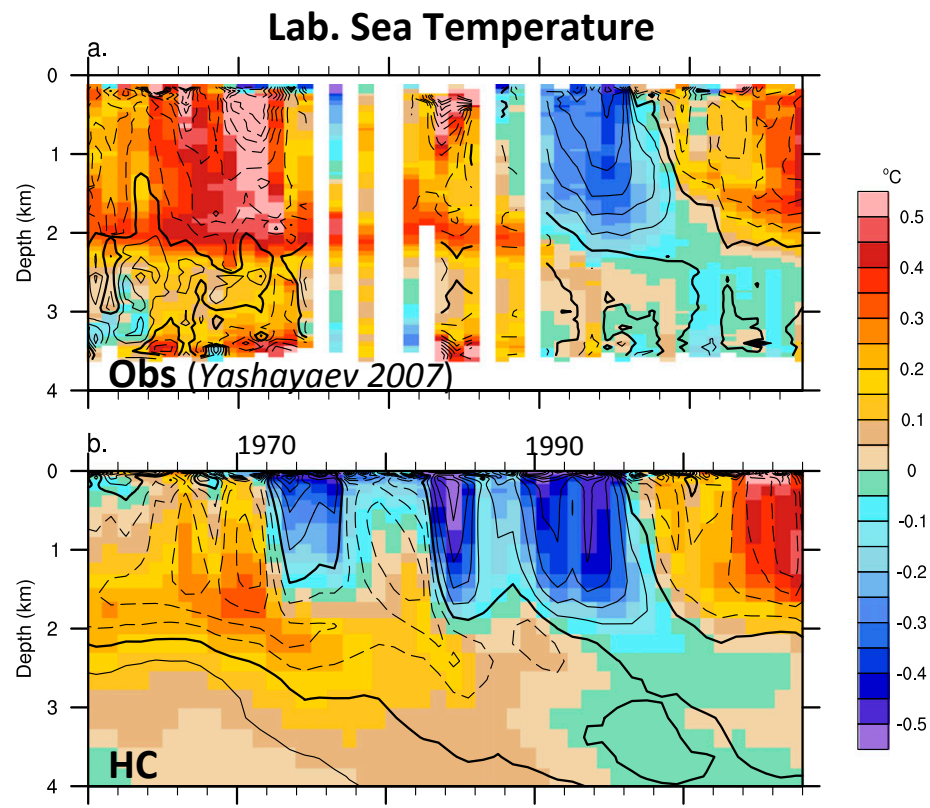
✓ **Ocean-ice hindcast simulation (HC**; *Yeager & Danabasoglu, 2014*)

- Forced with CORE-II interannual forcing (1948-2009; 1958-2009 analyzed)
- **Same ocean and sea-ice components as in LE**

  → we may expect a similar low-frequency AMOC variability as in LE if surface forcing is same (*Delworth & Greatbatch 2000*)
- **Shows a good agreement with available observations for AMOC-related variables**

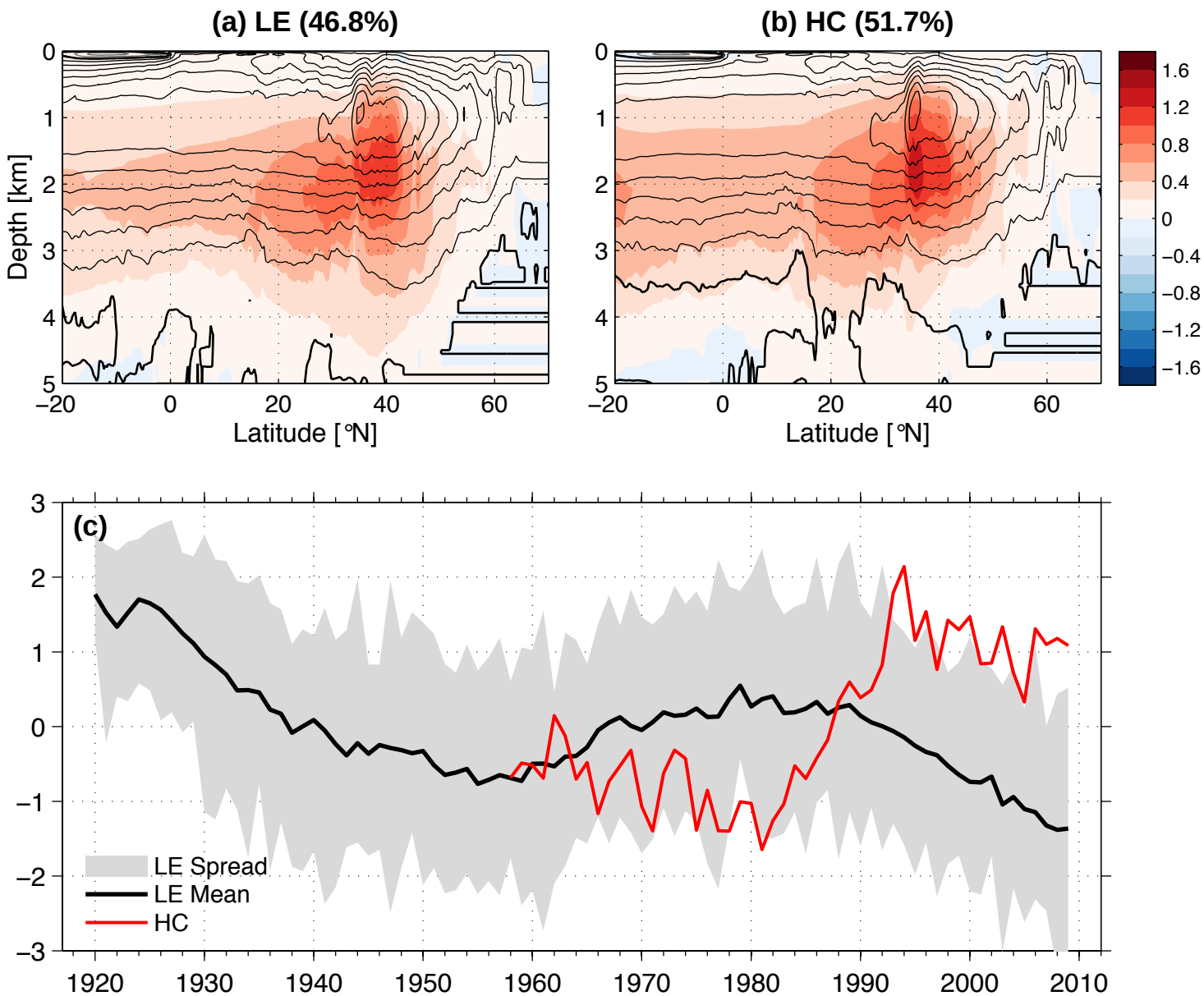


Kim et al. (2016)



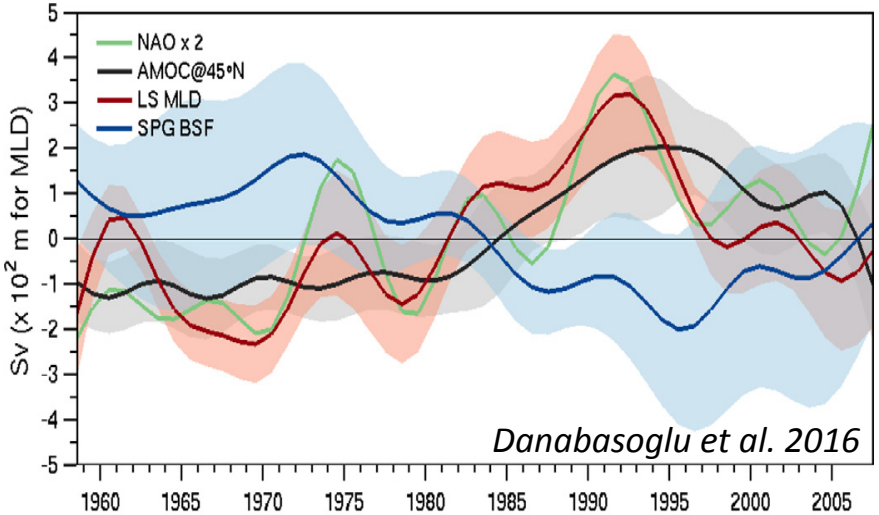
Yeager & Danabasoglu (2014)

AMOC

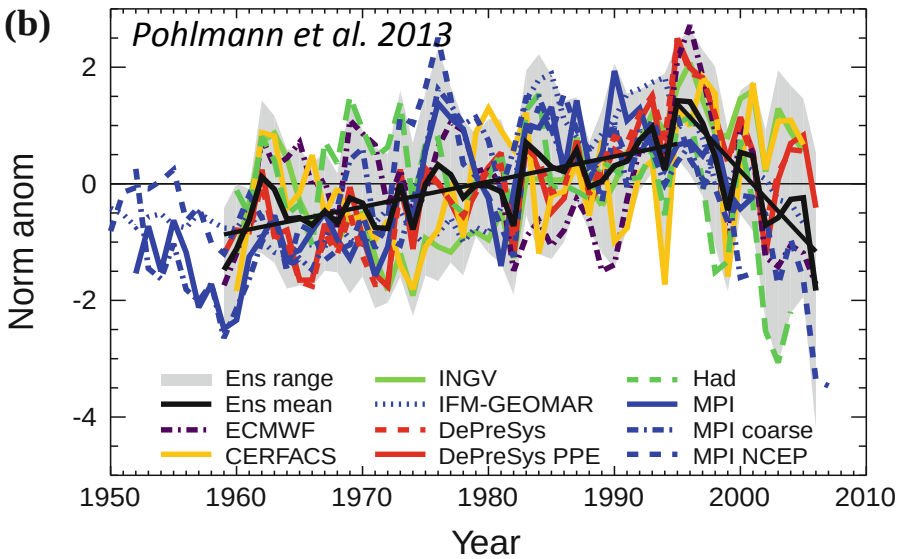

(a) LE (46.8%)
(b) HC (51.7%)
Depth [km]
Latitude [°N]
1.6
1.2
0.8
0.4
0
−0.4
−0.8
−1.2
−1.6
(c)
LE Spread
LE Mean
HC

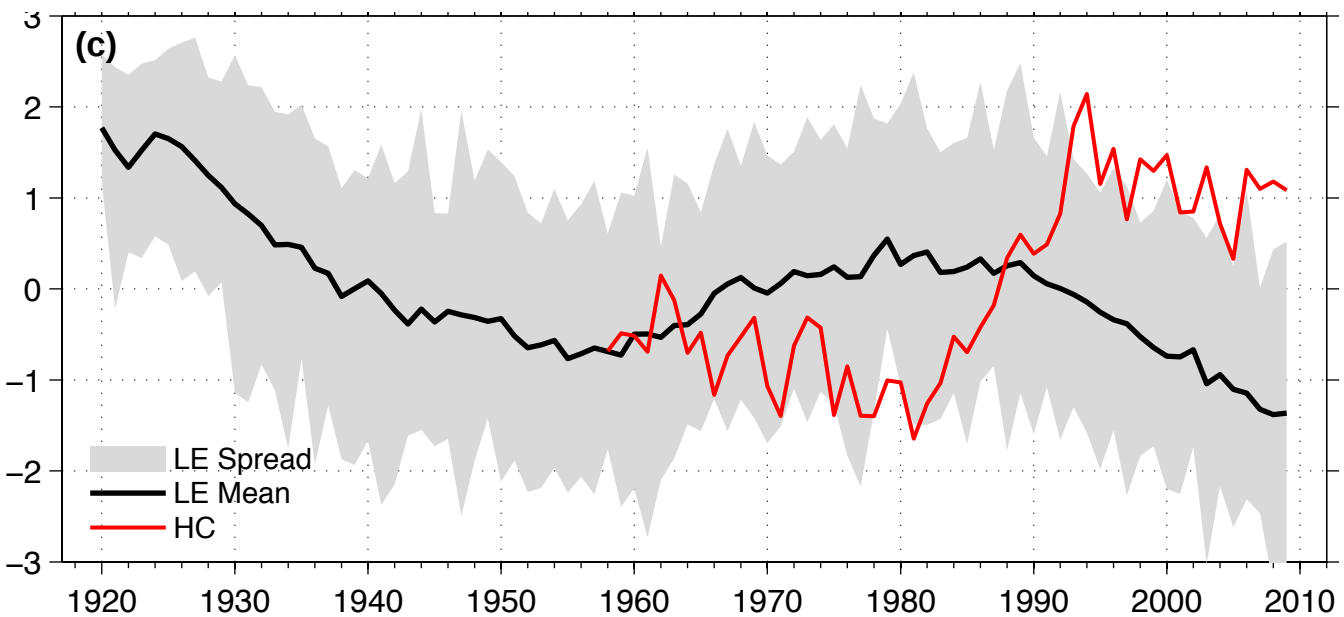
AMOC

19 CORE-II Hindcast simulations

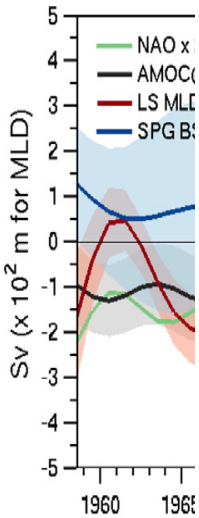


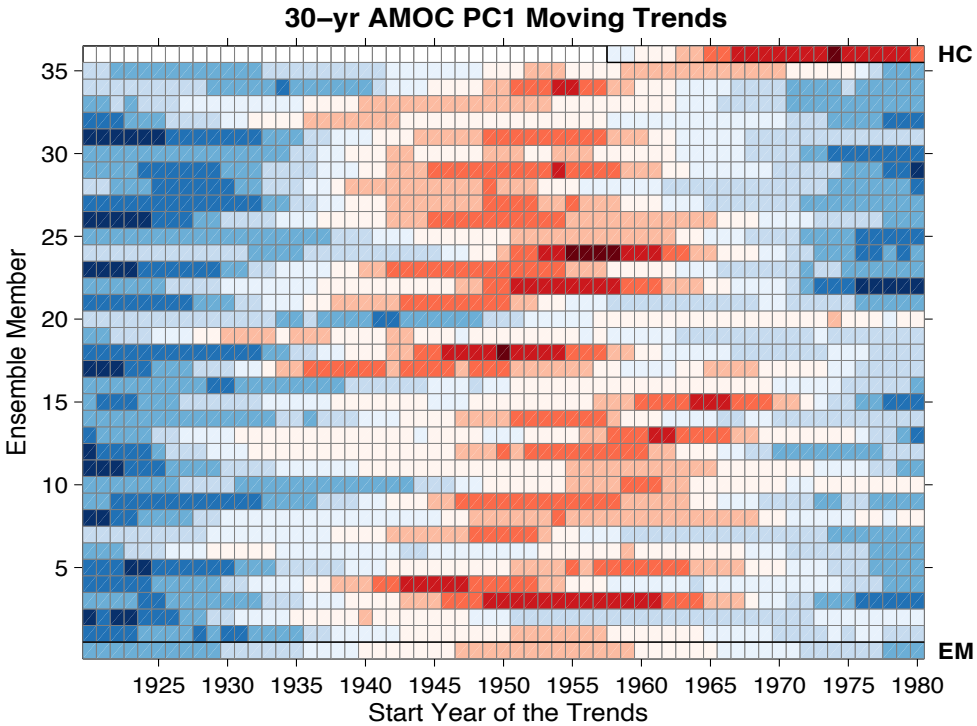
Ocean Reanalysis

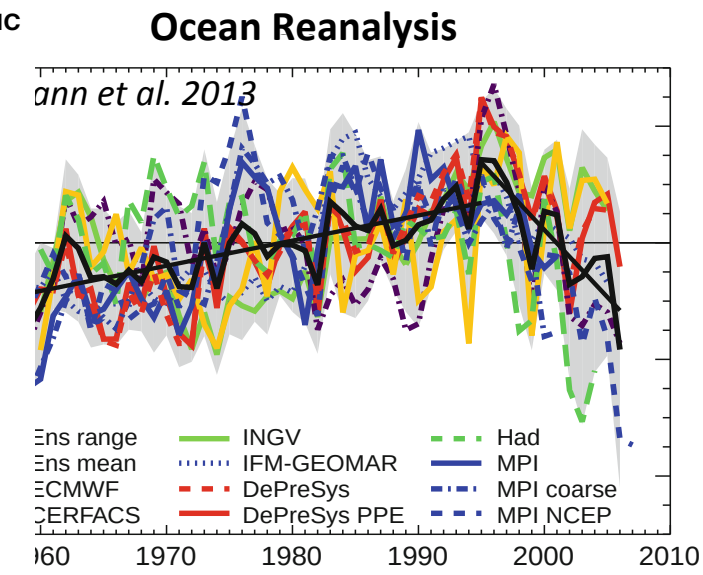


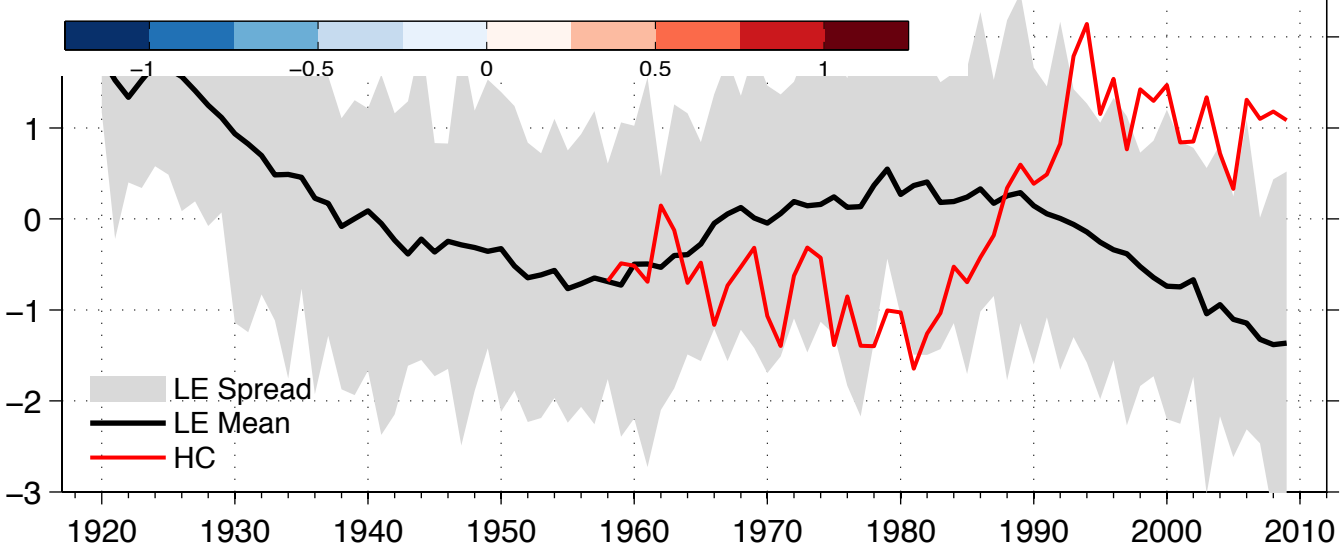


AMOC

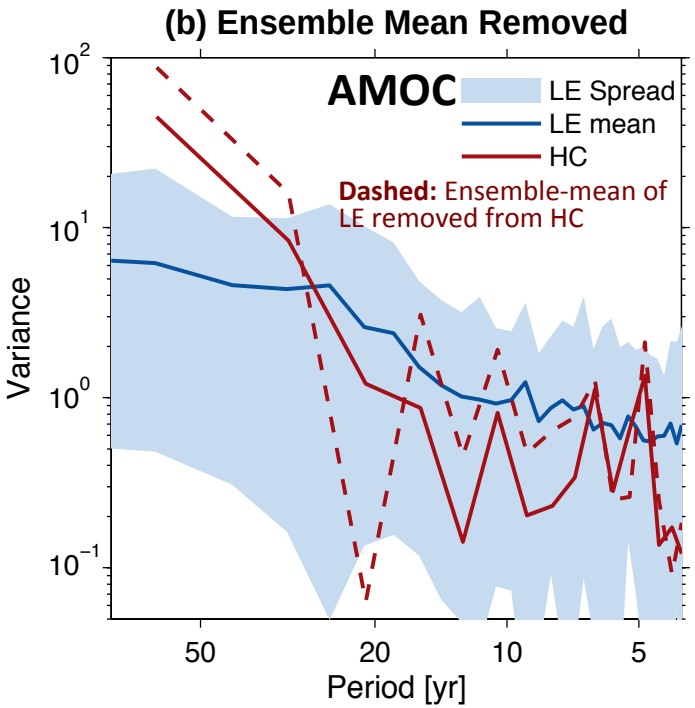

Sv (x 10² m for MLD)
NAO x
AMOC
LS MLD
SPG BS
1960


30–yr AMOC PC1 Moving Trends
Ensemble Member
HC
EM
Start Year of the Trends
–1
–0.5
0
0.5
1


Ocean Reanalysis
ann et al. 2013
Ens range
Ens mean
ECMWF
CERFACS
INGV
IFM-GEOMAR
DePreSys
DePreSys PPE
Had
MPI
MPI coarse
MPI NCEP
Year

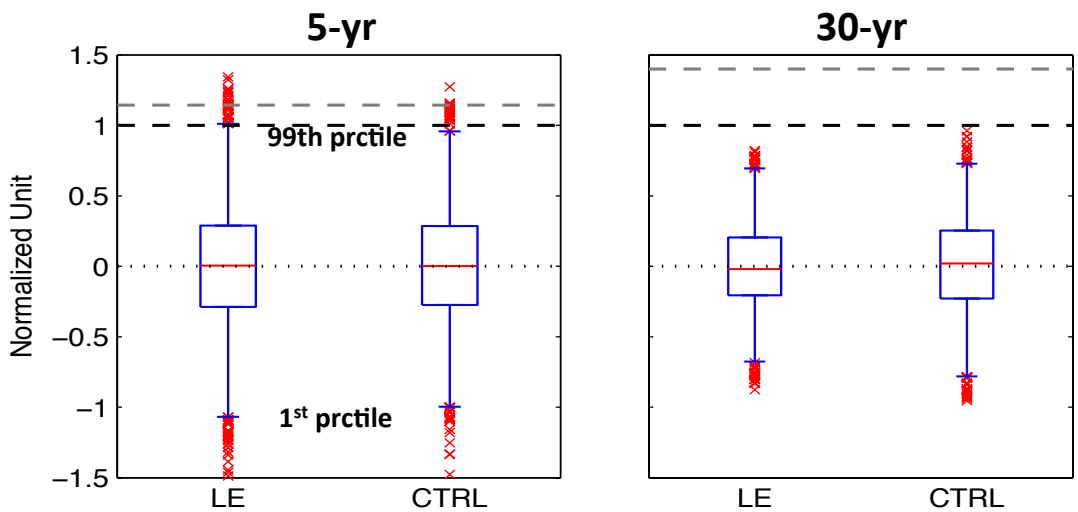

LE Spread
LE Mean
HC

Power Spectra



Distributions of Moving Trends

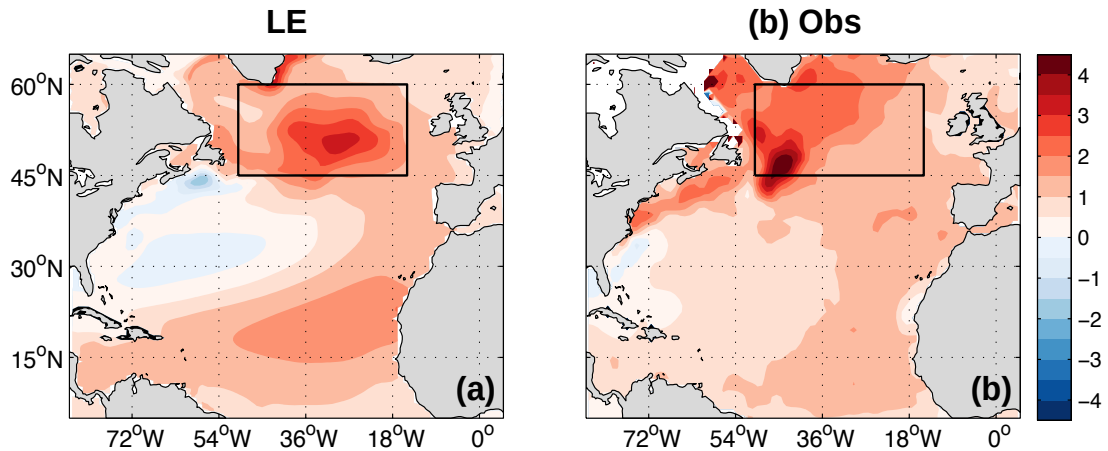
AMOC



* All trends are normalized to the corresponding max trend of either obs or estimates

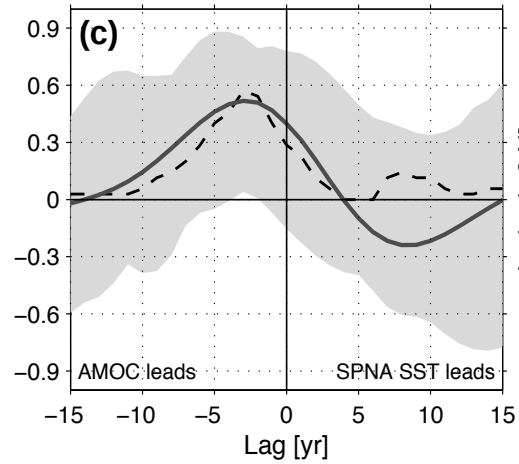
SPNA SST/AMV

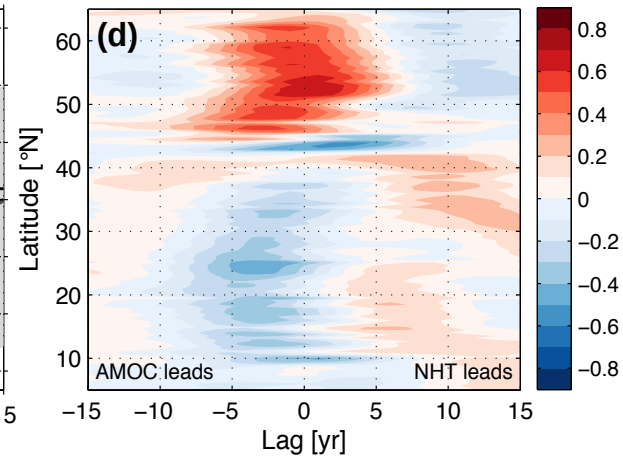
Regressions of SST onto NASST



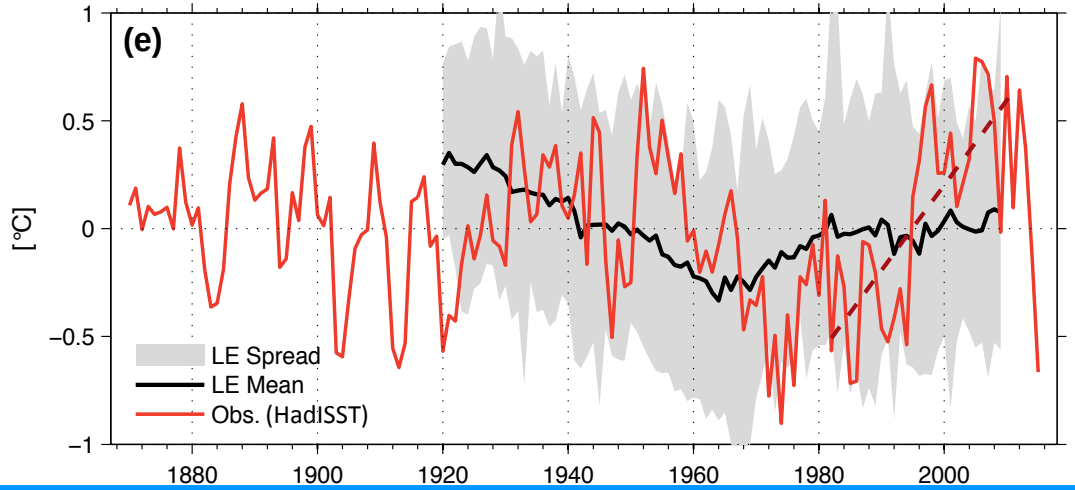
*** SPNA SST is central to AMV (*Zhang & Zhang, 2015*):** AMOC-driven heat is converged there and expands through the entire NA via tele-connections

Solid: correlations b/w AMOC PC1 and SPNA SST
Dashed: fraction of ensemble members with significant r





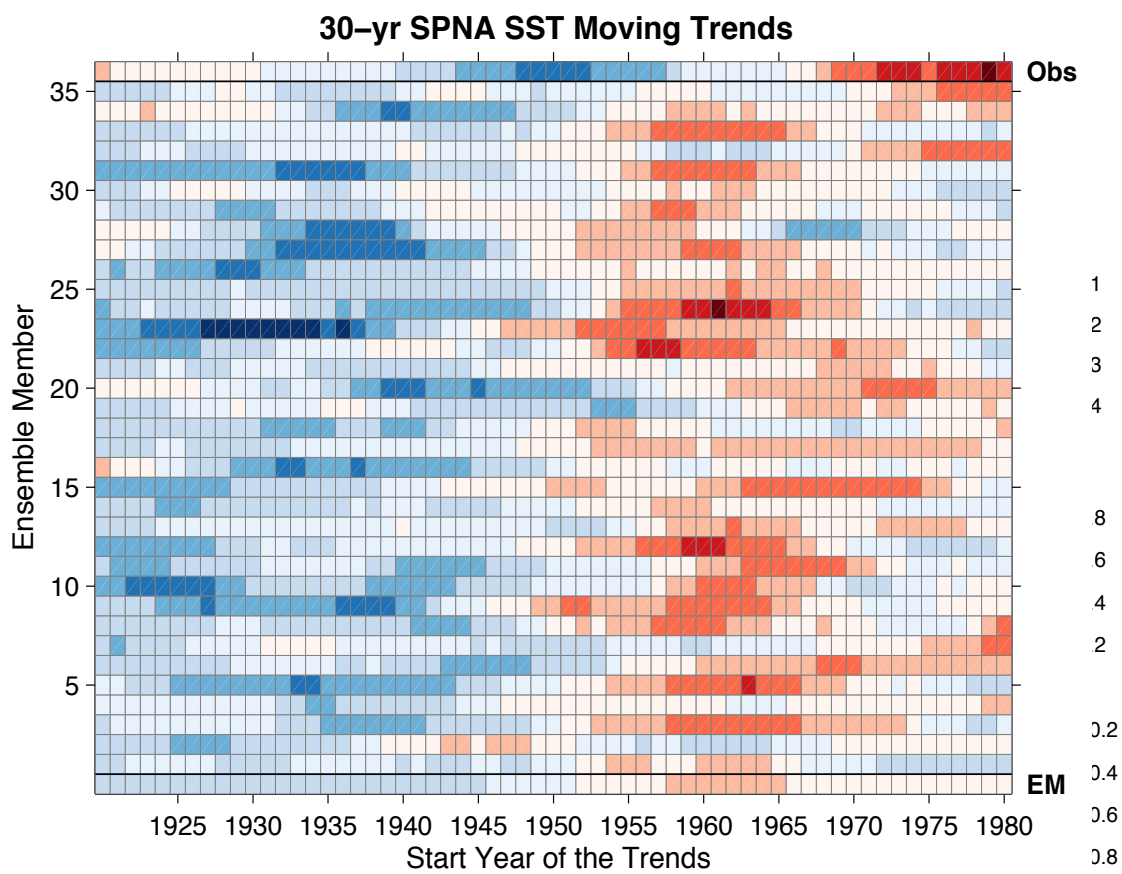
Correlations b/w AMOC PC1 and convergence of northward heat transport (dHT/dy)

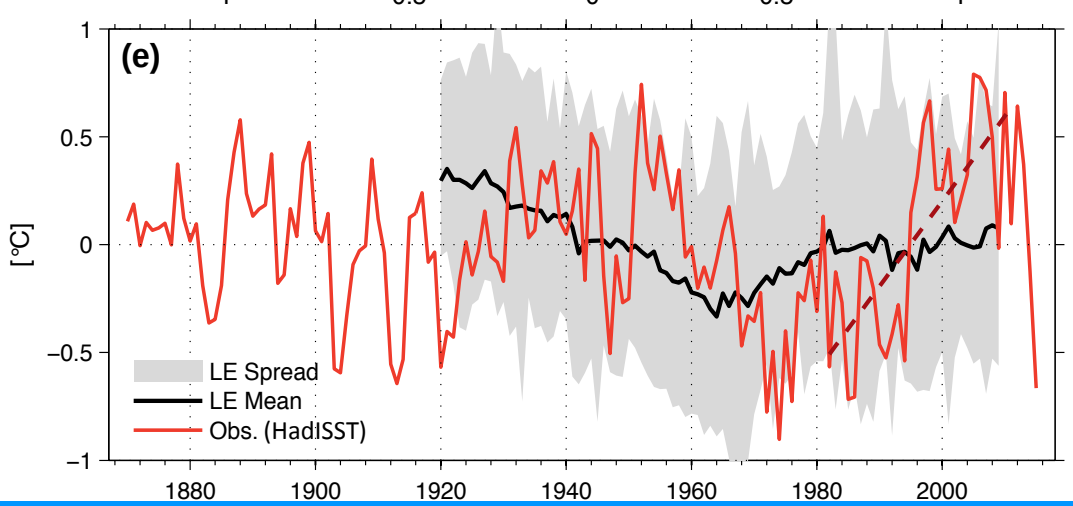


SPNA SST/AMV

Regressions of SST onto NASST

Solid: correlations b/w AMOC PC1 and SPNA SST
Dashed: fraction of ensemble members with significant r





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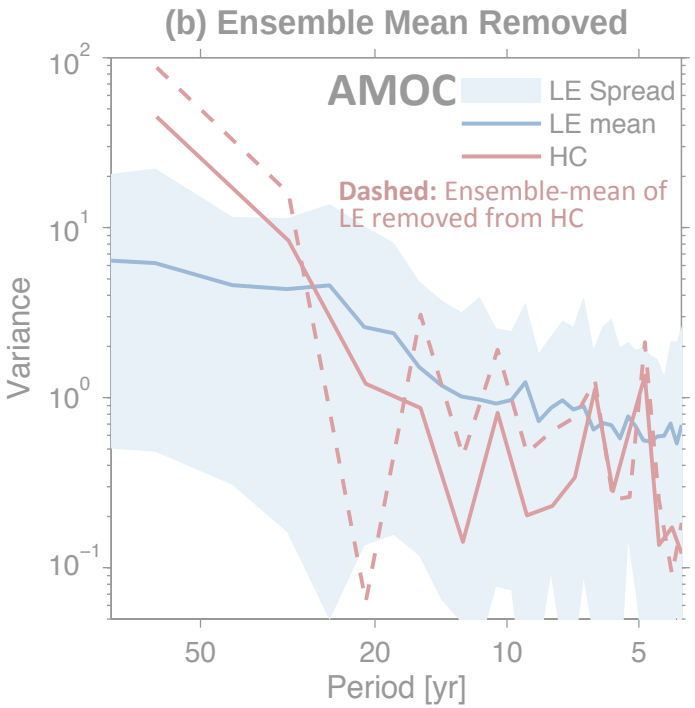
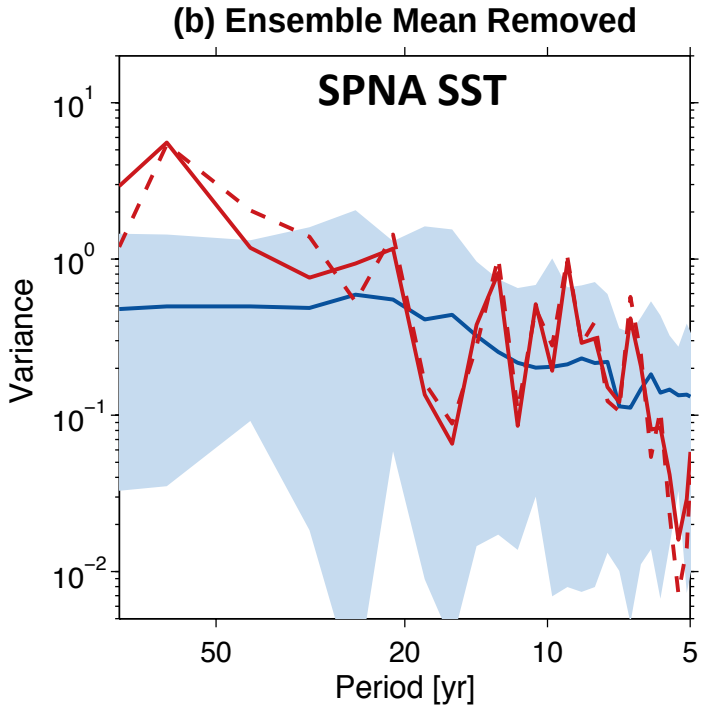
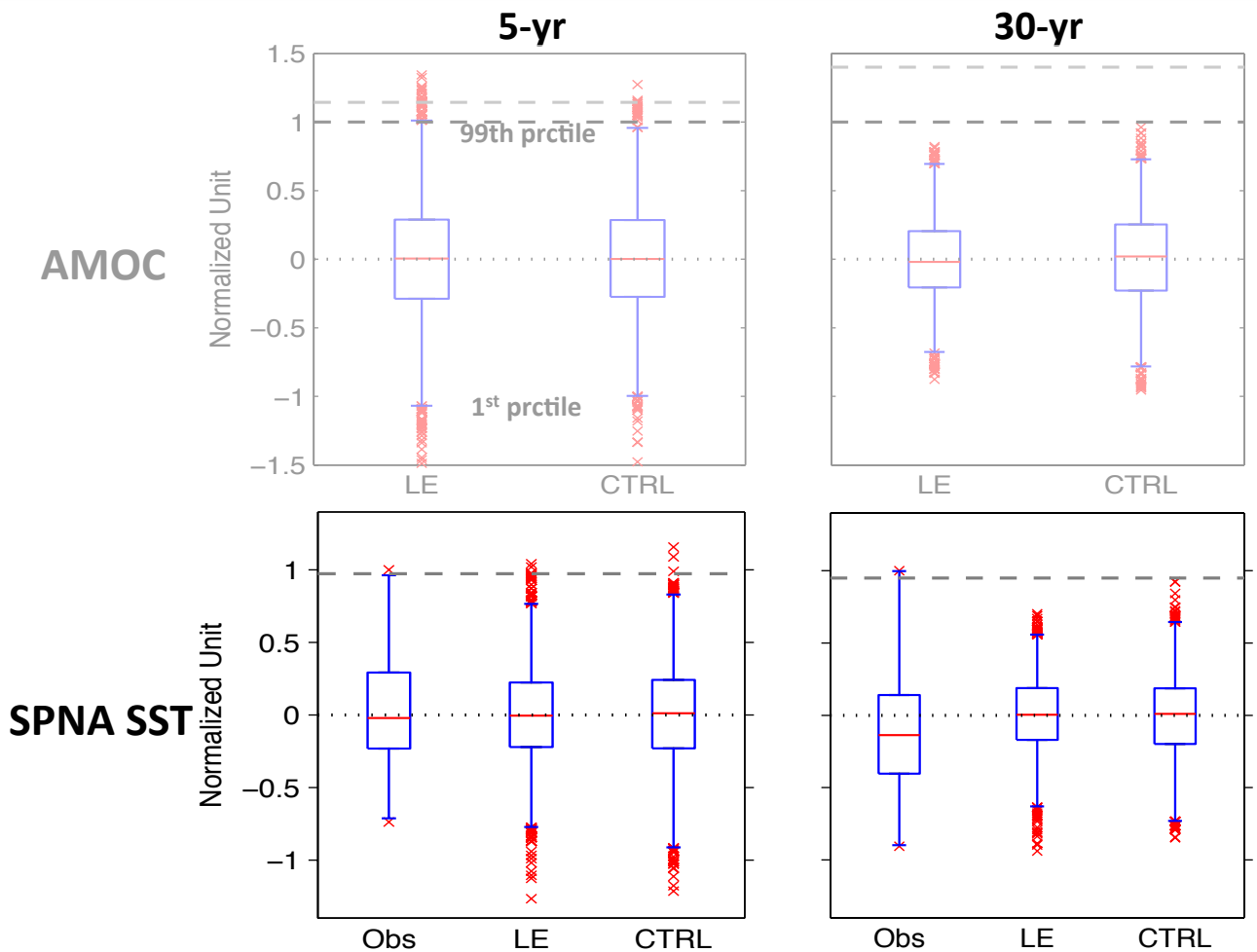
Correlations b/w AMOC PC1 and convergence of northward heat transport (dHT/dy)

Power Spectra



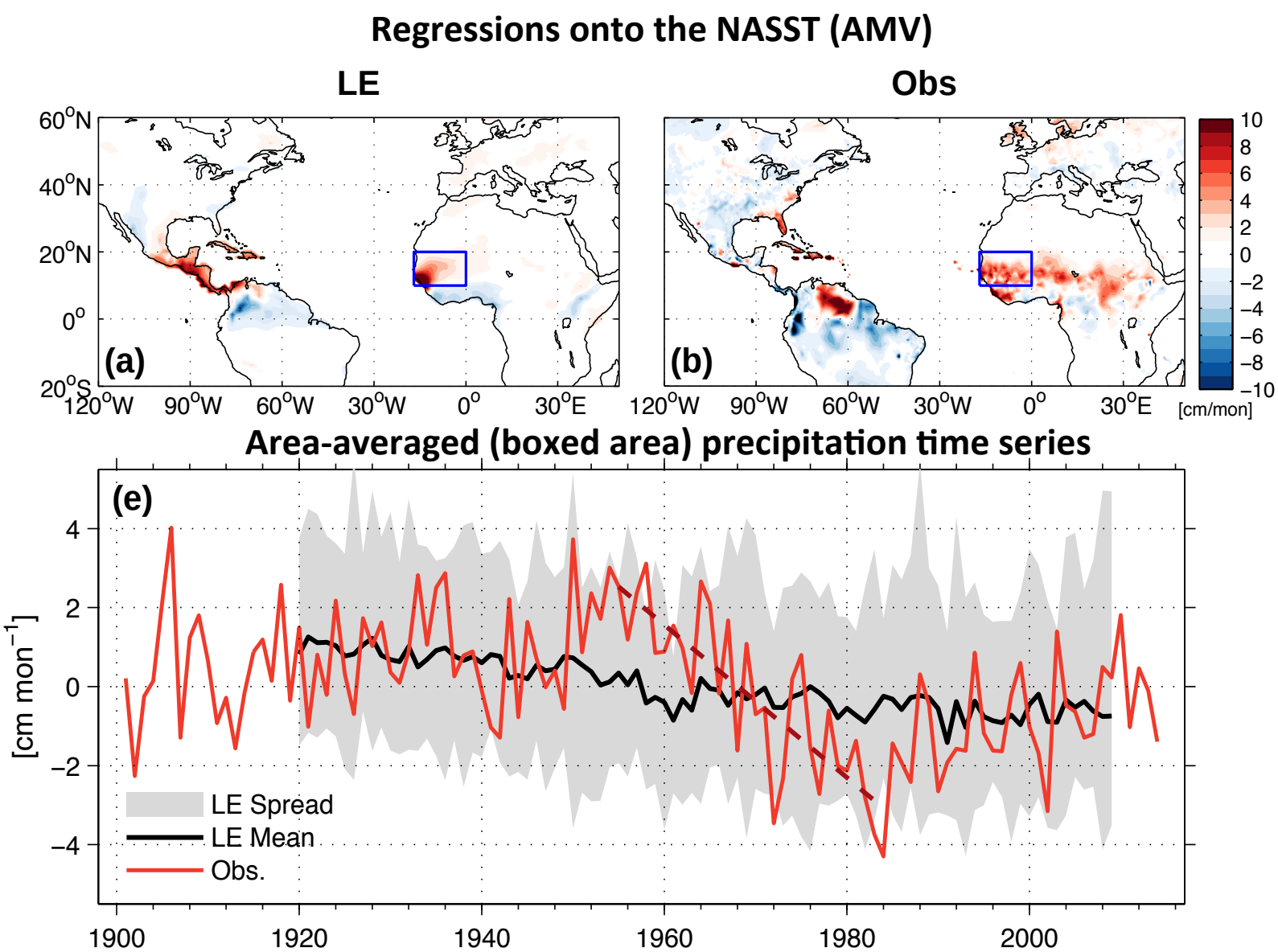


Distributions of Moving Trends

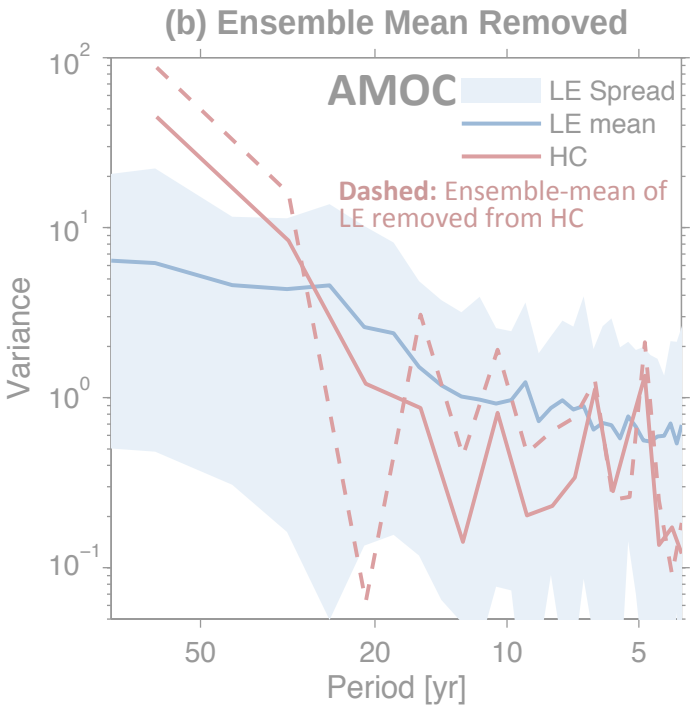


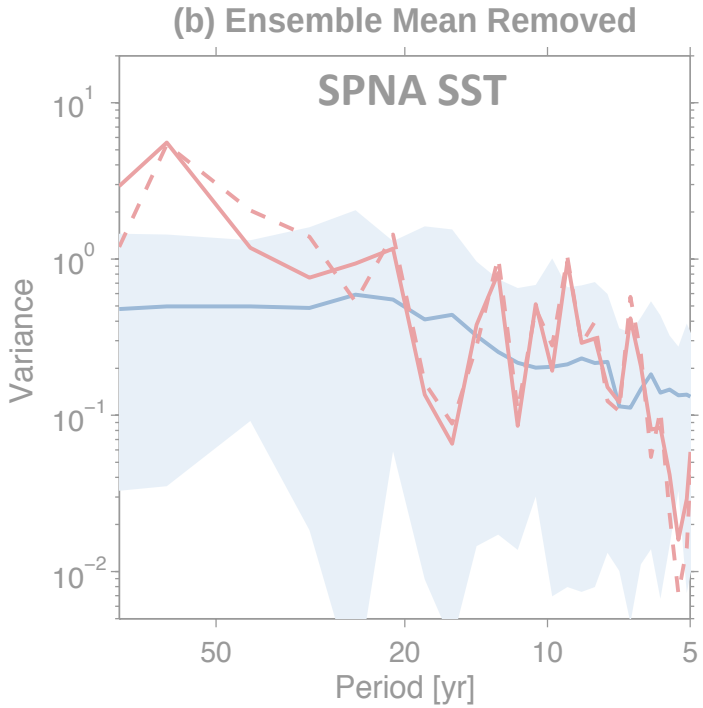
* All trends are normalized to the corresponding max trend of either obs or estimates

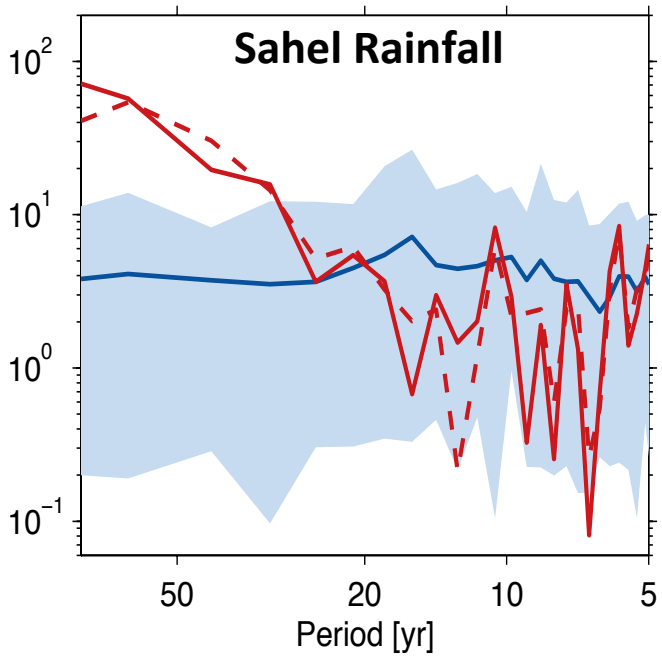
Sahel Rainfall (JJAS)



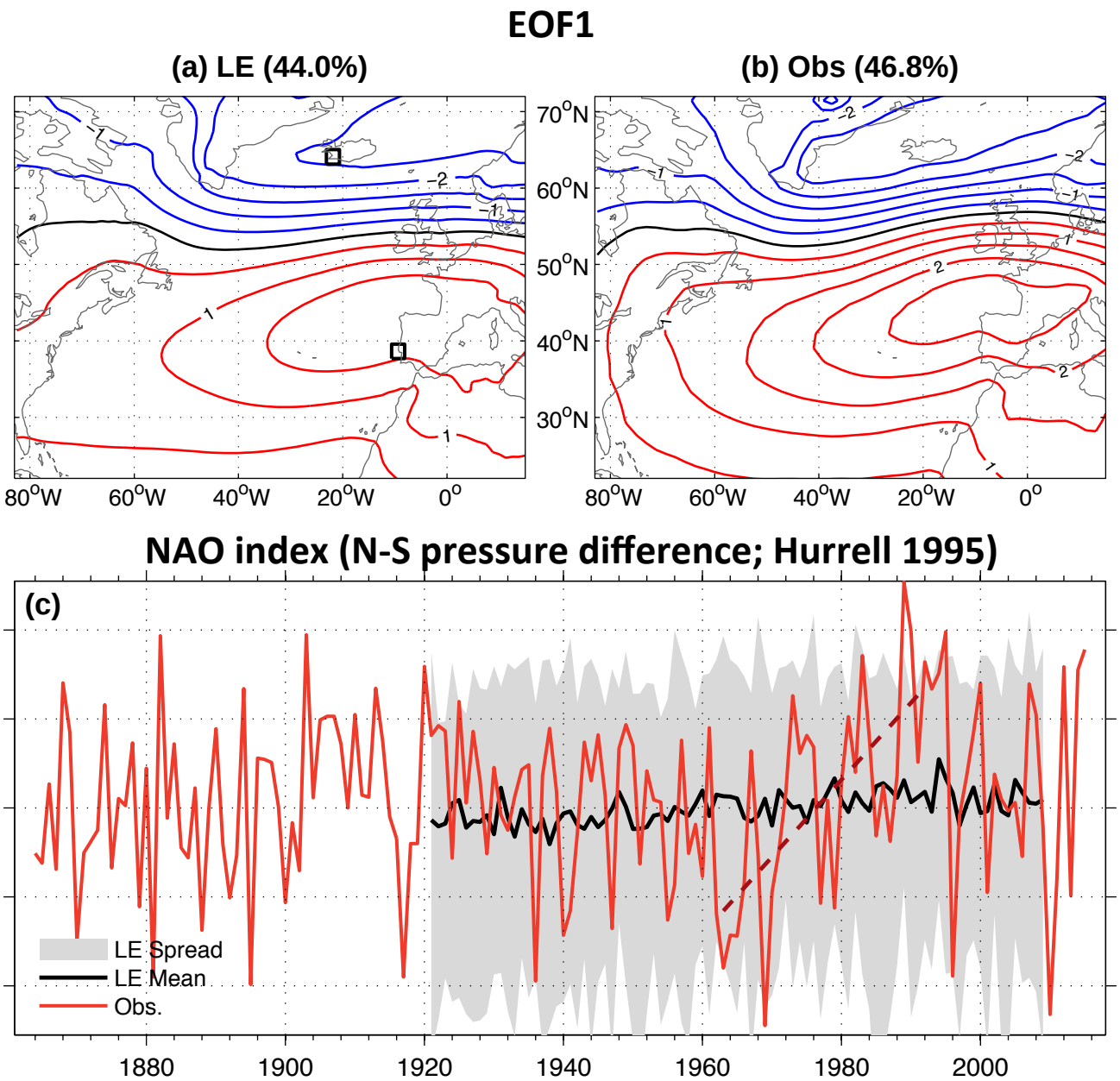
Power Spectra



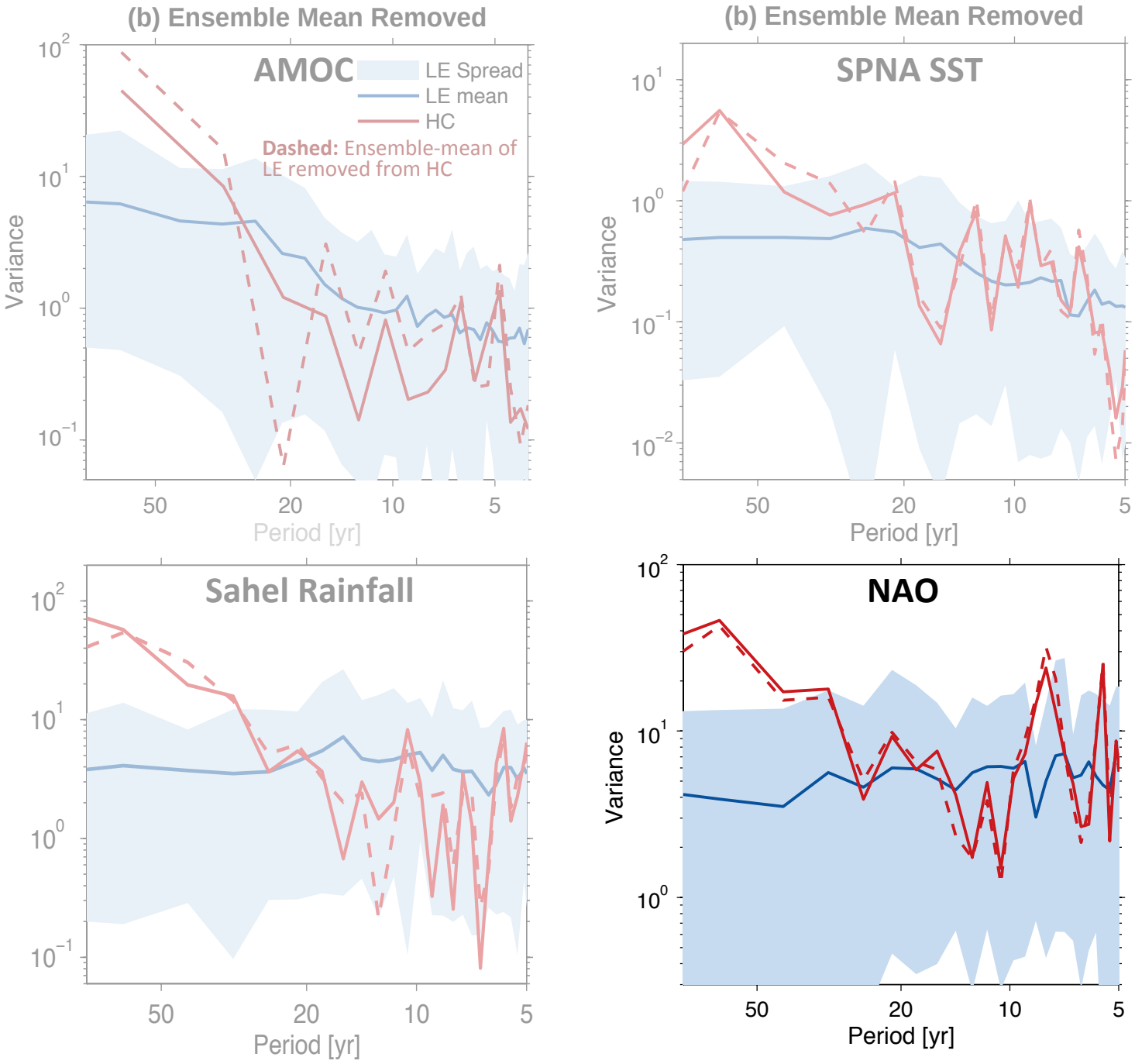




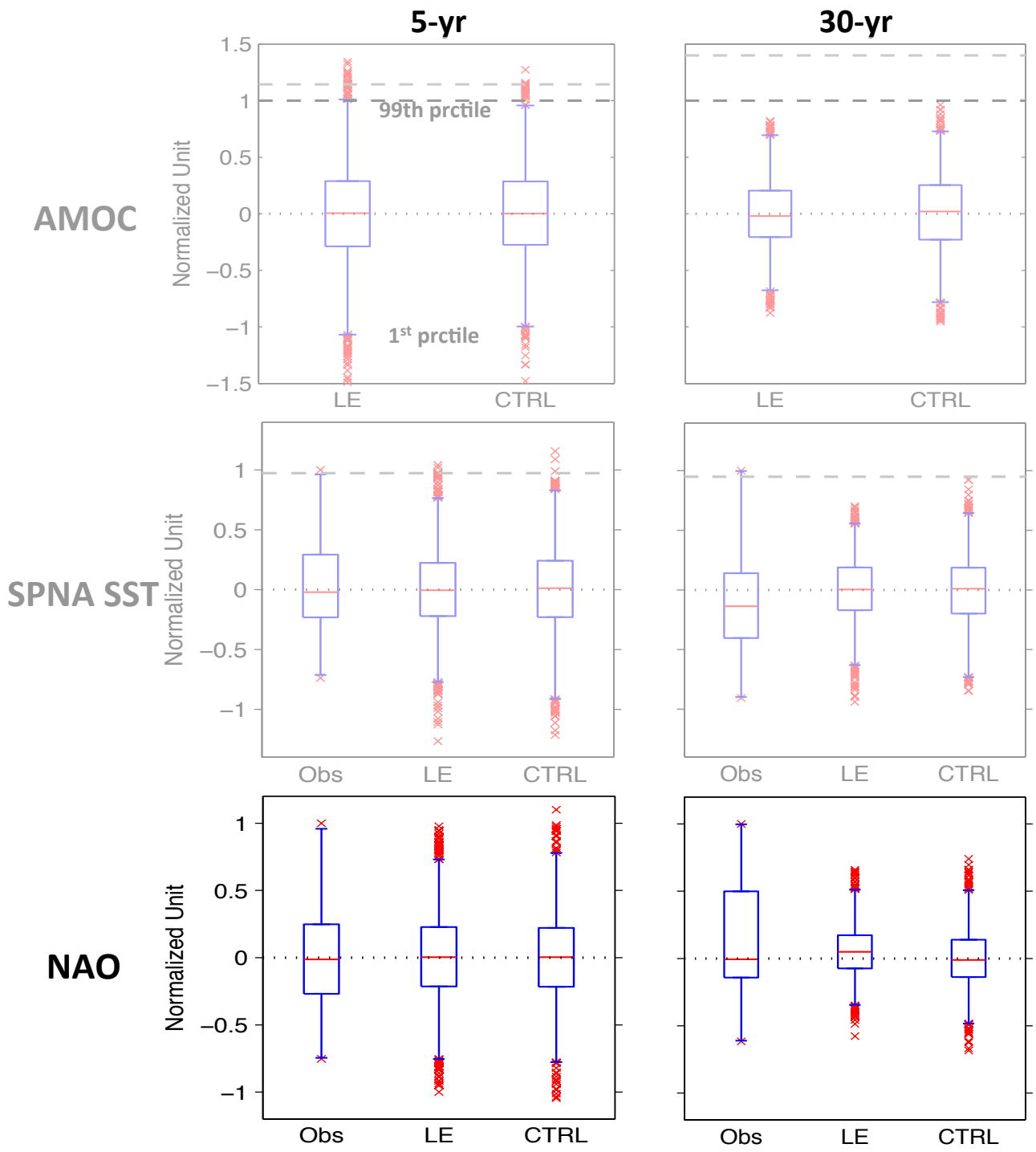
NAO (DJFM)


EOF1
(a) LE (44.0%)
(b) Obs (46.8%)
70°N
60°N
50°N
40°N
30°N
80°W
60°W
40°W
20°W
0°
NAO index (N-S pressure difference; Hurrell 1995)
(c)
[hPa]
4
2
0
−2
−4
1880
1900
1920
1940
1960
1980
2000
LE Spread
LE Mean
Obs.

Power Spectra



Distributions of Moving Trends



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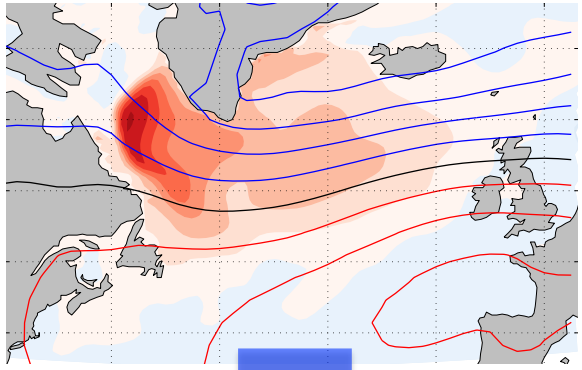
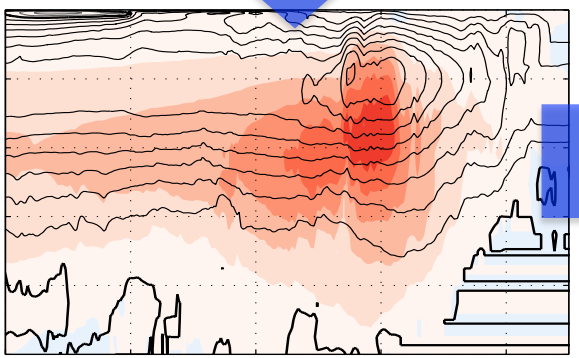
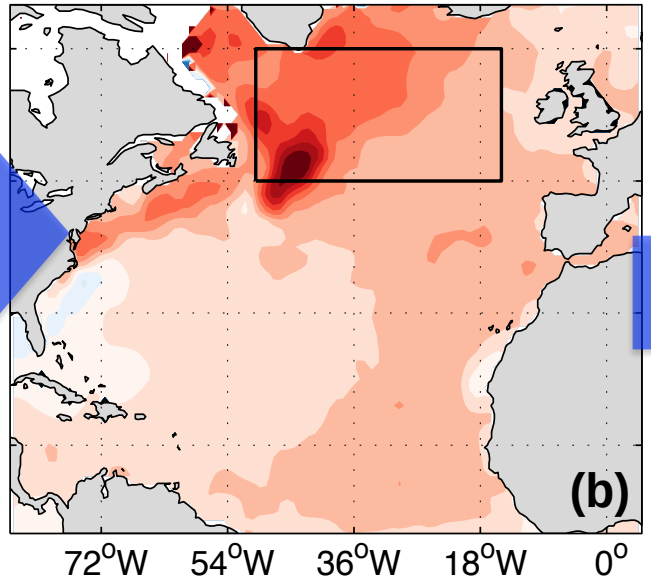
Weak multidecadal North Atlantic Variability in LE

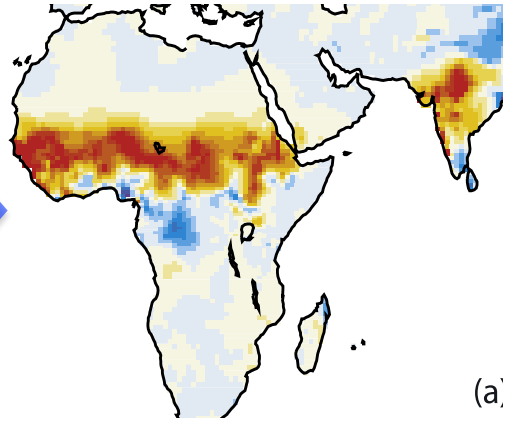




Simulated NAO in LE reveals weak multidecadal variability, compared to obs, which propagates to other variables through the link

➔ Why the simulated multidecadal NAO is weak?



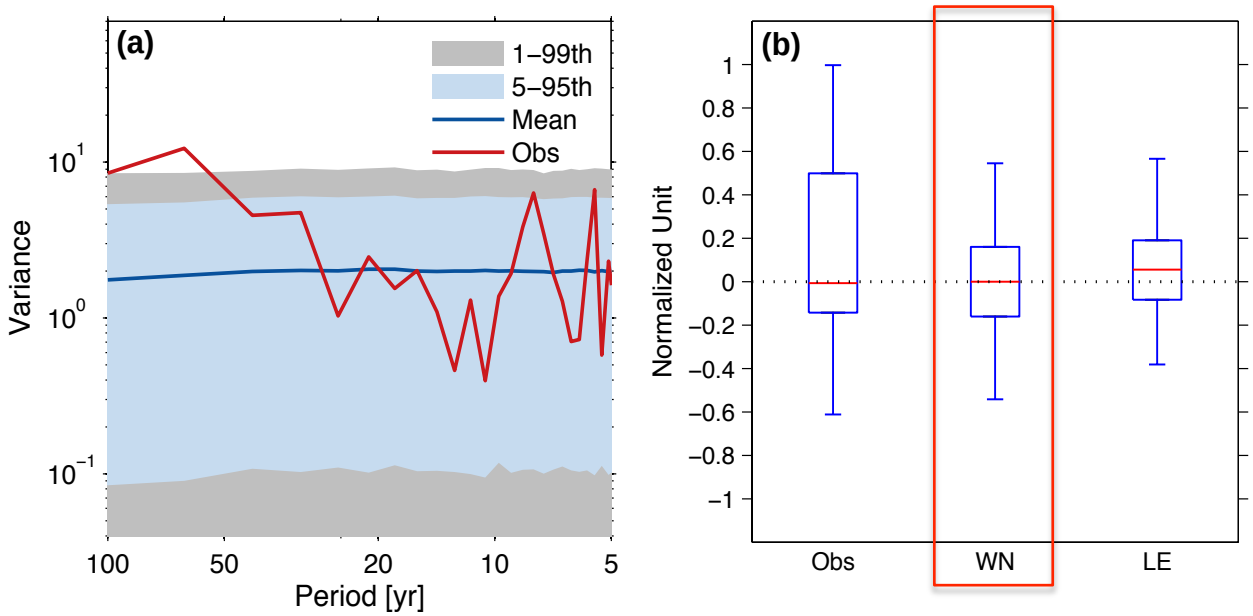


Some Remarks on the Multidecadal NAO

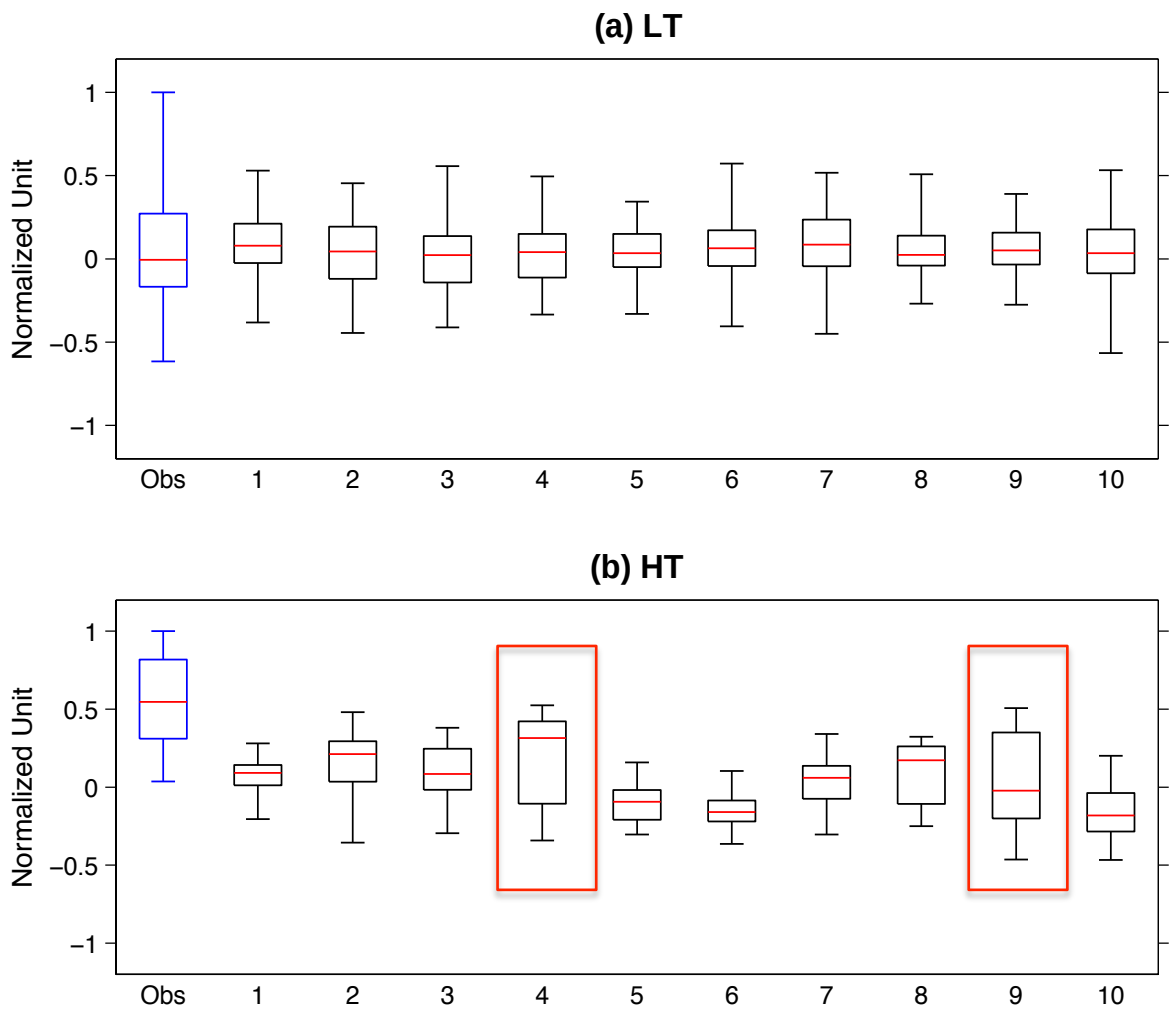
Is the observed NAO is a part of white noise and the ensemble size of LE is too small?

- ***Not likely*** (*Feldstein 2000*)
  → Other factors (e.g., air-sea & troposphere-stratosphere coupling) seem to be necessary

Power spectra and 30-yr moving trends of 89 yr x 10,000 synthetic white noise time series



Some Remarks on the Multidecadal NAO



30-yr NAO trends from

TOGA AMIP w/ CAM5
(1880 – 2014)
* Only tropical SST is time-varying

AMIP w/ "high-top" CAM5
(1952–2002)
Richter et al. (2015)
* Time-varying SST everywhere

✓ **Resolving stratosphere may be the key in simulation multidecadal NAO variability**

Summary/Discussion

✓ **The multidecadal North Atlantic variability in LE is weak compared to obs**

- We claim that this is ultimately due to **weak multidecadal NAO** in LE through NAO → AMOC → AMV link
- The weak multidecadal NAO in LE is consistent with the recent analysis by *Kravtosv & Callicutt* (2016, submitted) using CMIP5 models
- Other factors than intrinsic atmospheric processes seem to play a role for the multidecadal NAO (stratosphere-troposphere coupling?)
- Multidecadal variability seems to be under-sampled in coupled models, thus care should be taken when multidecadal variability is examined

  *** Interannual to decadal variability in LE agrees reasonably with observed one**

- Low-frequency AMOC variability can be driven by other mechanisms than NAO heat flux

  ➔ Evidence from many observational and modeling studies indicates that the NAO heat flux drives the AMOC, at least, during the second half of the 20th century