The role of historical forcings on Atlantic Multidecadal Variability

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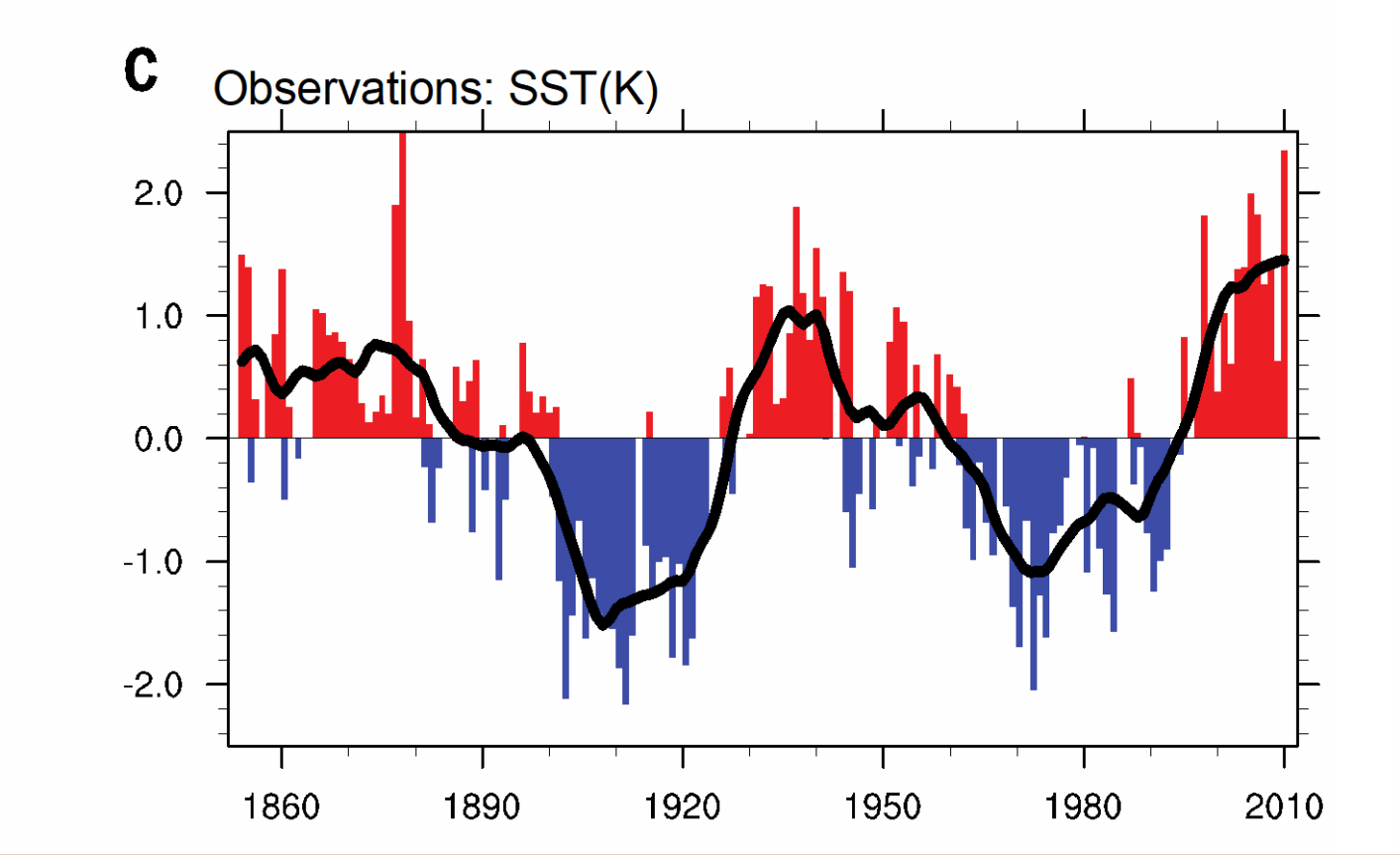
Why is there interest in the drivers of the AMV?



Clement et al. 2015

- Persistence of rainfall/drought and temperature anomalies
- Hurricane counts and intensity
- Influence on the ITCZ and monsoons
- Inter-basins connections

What are the sources of AMV persistence?

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Observations:

- ERSSTv4 reanalysis (1854-2005)

Model:

- Internal variability:
  - CESM preindustrial control
- Historical forcings:
  - CESM Large Ensemble (LE: 1920-2005), 42 members
  - CESM Last Millenium Ensemble (LME: 1854-2005), 10 members

Methods:

- **External** forcing: ensemble mean
- **Internal** variability: ensemble spread ("de-meaned")

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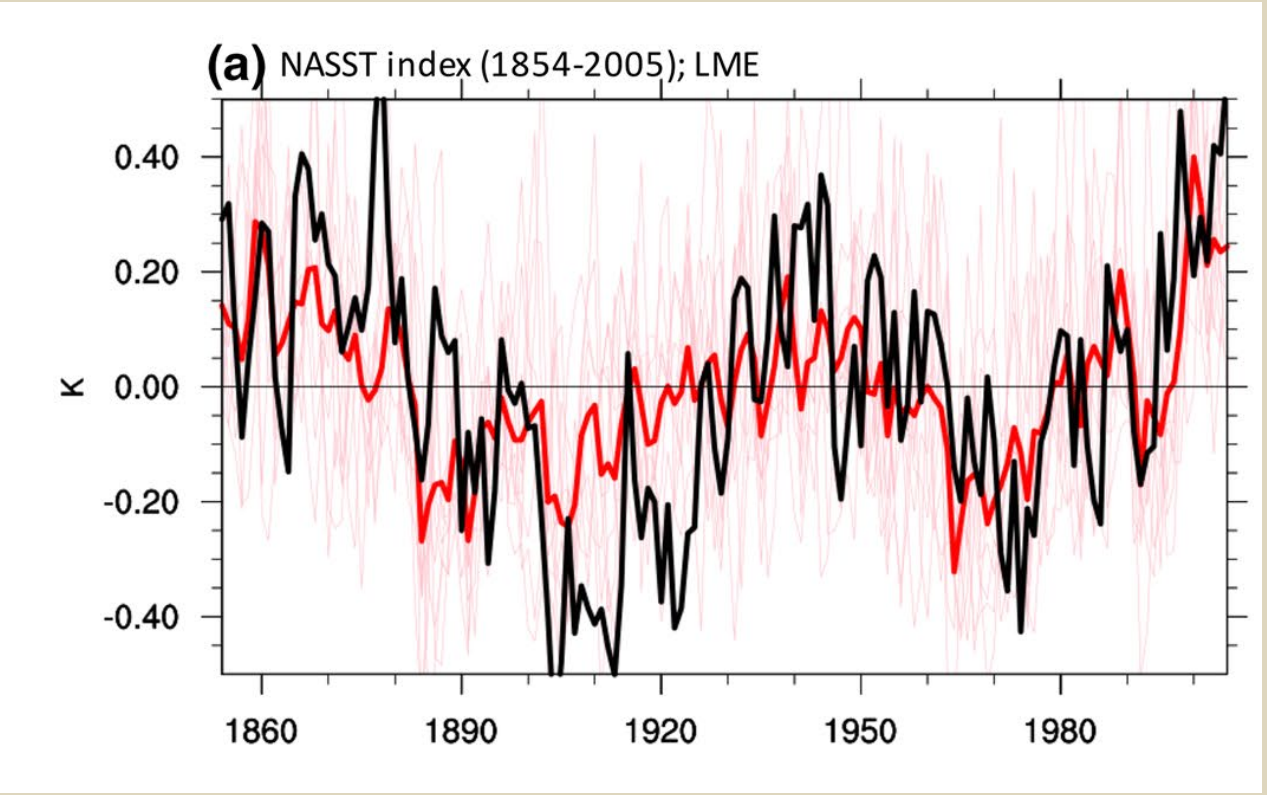
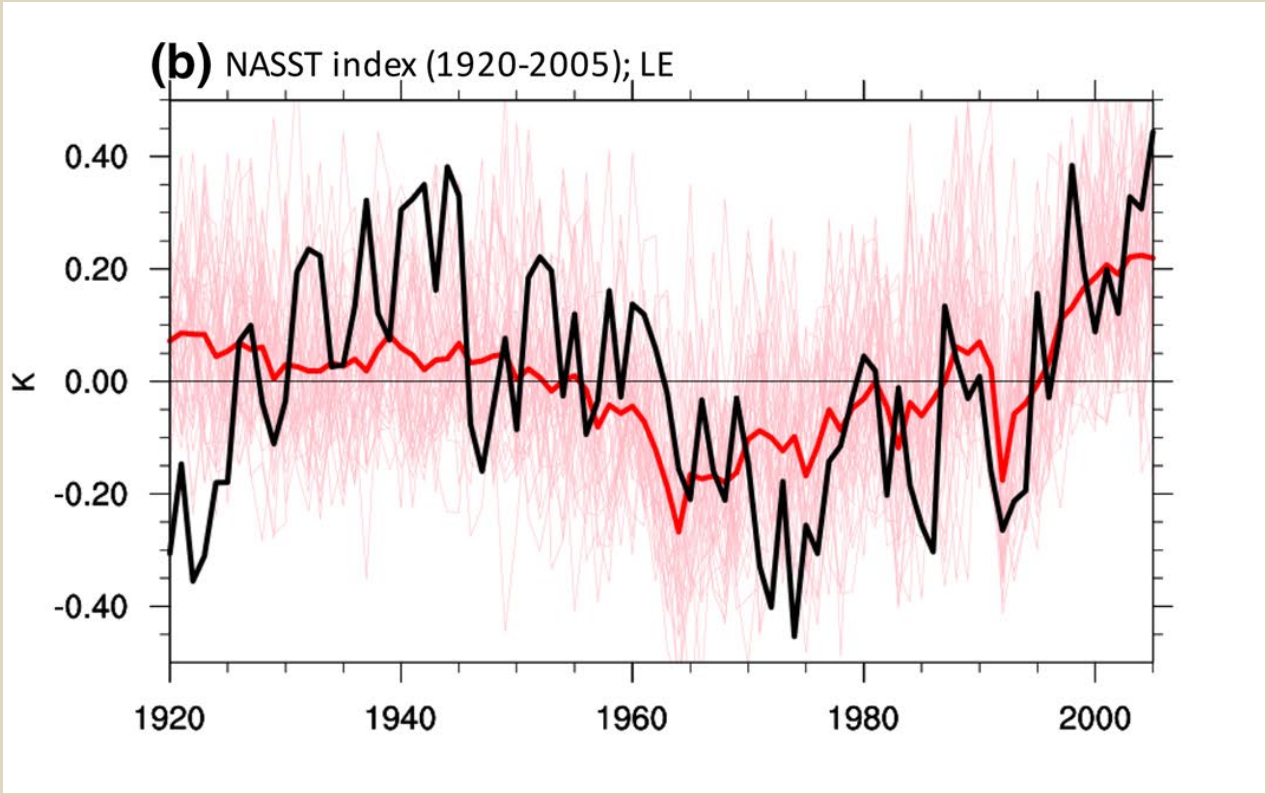
North Atlantic SST index (0-60N, 80W-0)



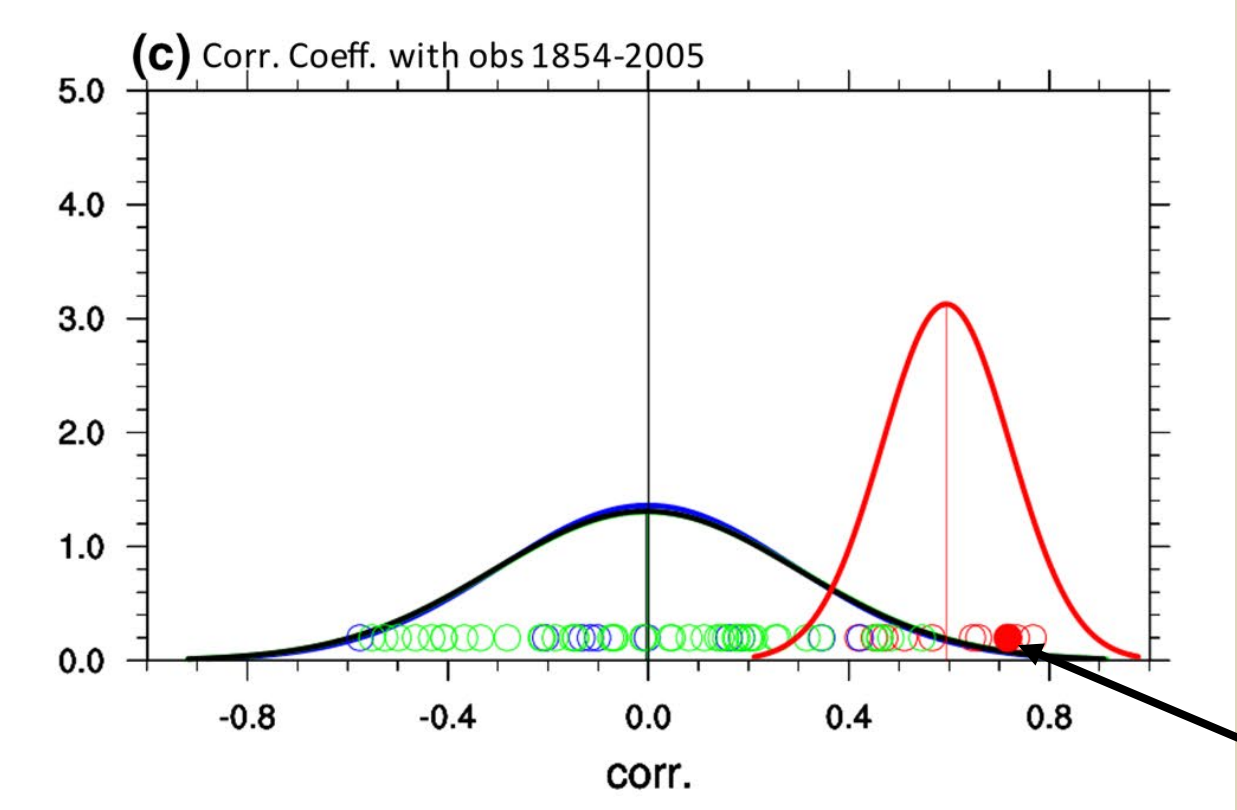


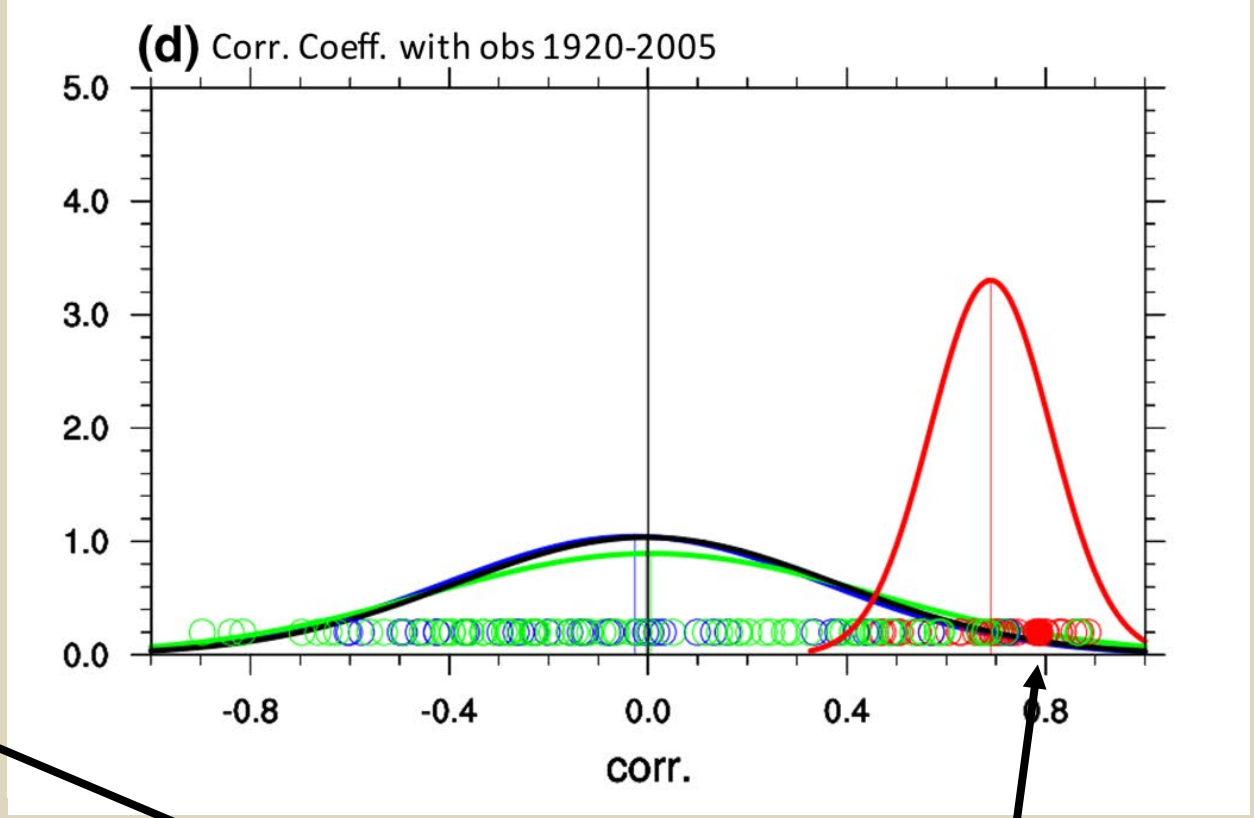
Black: Observations

Red (thick): Ensemble mean (forced)

Red (thin): Ensemble members (forced + internal)

Can you explain phase changes of the AMV without forcings?





Blue: preindustrial control (internal)
Black: random red noise time series (internal)
Green: de-meaned (internal)
Red: historical ensemble members (forced + internal)

ensemble members

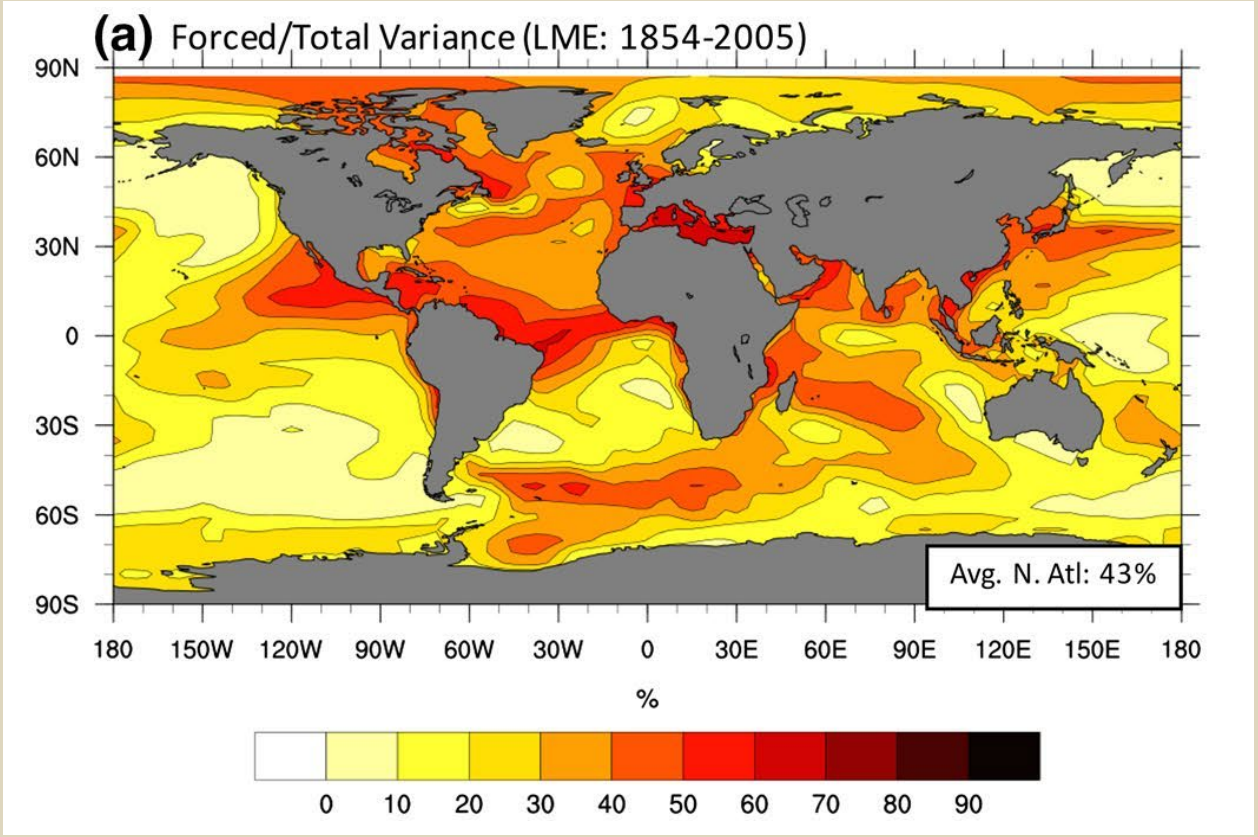
ensemble mean (forced)

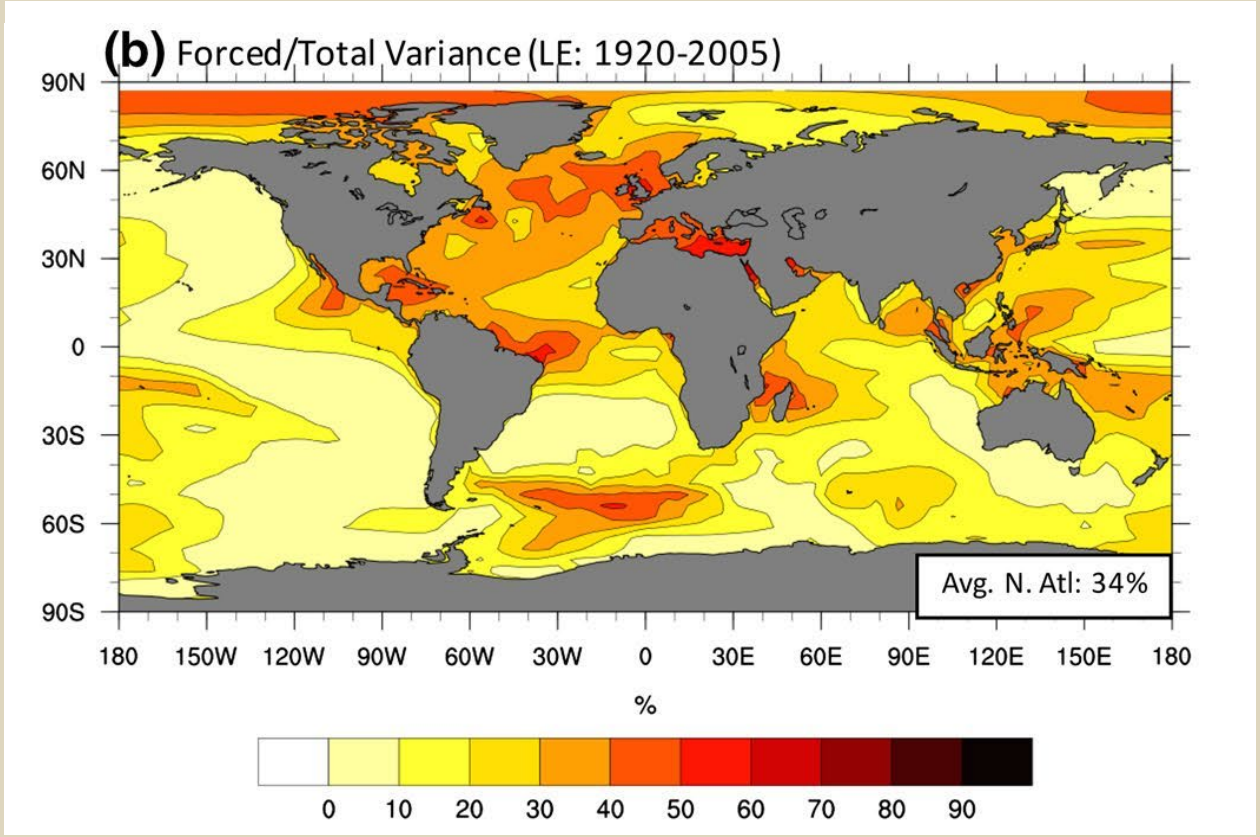
LME (1854-2005): 0.72

LE (1920-2005): 0.79

How much of the total variability is externally forced?

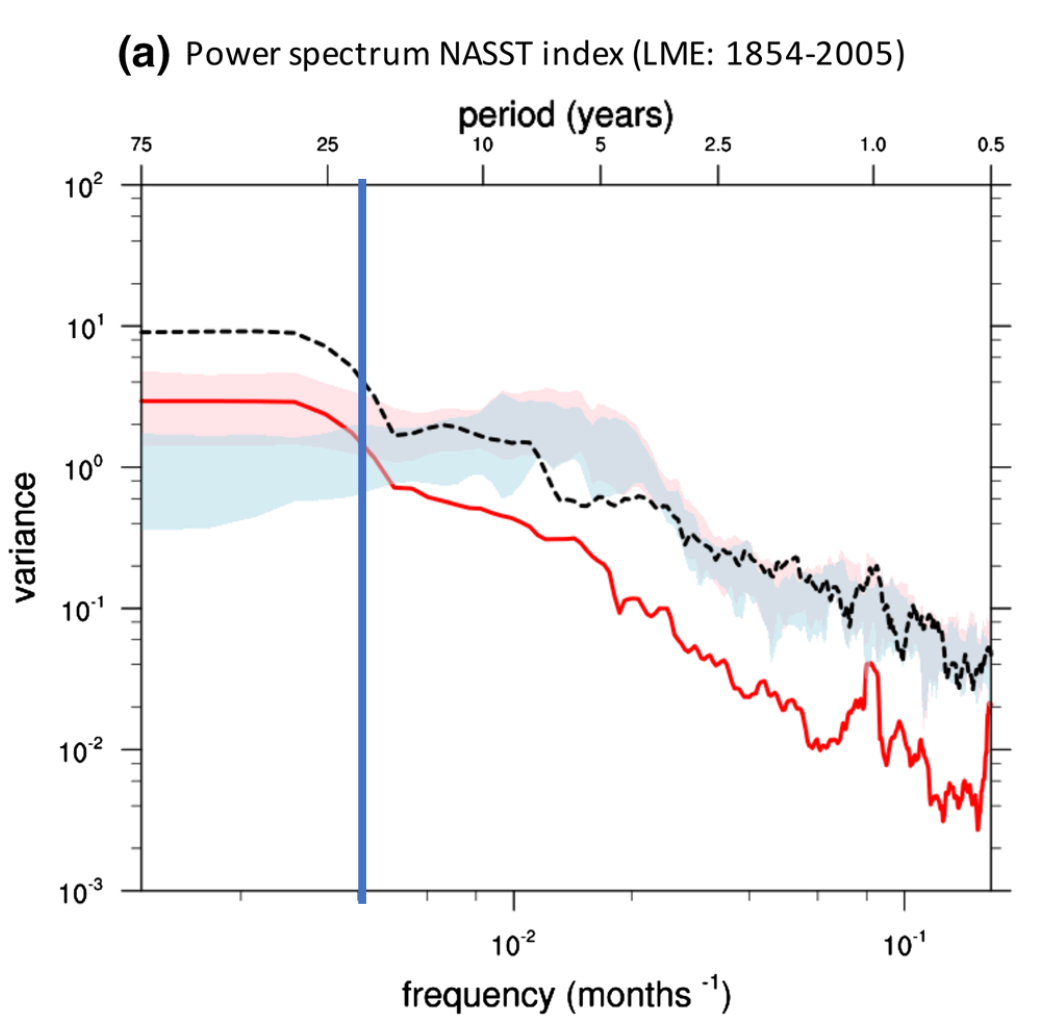
$$\frac{\text{Variance of the ensemble mean}}{\text{Mean of all the ensemble members' variances}} * 100$$

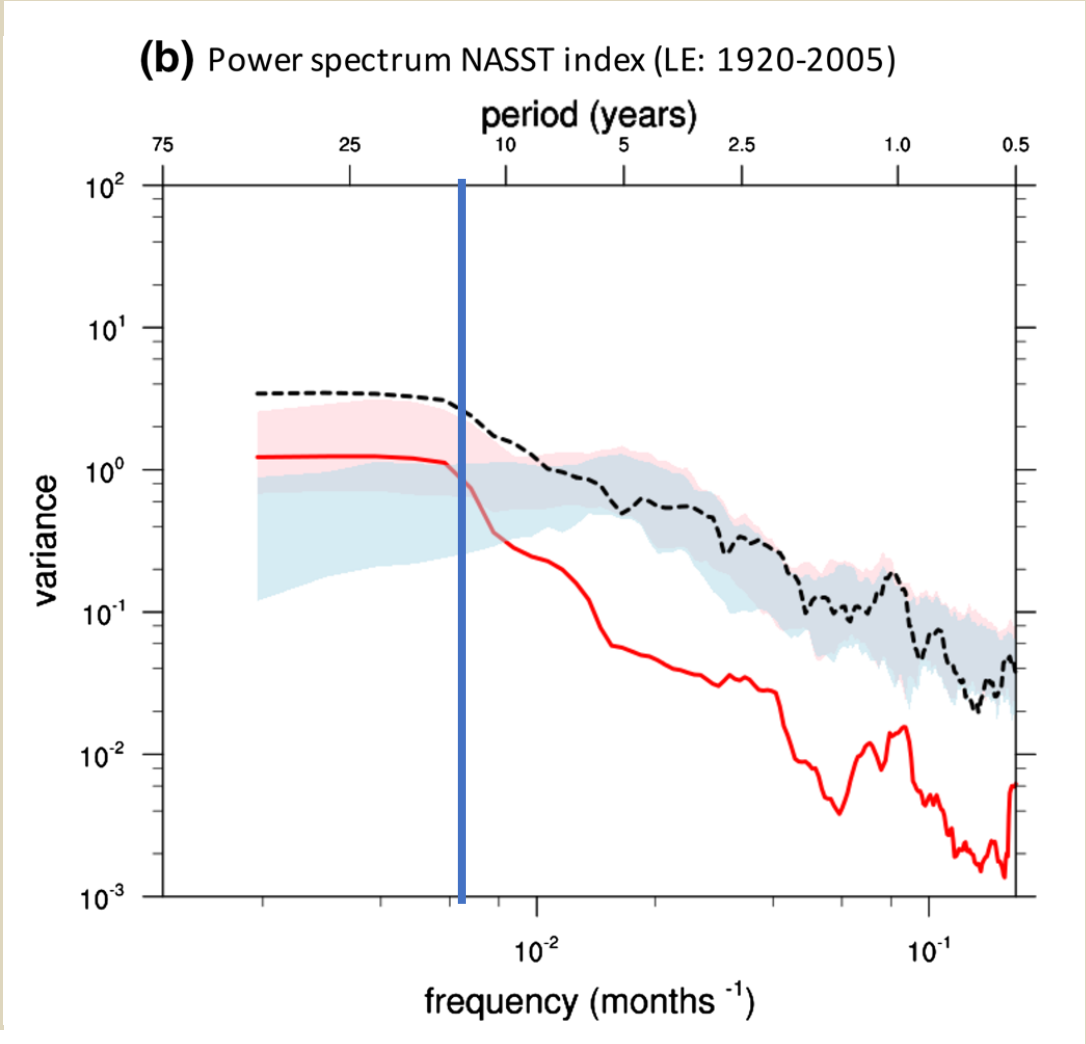




AMV index: 68% for LME, 72% for LE

At what timescales is North Atlantic variability externally forced?





Blue: de-meaned ensemble members (internal)

Black: observations (forced + internal)

Pink (spread): historical ensemble members (forced + internal)

Red: historical ensemble mean (forced)

Main conclusions

- The timing of AMV phase changes can’t be explained in the absence of external radiative forcings
- 68-72% of the AMV index over the years 1854-2005 is externally forced
- External forcing influences the low-frequency (> 10-20 years) North Atlantic SST variability

Some recent developments

- Role of ocean circulation
  - how does the ocean influence AMV variability and predictability? *e.g.: Zhang et al. 2019 and refs therein, Clement et al. 2015, Murphy et al. 2021*

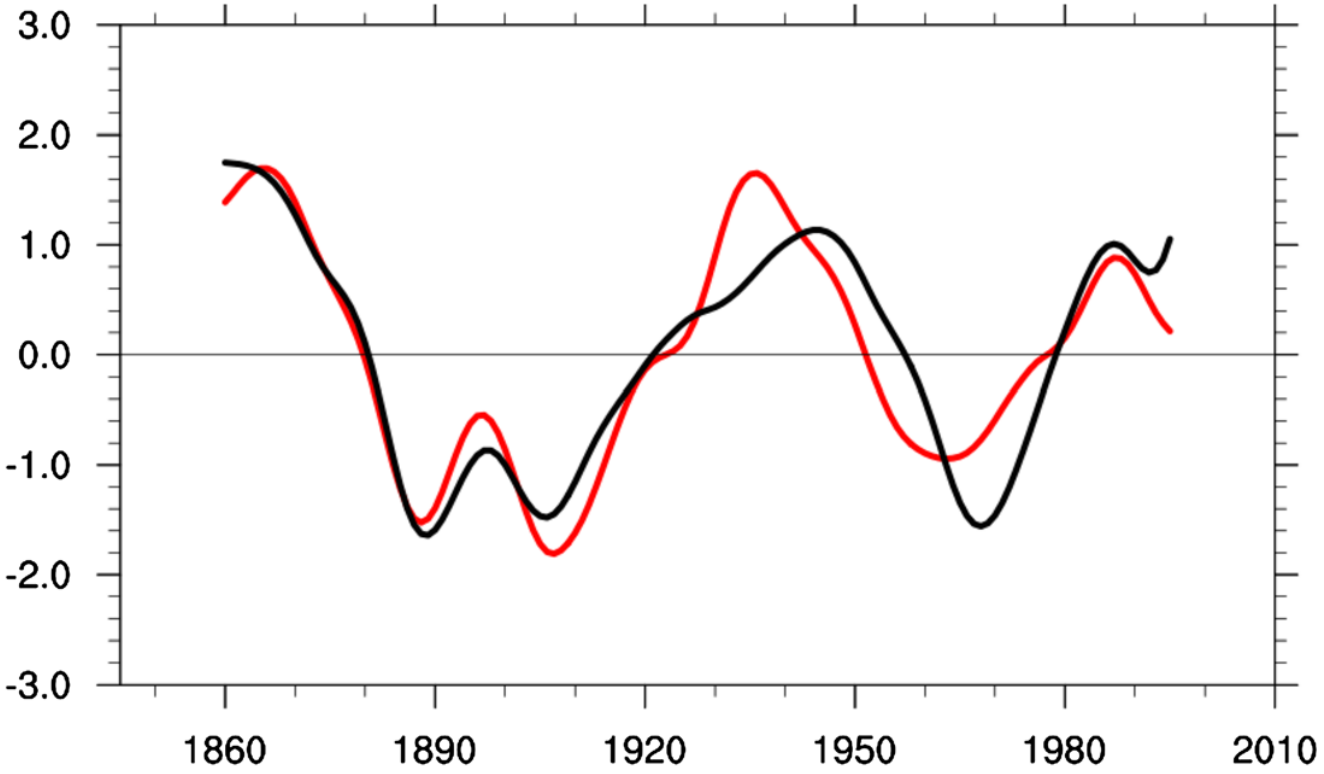
- Role of NAO in driving the AMOC, hence the AMV
  - is NAO too weak in models and unable to enhance the internal part of the AMV? *e.g.: Delworth et al. 2017, Wills et al. 2019, O'Reilly et al. 2019*

- Role of external radiative forcings
  - Examination of external forcings (especially aerosols) in driving the AMV, also using large ensembles *e.g.: Booth et al. 2012, Muprhy et al. 2017, Murphy et al. 2017, Klavans et al. 2019, Watanabe and Tatebe 2019, Ting et al. 2015, Yan et al. 2019*
  - Is the AMOC also forced by external forcings and what is the evidence in proxy observations? *e.g.: Menary et al. 2020, Undorf et al. 2018, Chen et al. 2013*
  - Is the AMV even an oscillation? *e.g.: Steinmann et al. 2015, Mann et al. 2020*

Thank you!

Single forcing experiments

(a) AMV index: black= all forcings, red=ghg+aer/ozone+strat aer+solar



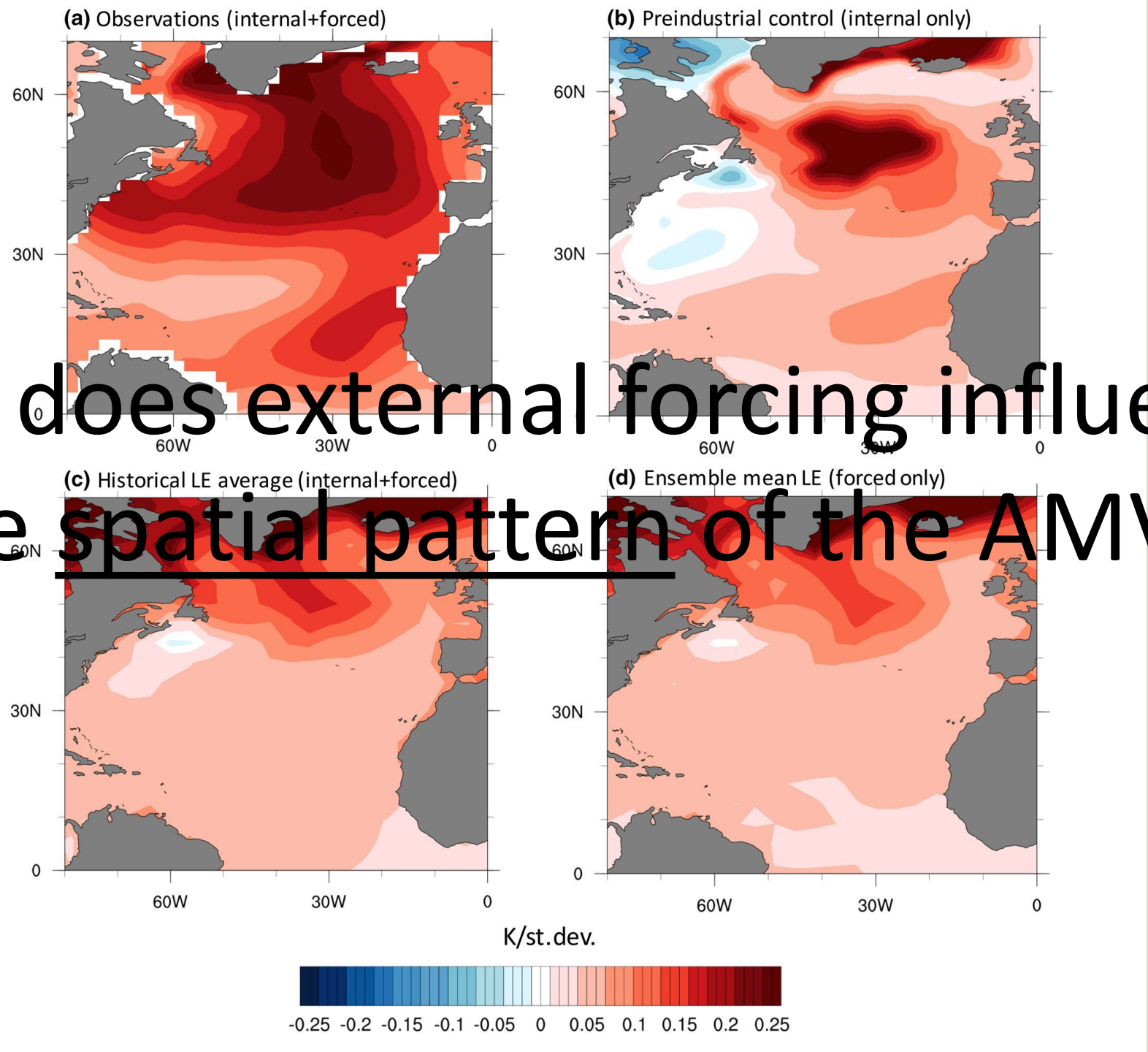
(b) Corr. Coeff. between all forcings and sum of single forcings

Forcing	**Corr. Coeff.**
GHG	0.45
GHG+AER/OZONE	0.83
GHG+AER/OZONE+STRAT AER	0.87
GHG+AER/OZONE+STRAT AER+SOLAR	**0.91**
GHG+AER/OZONE+STRAT AER+SOLAR+LAND USE	0.89
GHG+AER/OZONE+STRAT AER+SOLAR+LAND USE+ORBITAL	0.88

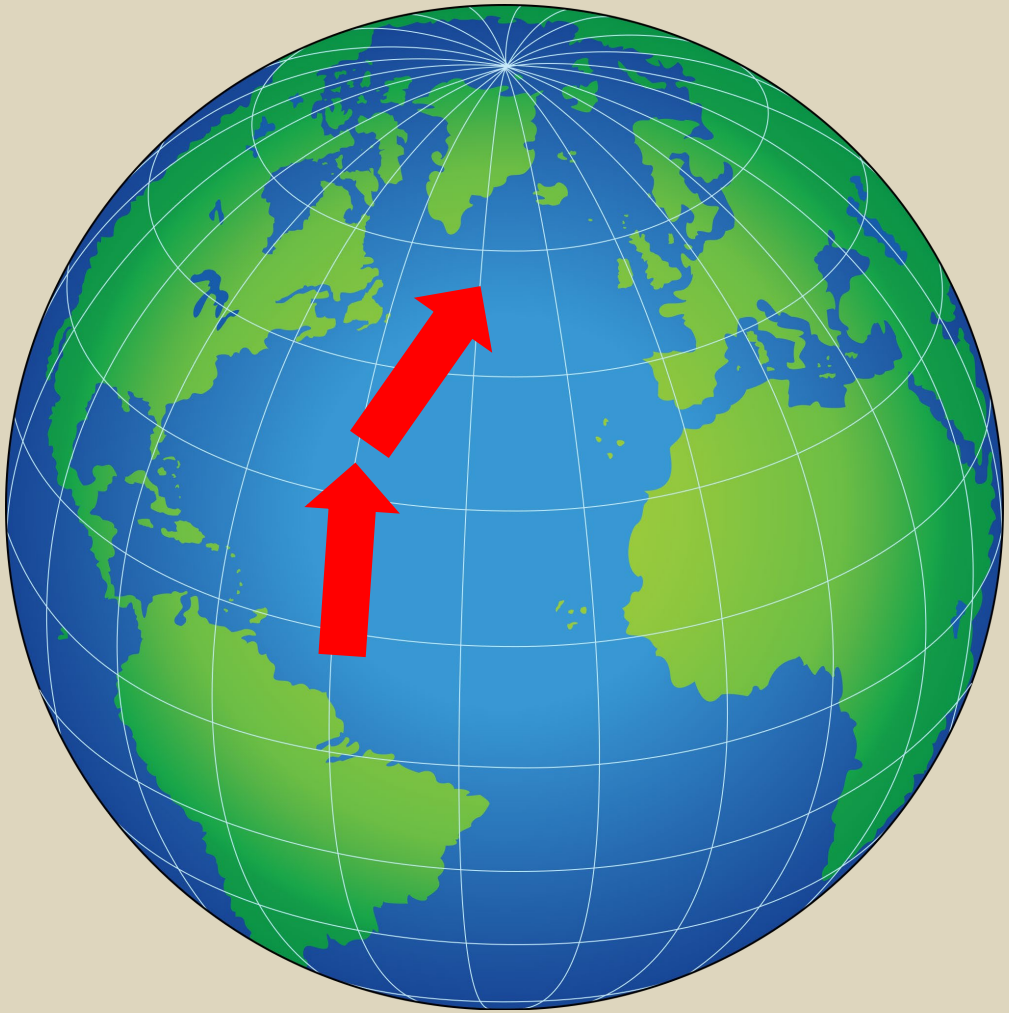
Table 1 Forced to total variance averaged over the North Atlantic (first row) and for the AMV index (second row)

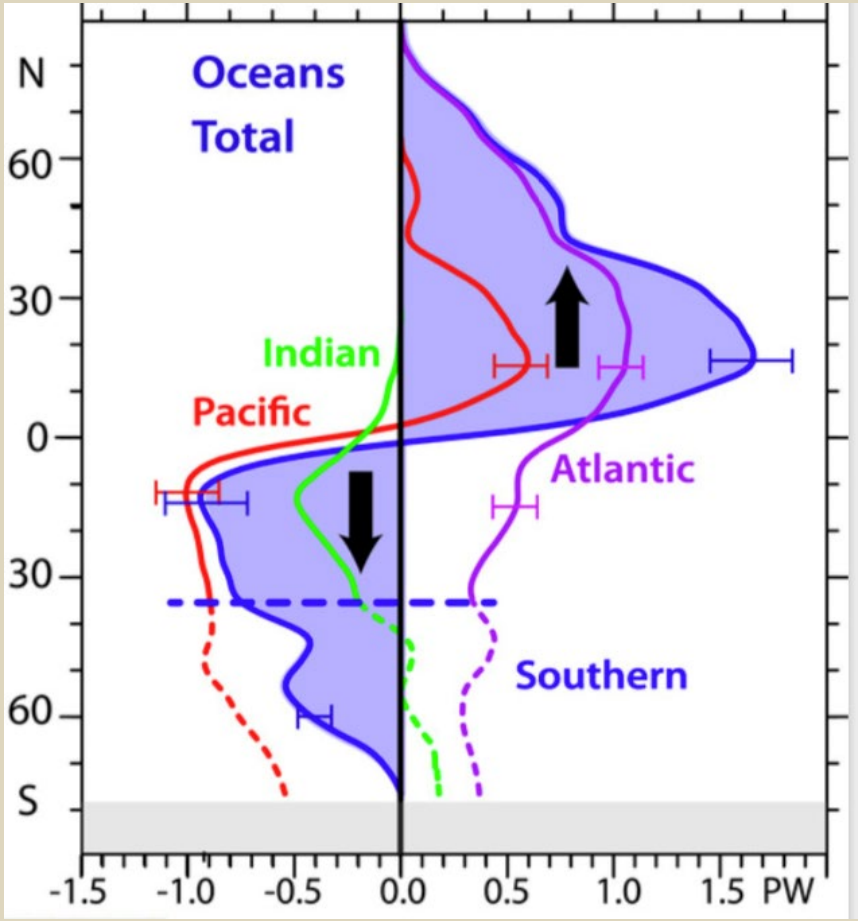
	LME (1854–2005)	LE (1920–2005)	LME (1920–2005)	LE (33 groups of ten members each)
Average North Atl	43%	34%	39%	Range 34–47% Average 39%
AMV index	68%	72%	70%	Range 70–81% Average 73%

How does external forcing influence the spatial pattern of the AMV?



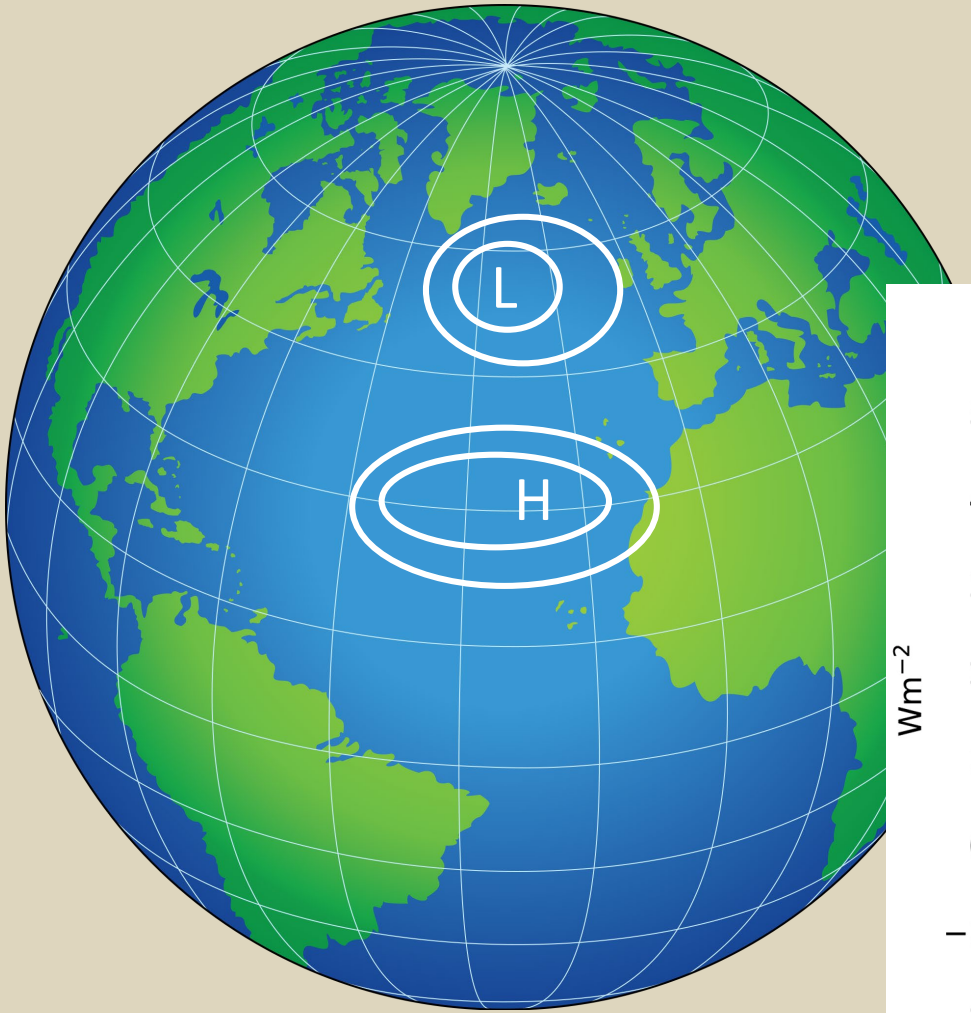
Ocean circulation: AMOC



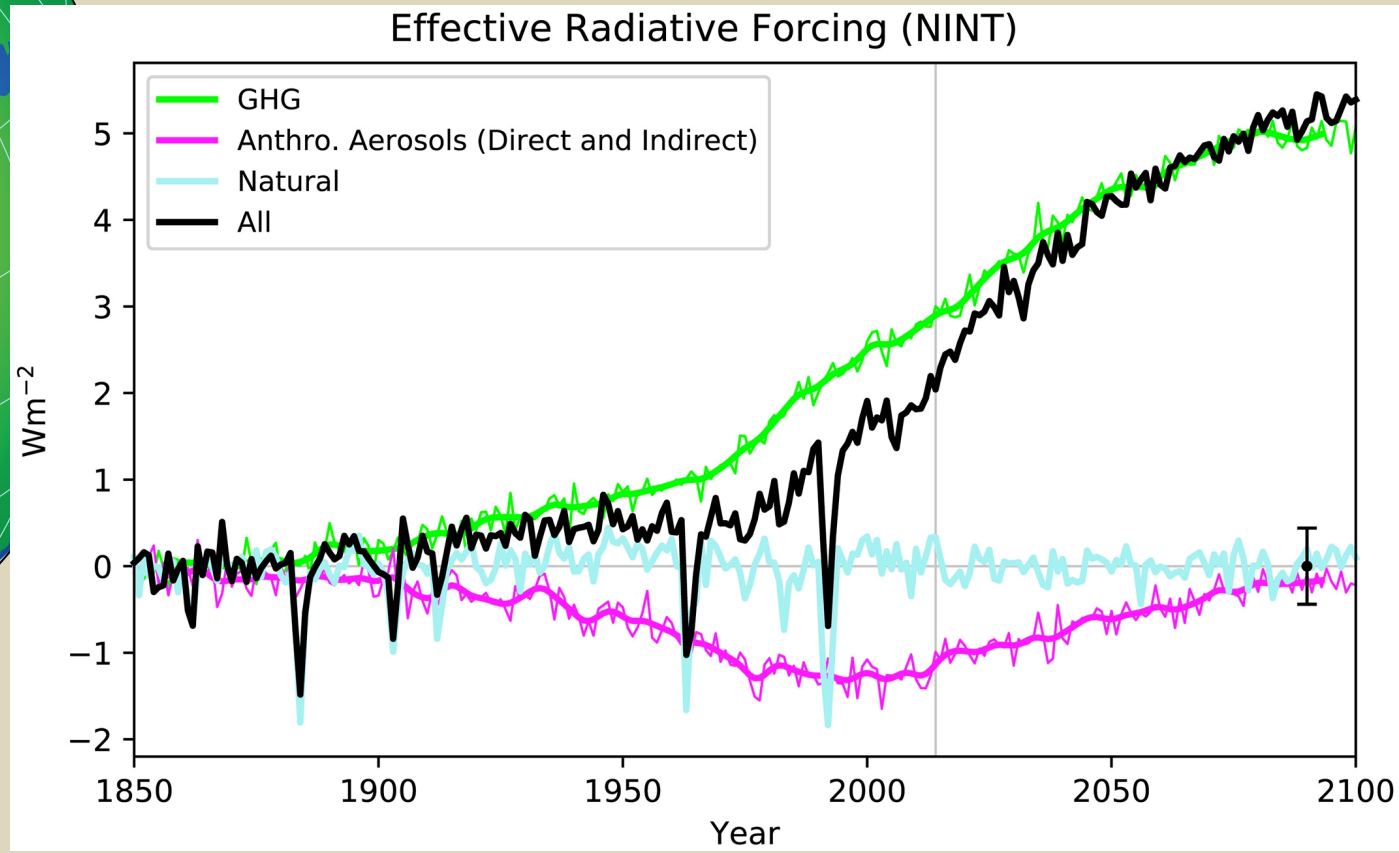


Trenberth et al. 2019

Atmosphere: NAO + external radiative forcing



- Atmospheric noise (NAO) integrated by the oceanic mixed layer
- External radiative forcings (aerosols)



Miller et al. 2021