North Atlantic decadal climate variability in a large ensemble of CGCM runs

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Outline

1. Introduction

Motivation & Introduction

- It is part of an ongoing debate what drives multi-annual to decadal SST variability in the North Atlantic (e.g. Clement et al., 2015 and responses)
  - Is the AMV only a result of integrating atmospheric noise?
  - or do changes in the AMOC related ocean heat transports into the North Atlantic the cause the SST variability there?

- Here we use a large ensemble of CGCM runs to...
  - ...identify modes of ocean variability.
  - ...analyse the impact of moderate and strong external forcing.
  - ...better understand and quantify the links between different ocean modes in the Atlantic.

Experimental Setup

Expansion of the CMIP5 ensembles

- MPI-ESM-LR
  - atm. resolution: T63L47
  - ocean resolution: GR15L40
- **Control:** 1 run, 2000 years, climatological radiative forcing
- Set of 2 different ensembles with varying radiative forcing:
  - **Historical:** 100 runs, 138 years each, hist. radiative forcing
  - **1% :** 69 runs, 138 years each, 1% CO_2 increase per year

2. Modes of multi-annual SST variability in MPI-ESM

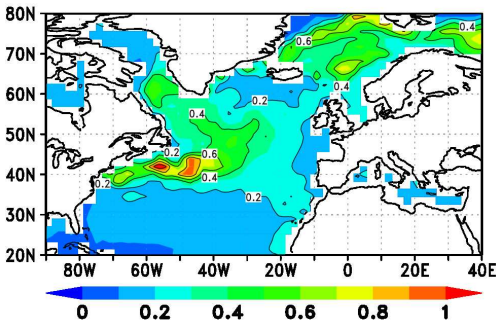
- How do typical patterns of multi-annual SST variability in general look like in the MPI Earth system model?
  - How robust are these throughout the ensemble?
  - How does radiative forcing impact SST variability?
- Are the variability patterns the same throughout the whole historical ensemble or is it possible to find different "clusters" of individual runs with different patterns of variability?

Multi-annual SST variability & the role of ext. forcing

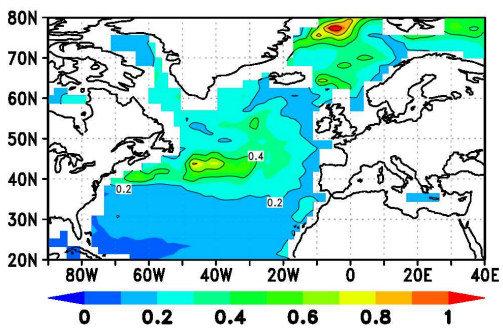
Time std. of 11-yr running mean SST [K]

- Patterns of low frequency SST variability agrees between historical and control run.
- ...but is reduced in the 1% scenario (subject to detrending method?)

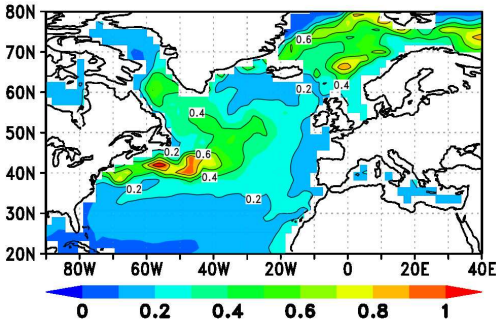
historical



1% (1950-1999)



pictl

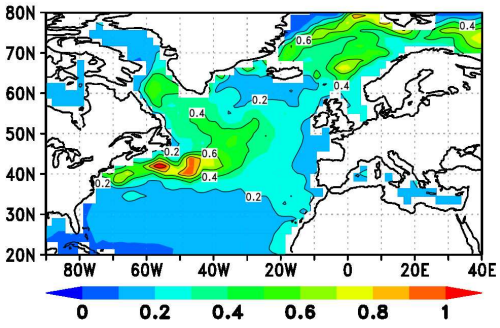


Multi-annual SST variability & the role of ext. forcing

- Patterns of low frequency SST variability agrees between historical and control run.
- ...but is reduced in the 1% scenario (subject to detrending method?)
- Ensemble spread is highest in regions with high temporal variability
- Higher differences between the individual runs in 1% experiments

Time std. of 11-yr running mean SST [K]

historical



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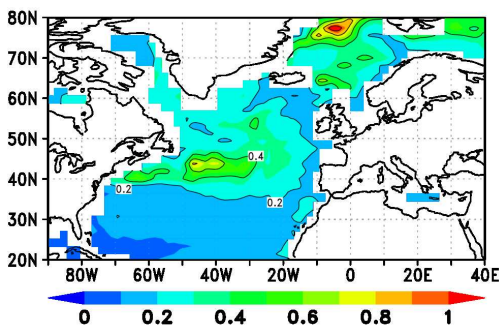
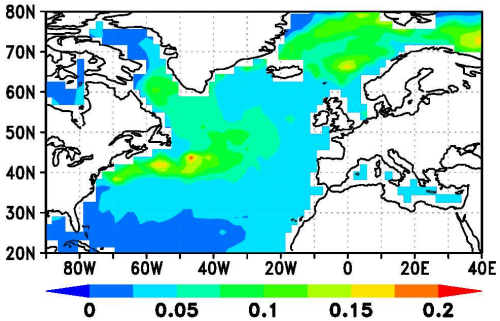


Ensemble spread of SST time standard deviations computed for each run individually [K]

historical



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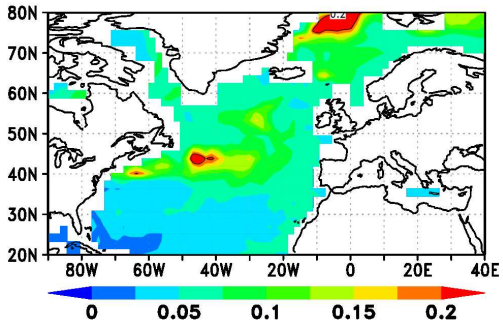
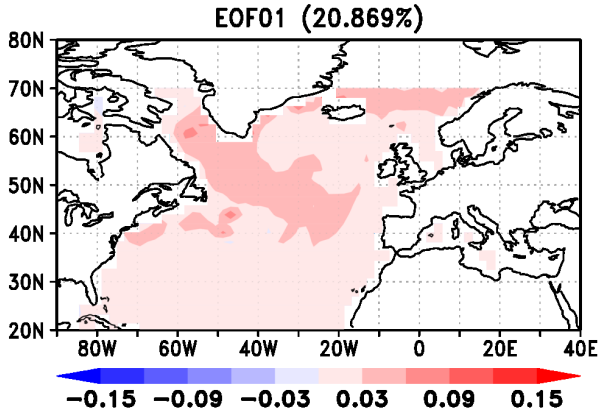
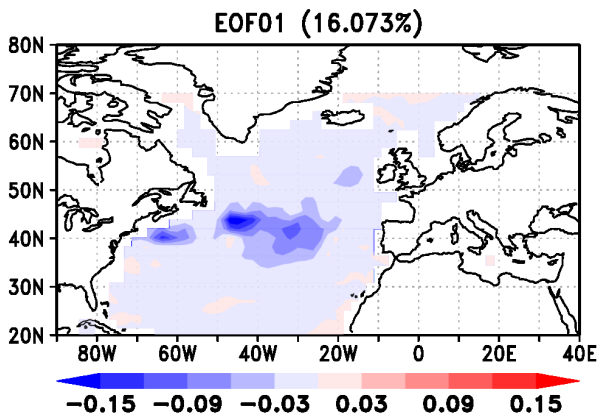
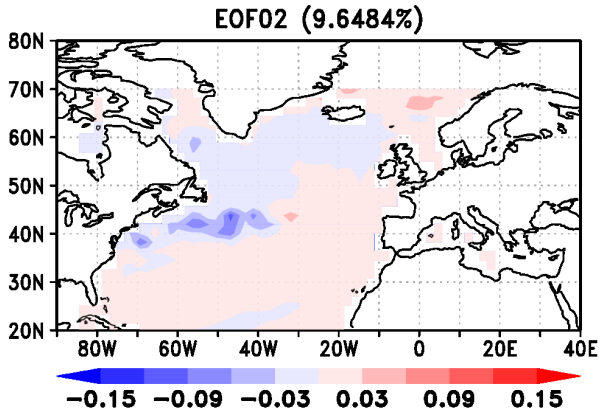


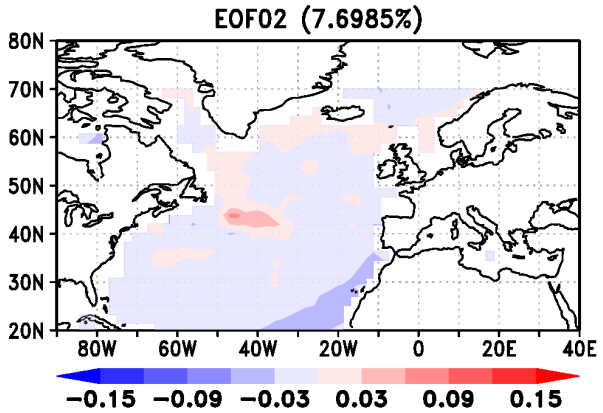
Is it possible to group runs in terms of variability patterns?

EOF decomposition of the Time standard deviations of the individual runs historical 1%(1950-1999)



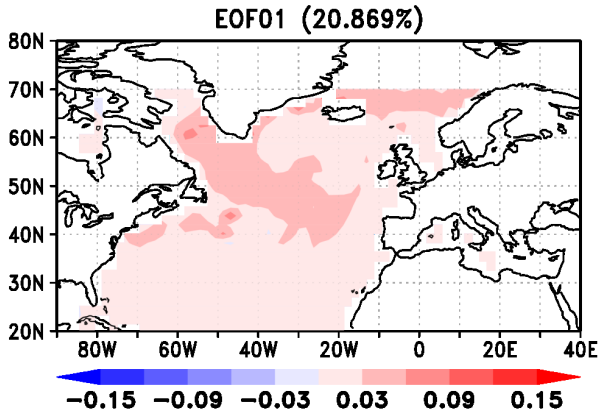


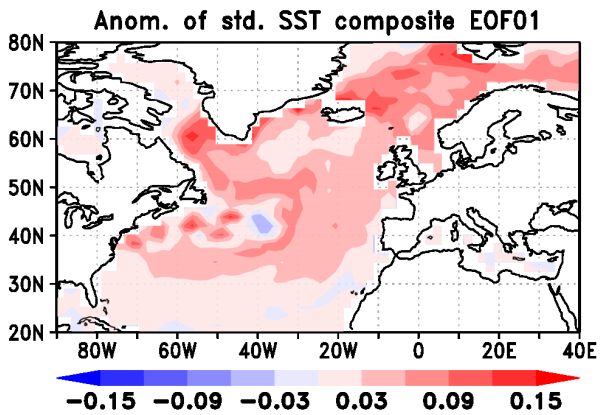


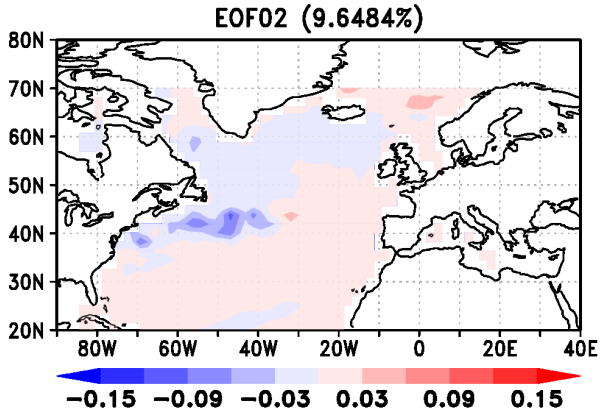


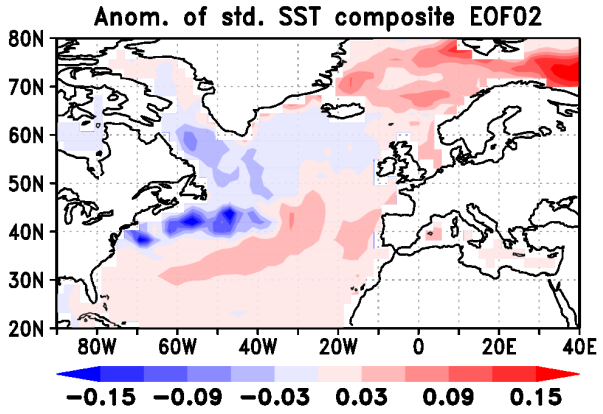
Is it possible to group runs in terms of variability patterns?

EOF decomposition of the Time standard deviations of the individual runs historical Top ten compos.









...maybe. → ongoing work

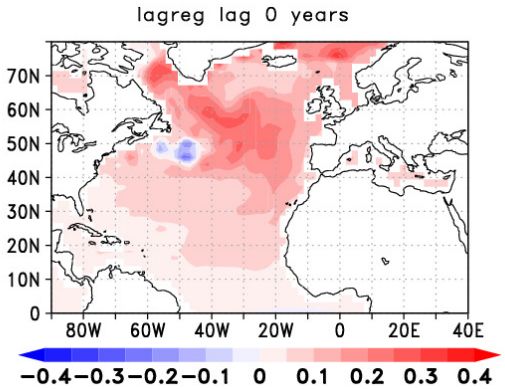
3. Spatial structure & time series of the AMV

- How is the AMV represented in the ensemble?
- Does a changed forcing impact the spatial structure or the temporal variability of the AMV?

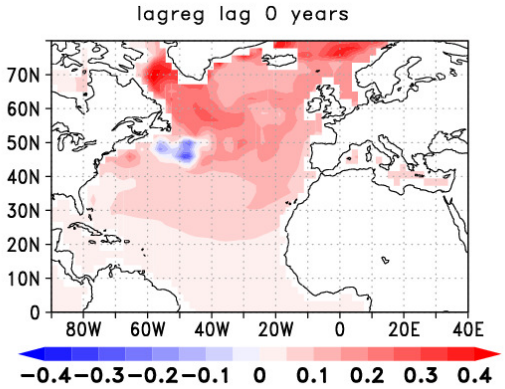
Spatial structure of the AMV is robust over all experiments

Regressions 11-year runmean detrended SST anomaly fldmean 85W:20E/0:70N on 11-year runmean detrended SST anom.

pictl



historical



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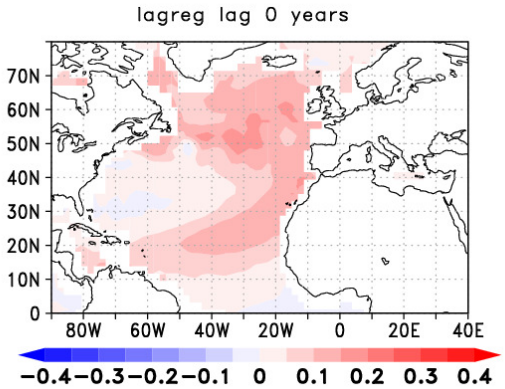
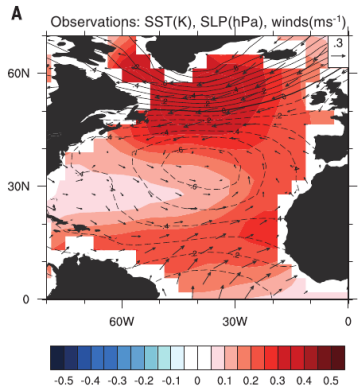


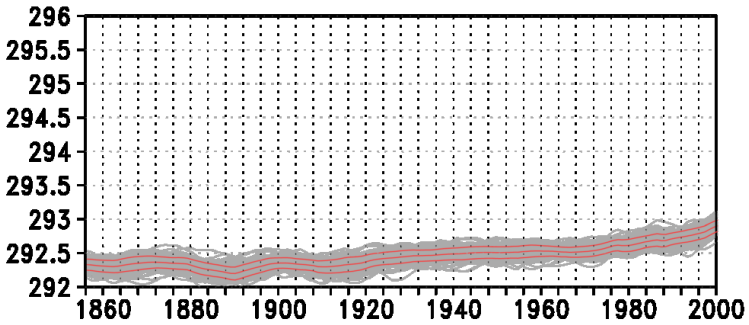
obs. (Clement et al., 2015)



AMV timeseries has forced signal in the hist. runs

11yr-runmean of SST fldmean 85W:20E/0:70N

historical
abs. SST, non-detrended



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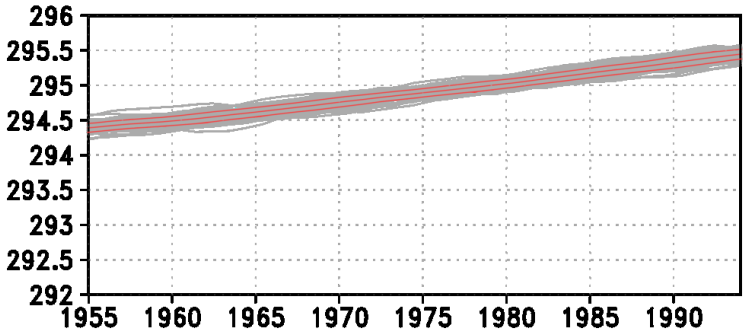
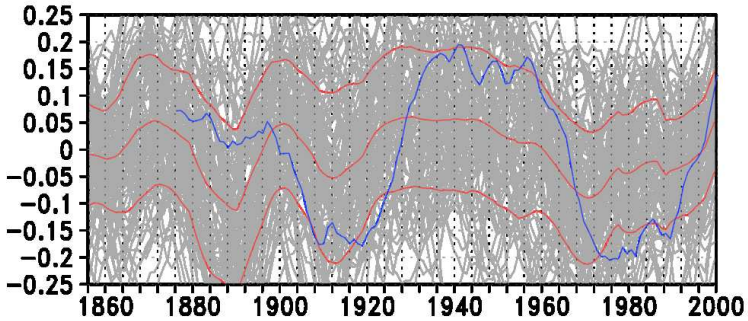


detr. anomalies



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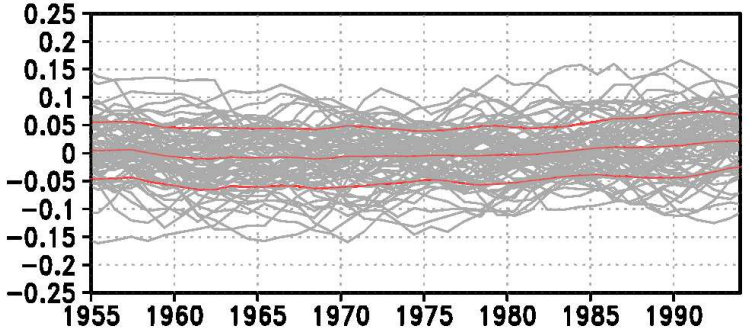
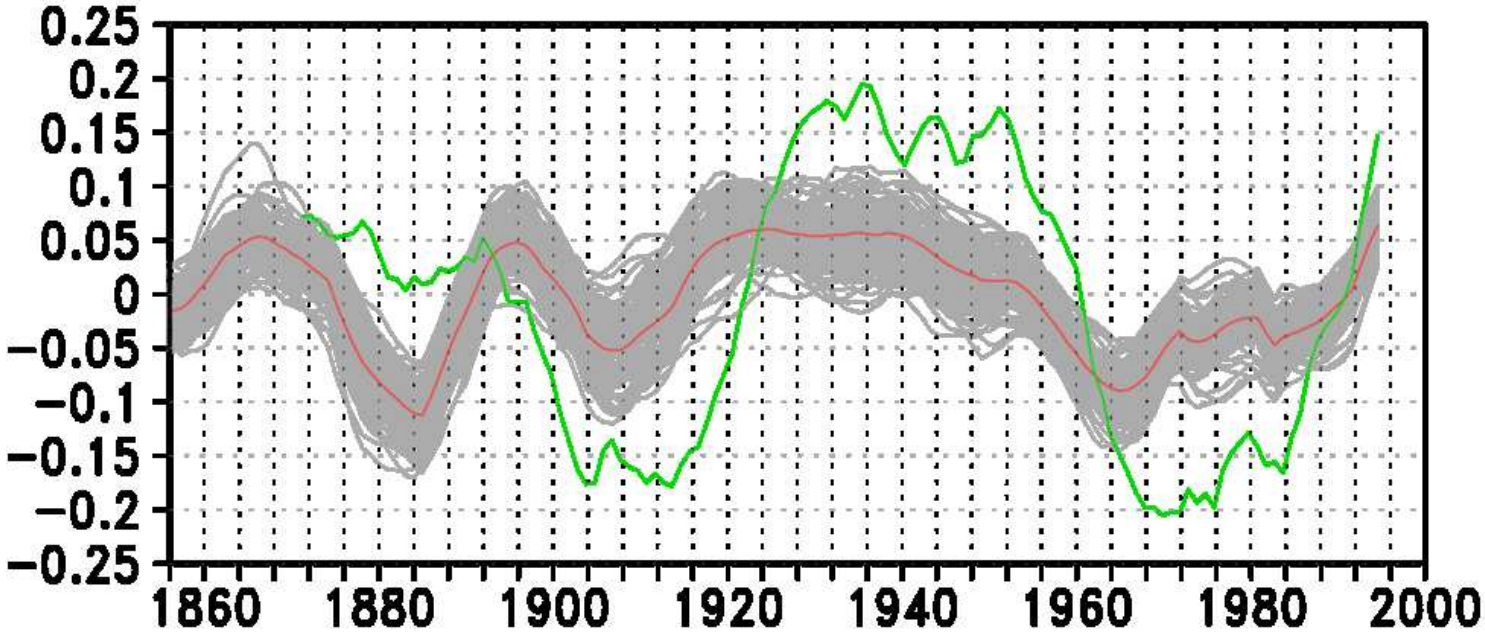


Forced signal in historic runs is robust...

... even when reducing the ensemble size



AMV ensemble mean timeseries of 100 subsamples, each consisting of 30 randomly choosen historical runs (red: ensemble mean, green: HadISST)

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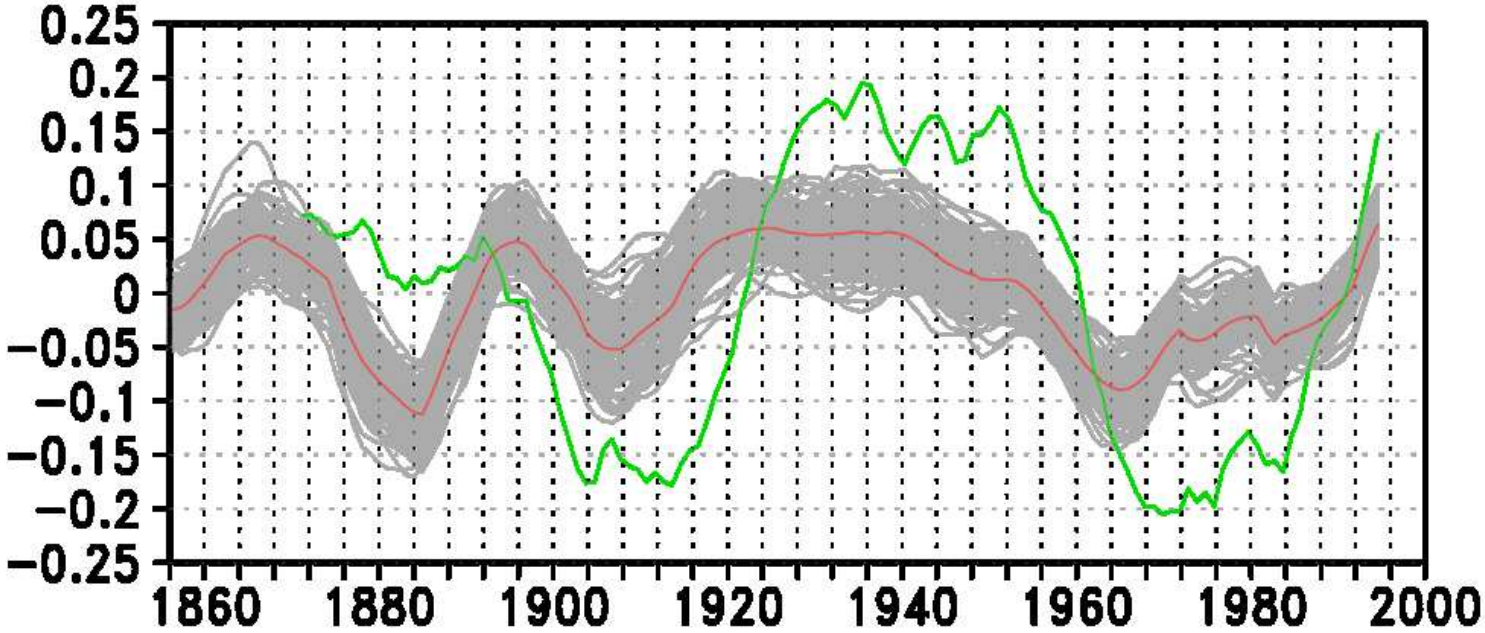
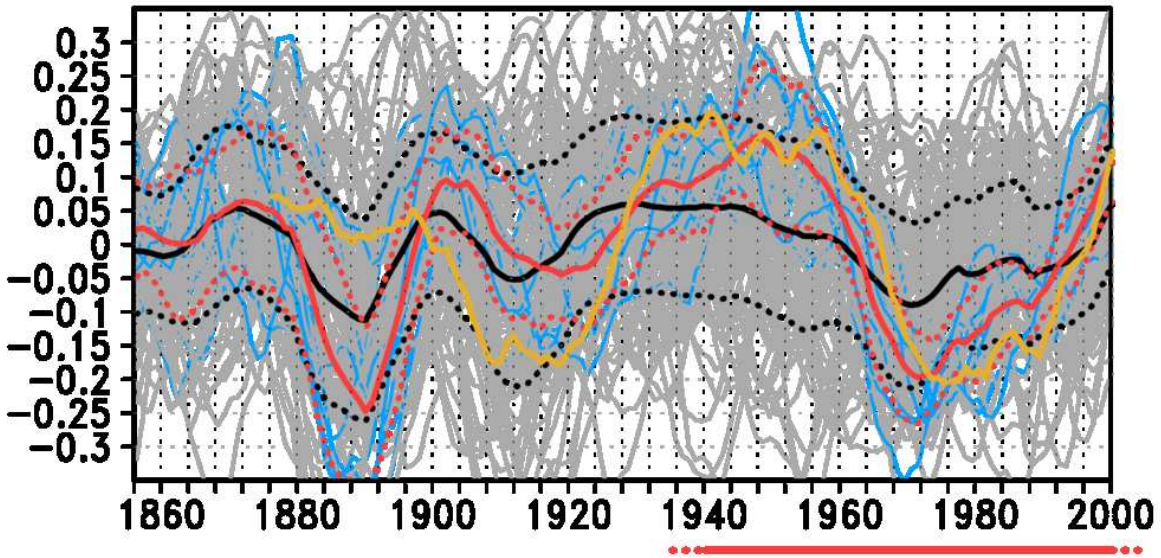


AMV ensemble mean timeseries of 100 subsamples, each consisting of 30 randomly choosen historical runs (red: ensemble mean, green: HadISST)

next step: pick runs with high correlation to observations:
What are the ingredients to get a correct AMV?
Which are the important processes connected to the AMV?

Do we find ensemble members with a realistic AMV timeseries?



individual runs entire ensemble
ensemble mean and +/- 1 std. of the full ensemble
subsample 10 ensemble members with highest correlation to observations
ensemble mean and +/- 1 std. of the subsample
HadISST

- "best-of" subensemble shows sharp transitions
  $\rightarrow$ key to understand the mechanism that control AMV phase changes?
- ensemble spread of subensemble is narrower than that of the entire ensemble

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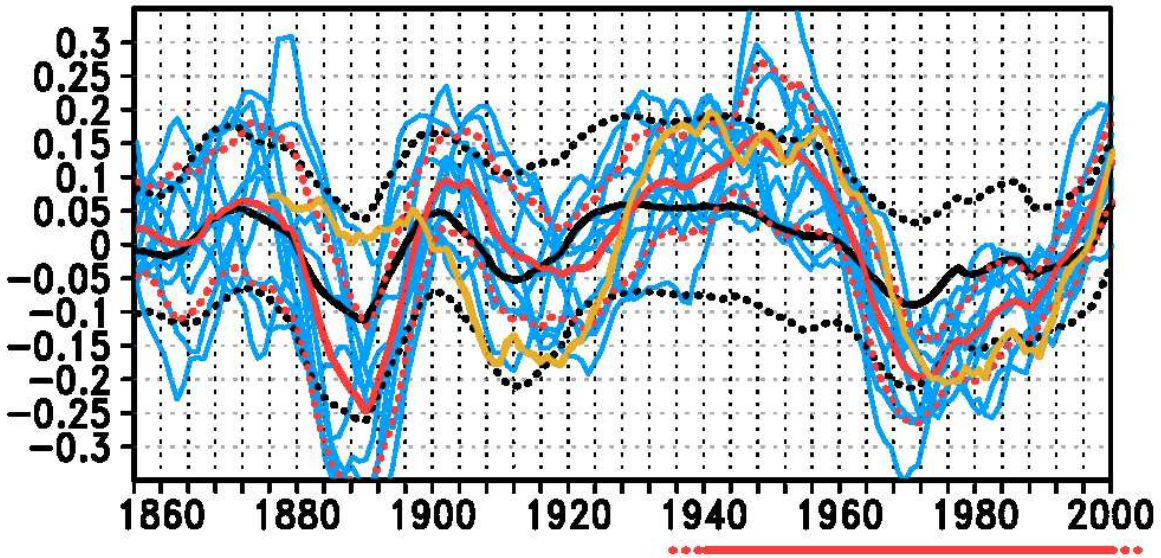

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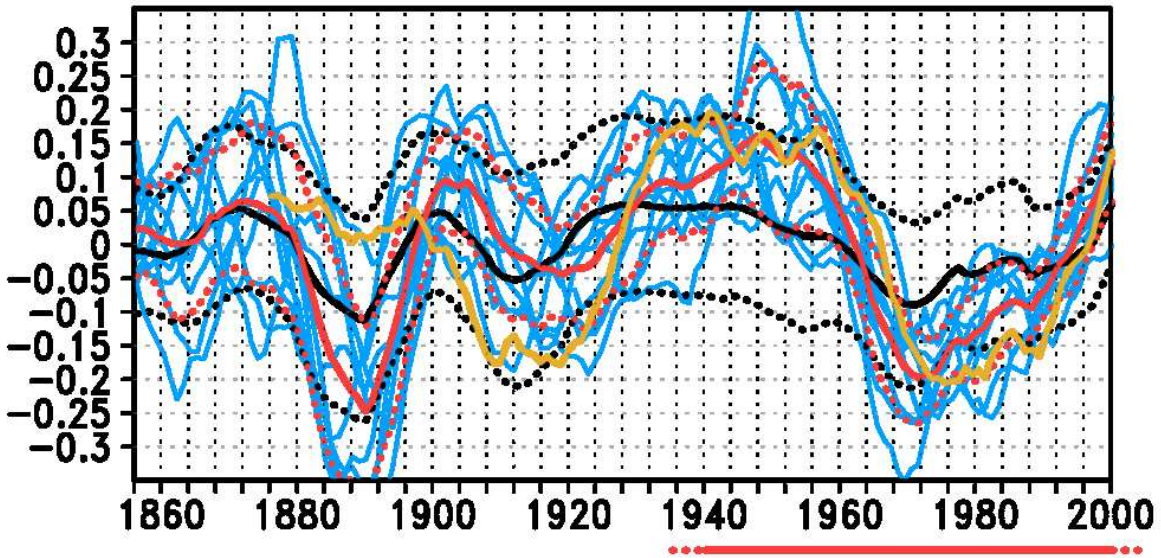

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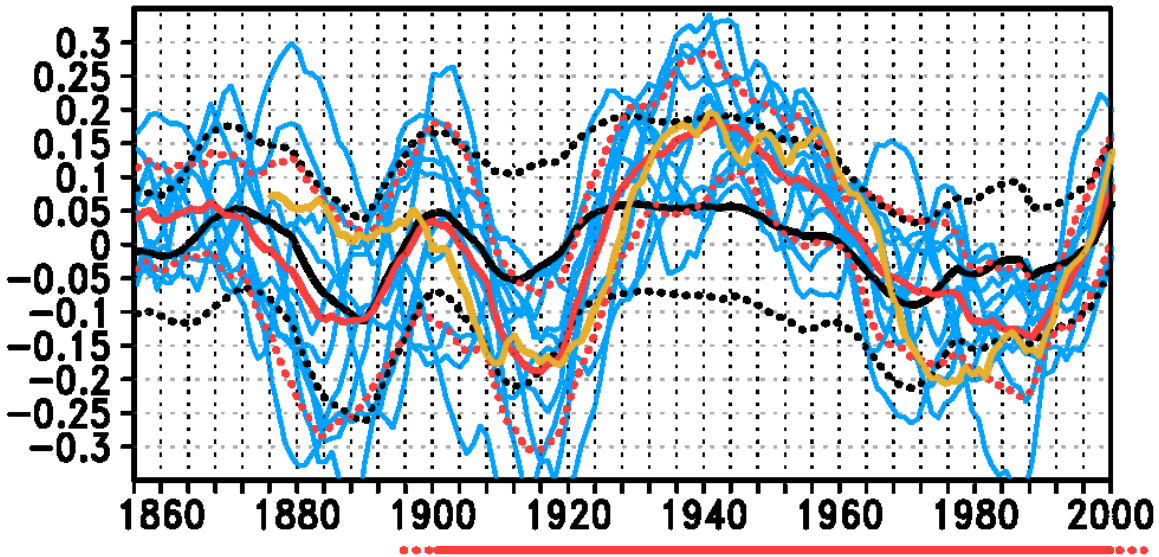


individual runs entire ensemble

ensemble mean and +/- 1 std. of the full ensemble

subsample 10 ensemble members with highest correlation to observations

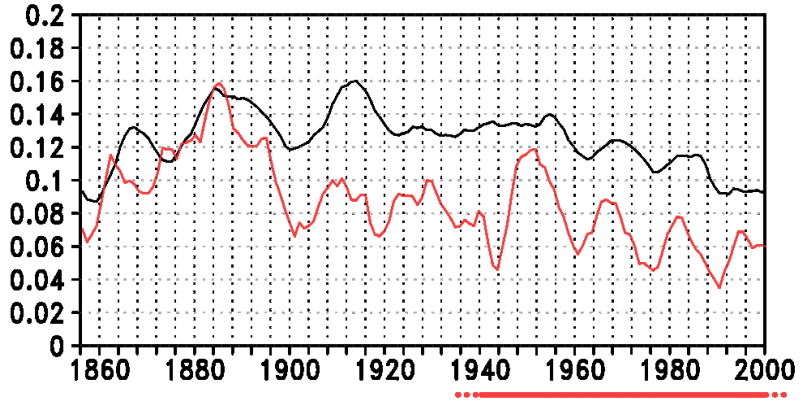
ensemble mean and +/- 1 std. of the subsample

HadISST

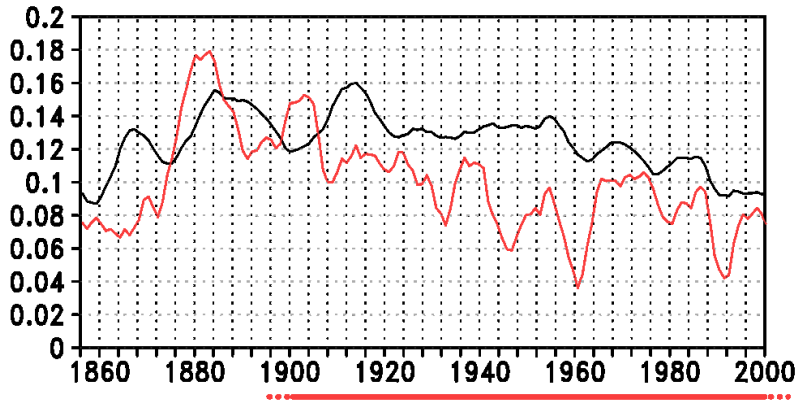
- **but:** when choosing a different period to compute the correlation the subensemble is not distinguishable from the entire ensemble

Is there potential predictability of the AMV?

correlation period 1940-2005



correlation period 1900-2005



ensemble std. of the full ensemble

ensemble std. of the 10 runs with AMV highest correlated to observations

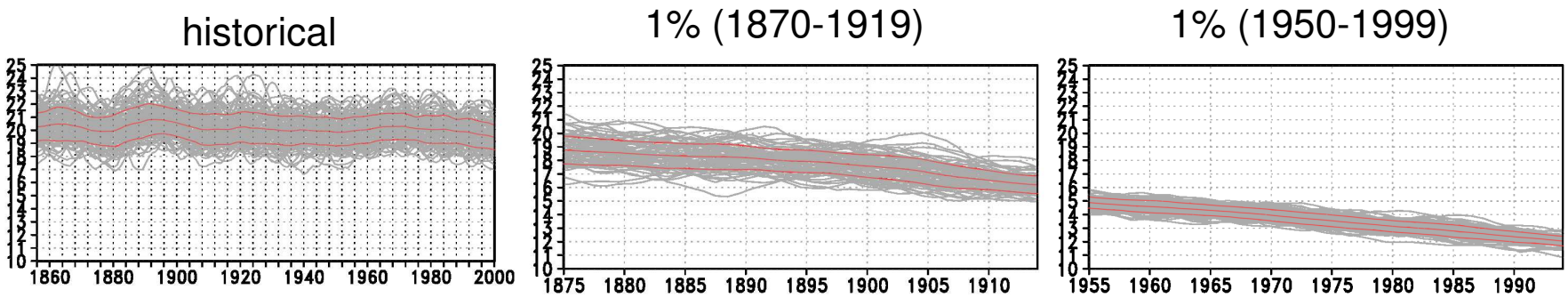
- **What explains the difference of the between the subensemble spreads computed for the two different periods of AMV correlation?**
  - Was choosing 1940-2005 as period just a lucky punch?
  - Do background conditions at initialization time play a role for predictability?
  - Does ocean memory of the forcing play a role?

4. The AMOC under moderate and strong radiative forcing

- How is the AMOC represented in the ensemble?
- Does a strong forcing impact the the mean state or the variability of the AMOC?

AMOC shows strong changes in 1% simulations

AMOC as baroclinic stream function at 45N, 1000m (11-yr runmean, in Sv)



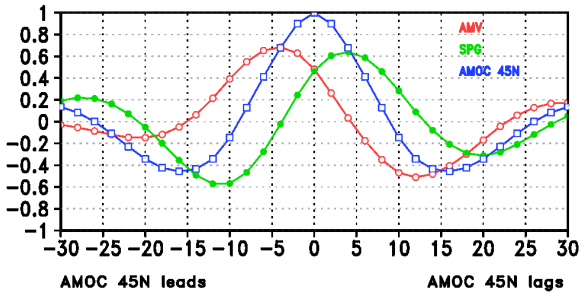
- Mean AMOC is more or less stable throughout the historical simulations
- Historical simulations show a high ensemble spread
- AMOC slows down in the 1% simulations
- Slow down goes along with reduction in ensemble spread

5. Lag Correlation analysis of the AMV with the AMOC and the SPG

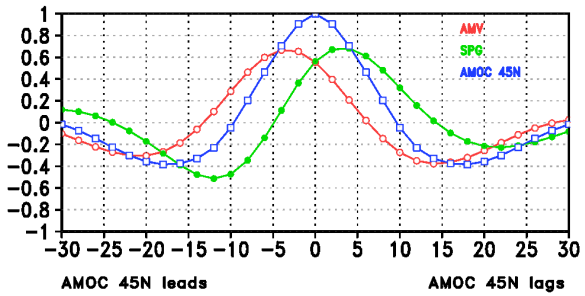
- What are the links between different ocean processes MPI-ESM?
- What is the impact of forcing on the link between ocean indices?
- Are there indices that might form useful predictors for others?

Link between modes of ocean variability changes under strong forcing

pictl



historical (1850-2005)



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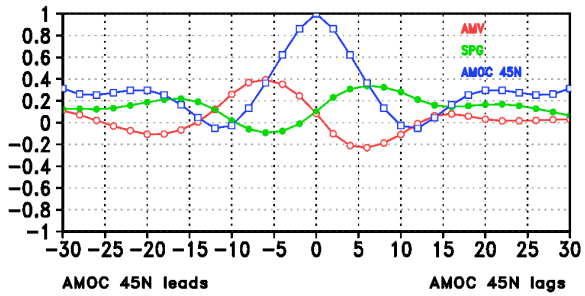
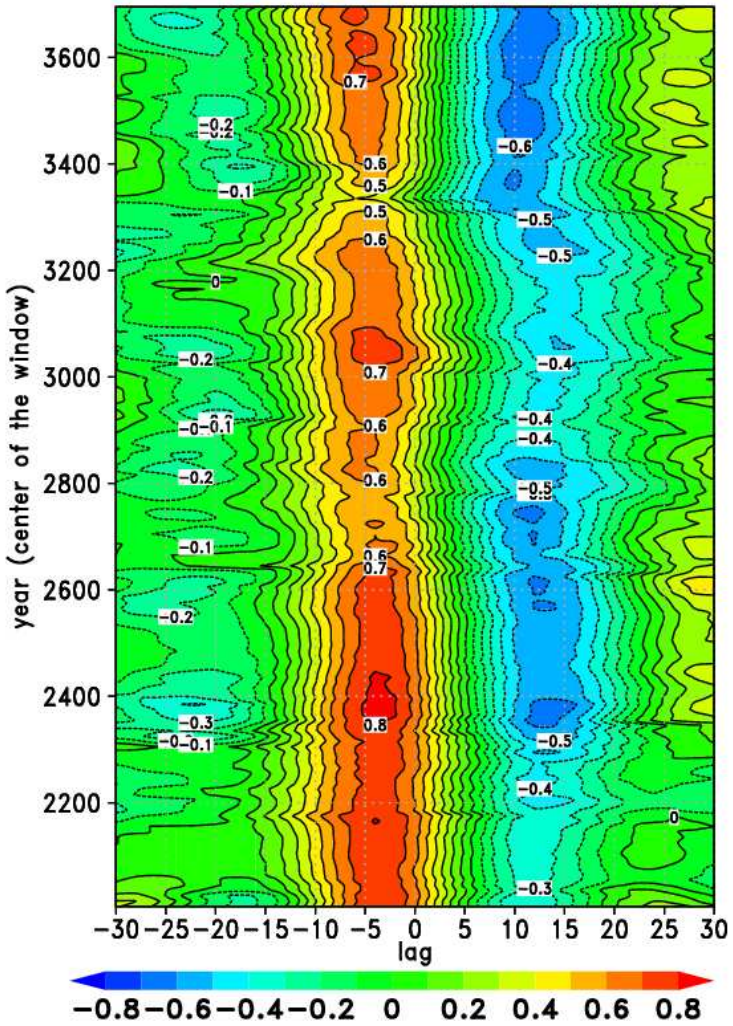


- Correlation between ocean indices is the same in pictl and under moderate time varying forcing.
- Corellations are reduced in the 1% runs $\rightarrow$ partly masked by internal variability due to smaller AMOC and AMV variability in the future climate

AMOC-AMV Lag-correlation has varying strength pictl

pictl

sliding 150-yr window lag corr. AMOC vs. AMV



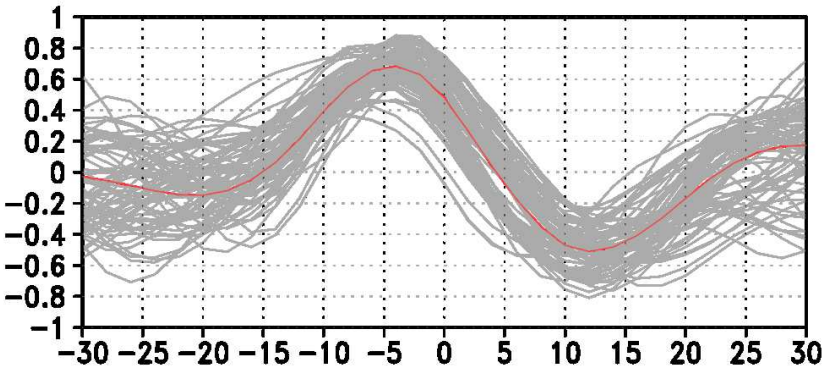
AMV lags AMOC ← → AMOC lags AMV

- Lag-correlation shows qualitatively robust link,...
- ...but the strength of the correlation varies during time

Spread of AMOC-AMV lag-correlations in pictl & the historical ensemble

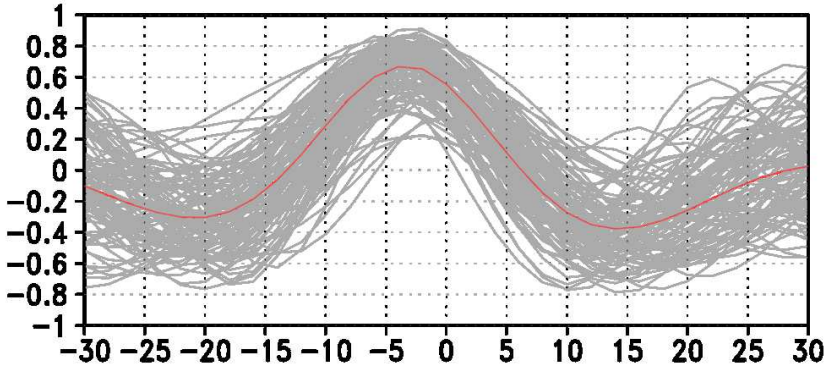
spread of lag correlation AMOC(45N)-AMV

pictl
random 150-yr chunks



AMV lags AMOC ← → AMOC lags AMV

historical
individual ensemble members



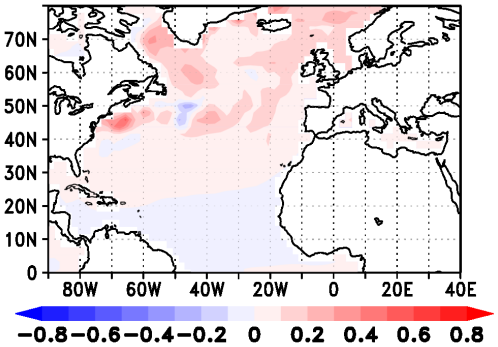
AMV lags AMOC ← → AMOC lags AMV

- There are also quantitative (but not qualitative) differences between the individual members of the historical ensemble.
- The spread is slightly larger than that of the random 150-year chunks from pictl
- Open question: What determines the strength of the link between AMV and AMOC? Are the differences between the different ensemble members/time chunks randomly or can they be explained by physical processes.

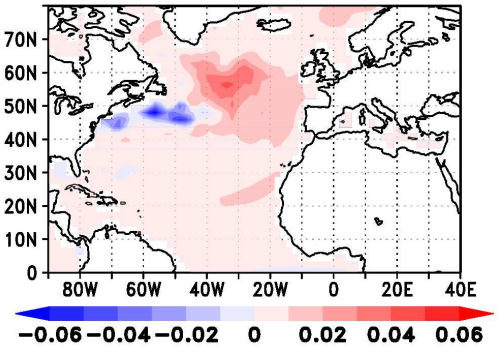
AMOC regression patterns

Regressions of SST and SST trend on 11-year runmean detrended AMOC at 45N.

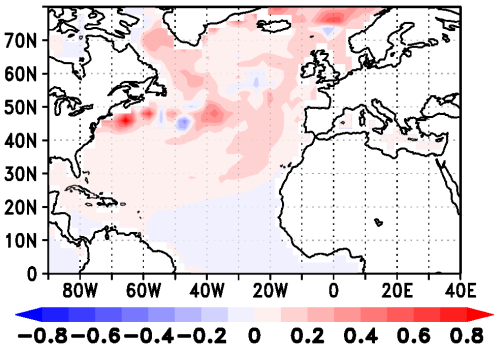
pictl SST



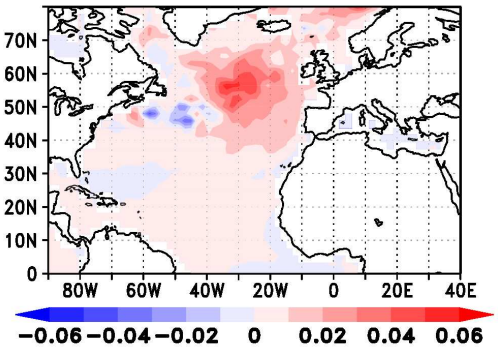
pictl SST trend



historical SST



historical SST trend



- Strong AMOC goes along with large-scale warming trend in the North Atlantic

6. Outlook & Summary

Summary

- AMV has an external forced signal in the historical ensemble
- Understanding the mechanism of AMV phase shifts might be of importance to simulate the AMV correctly
- Indication for AMV precictablility in the historical ensemble
- AMV and AMOC show qualitatively robust relationship in pictl and the historical ensemble
  - **but:** strength of the correlation varies during time in pictl and between the individual ensemble members in the historical ensemble
- AMV and AMOC show reduced variability in a changed climate
  - link between AMV and AMOC might be masked in a future climate

Outlook

- Expand the regression analysis to other indices (e.g. also to large-scale atmospheric modes)
- Compute the ocean heat transports and investigate how the ocean processes influence the redistribution of heat
- Perform dedicated sensitivity experiments to modulate certain modes
  - How could a proper setup look like?

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Thank you for your attention!
contact: ralf.hand@mpimet.mpg.de